

Real-Time and Dynamic Planning and Scheduling under Disruption using Multi-Hybrid Simulation and Optimisation

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Abstract

Planning and scheduling are the principal components of construction contract execution. Distinct studies have developed a wide range of tools and technologies for solving construction planning and scheduling problems. The distinguishing feature of construction planning and scheduling is its complex and dynamic characteristics. But, most studies in construction planning and scheduling have only focused on operational and static parameters without the consideration for strategic and tactical variables. This research proposed a new dynamic planning and scheduling solutions that integrated operational, tactical and strategic parameters. The implementation followed two pathways: 1) comprehensive literature review on methods in planning and scheduling; 2) construction project time factors (CTF) influence on construction project time management (CTM) and; 3) multi-hybrid modeling, simulation and optimisation. The literature review with information gathered from the case study company (CSC) identified the need to integrate planning and scheduling with its dynamic and complex characteristics. A combination of data from the joint literature and CSC for the case study (Multi-million \$ road improvement contract) depicted the need to connect the system components and characteristics.

The second segment of the study investigated the influences on construction time management (CTM) using a dynamic Bayesian network (DBN). Although the DBN analysis created significant insight into CTM influences to support decision-making, the study conducted an in-depth investigation to integrate the dynamic and complex characteristics of the multi-component systems in the construction project. In the

multi-hybrid model, a dynamic framework of agent-based simulation (ABS)-discrete event simulation (DES)-discrete-rate simulation (DRS)-system dynamics (SD) and scatter search optimisation was developed. The dynamic framework used the bidding phase and construction phase that formed the case study from CSC. In the stages, the mechanism of the investigation comprises operational, tactical and strategic planning. The construction phase is the construction of the road improvements contract in 33 different locations (multi-case-in-one-case). Groundwater table and access egress factors influenced the construction operations. The first idea of the research is the integration of the framework as a unit. The multi-method and dynamic framework were integrated and implemented in AnyLogic software with root in java script. After determining the framework and model integration, internal validation of the model was performed with real data collected from the CSC construction operations.

The internal validation confirmed 99 % confidence between the model data and the real data. The research created variation and sensitivity experiments of the model with the influences. The scatter search optimisation experiment was executed to generate an optimal and feasible solution of the defined objective from current and infeasible solutions. A Gantt Java-class was established in each activity to gather the time spent to execute specific tasks and to carry out the scheduling solution, which was exported into Microsoft Project. External validation was implemented to get feedbacks from the CSC. The positive feedback gives the framework and its resolute solutions acceptance for practical application for predictive and reactive dynamic planning and scheduling in the construction enterprise. The feedback from CSC about the developed tool has recommended the application of the system in one of their project at the design phase.

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Attestation of Authorship

I hereby declare that the thesis submission is my own work and that, to the best of my knowledge and belief, it contains no materials previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

A handwritten signature in blue ink, appearing to read 'Okechukwu Bruno Kizito Nwadigo', with a stylized flourish at the end.

14/11/2019

Okechukwu Bruno Kizito Nwadigo

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To God be the Glory, Honour, Adoration and Divine Wisdom.

Chapter 1

Introduction

The application of project management in construction project is increasing rapidly because of its broad application and devising a better decision technique. Construction project, either small or large-scale project, is initiated and executed to ensure sustainable development (Aarseth, Ahola, Aaltonen, Økland, & Andersen 2017, Brookes, Sage, Dainty, Locatelli, & Whyte 2017). Though construction project management has insufficiencies: the strengths lie in its utilisations to transform project plans into physical structures (F. Guo, Chang-Richards, Wilkinson, & Li 2014, Kivilä, Martinsuo, & Vuorinen 2017). Besides, the weakness, at least, is about overruns and variabilities in project realisation (Z. Zhang & Xu 2016).

It is of interest for the project professionals to articulate a proper planning and scheduling process, before project execution, to mitigate the persistent overrun in projects and secure the profitable future of the construction project industry (Kerzner 2013). Construction project companies need planning and control systems that strengthen the management of activities for a construction project in the light of having the prior insight of impact on project disruptions (AlNasseri & Aulin 2015). The determined nature of the project environment requires multiple base-case-interventions to withstand and improve the effects of disturbances as they occur (Collier & Lambert 2018).

Apart from the construction project inadequacies, contract planning, scheduling and execution are influenced by many operational and contextual variables interrelated without a clear boundary in their interactions (Nasirzadeh, Khanzadi, & Mir 2018a). A wide range of factors and variables, detailed in the diverse body of knowledge, can be the reason for the real-world scenarios and disruptions that characterise the construction project system. One of the main characteristics of the system for the construction project is its dynamic and non-deterministic essence triggered by complexity, scale, change, and uncertainty (Lamas & Demeulemeester 2016, The Standish Group International 2015, Wilkinson & Schofield 2010).

be an evolvement of more states (Wilensky & Rand 2015). It is vital to consider those variables in developing planning and scheduling systems.

Construction project planning entails multi-complex decision making to resolve uncertain events and schedule activities (Browning & Yassine 2010, Can & Ulusoy 2014, Hans, Herroelen, Leus, & Wullink 2007, X. Wang, Chen, Mao, Chen, & Li 2015). The decision concepts are subject to the precedence of activities, resources constraints, optimal allocation of limited resources and project performance optimisation (Raoufi, Seresht, Siraj, & Fayek 2018). The system nature and characteristics of construction project lead to a wide range of problems requiring efficient planning and scheduling technologies and solutions.

In the time domain of static scheduling, planning and scheduling method can be deterministic, predictive and unreactive to real-time disruption events (Davari & Demeulemeester 2017, Hazır 2015, Herroelen & Leus 2004). Static scheduling is amongst the popular technologies utilised to manage and control construction project, even though it is contrary to the realities of construction projects (Ashtiani, Leus, & Aryanezhad 2011). According to (Fahmy, Hassan, & Bassioni 2014), real-time events and disruptions continually occur in the construction project, and are the causes of 85 percent of the disruptions in the project schedule.

Likewise, the level of project failures, initiated by disruptions, has increased with companies experiencing an average of 74 per cent overrun in time and of 59 per cent overrun in cost (The Standish Group International 2015). The widespread application of static scheduling has become a cause of concern for the prevalent escalations, overrun, and infeasible schedule (Dürr et al. 2018, F. Y. Ling 2018, Pinha & Ahluwalia 2019) that have been the salient features of most construction projects.

A mix of strategic, tactical and operational variables affects the characteristics of the scheduling problem (Han, Love, & Peña-Mora 2013, S. H. Lee, Pena-Mora, & Park 2006, Peña-Mora, Han, Lee, & Park 2008, J. Wang & Yuan 2016). Despite the features

of the construction environment; sometimes, instability in the contract procurement and execution can be attributed to not only the economic, financial and political decisions but other times on the approaches. It is also related to the processes and decision-making techniques used by managers to achieve a successful outcome on the due date. The decision-making in this situation involves different phases; tendering, planning and construction (Cantarelli, Molin, van Wee, & Flyvbjerg 2012, Flyvbjerg, Skamris Holm, & Buhl 2004, Huo et al. 2018). The interdependencies of the phases pose challenges because the outcome of one stage is likely to determine the result of the ensuing stage.

There are pre-construction activities before the procurement and execution of a construction project contract, for instance, tendering and bidding. Both the client and contracting organisations are required to be aware of the dynamics of that phase, which is a determinant to project success from procurement to close-out (Yoshimatsu 2018). Although, most often, clients and contractors ignore the interactions and planning at that stage. Integrating the bidding and tendering into the entire construction planning is expected to stand out as the first solution to construction project uncertain environment (Hastie, Sutrisna, & Egbu 2017).

The decision-making support systems are applied only at the construction phase without substantial interest at the tendering and bidding and planning stage (J.-S. Hwang & Kim 2016). The consequence becomes the formation of linkage effects because the decision-making and planning begin from the tender phase, resulting in difficulties that affect the entire construction project system (M. L. Martens & Carvalho 2017, Rashidi, Samali, & Sharafi 2016). Building construction and infrastructure industries have established the process for managing the tender and bidding process. The challenge from the process is expected to rely on making strategic decisions on the tender and bid requirements generated by the influences of the collaborating bidding agents (Shokri-Ghasabeh & Chileshe 2016a). As part of the strategic elements, decisions on resources allocation, schedule, project vision and the project development team are

assembled at that stage (J. Liu, Love, Sing, Smith, & Matthews 2016). The actual planning analysis begins from this stage because the input to the tender requirements forms the basis of negotiation and signing of the contract.

A deficiency of strength to integrate the tactical and operational parameters during the bidding process and the subsequent construction phase can adversely affect the construction activities, if peradventure, the bidding organisation wins the contract (J. Wang & Yuan 2016). The system aspect of the tendering and bidding phase involves the client, contractors and general decision-making processes as the input (G. Richards & Marques 2016). The assessment of the construction scope statement, work breakdown structure (WBS), constraints and assumption, project alliances, opportunities and risks in the tendering phase comprises management influences (Elhag, Boussabaine, & Ballal 2005).

The management influences are likely to either delay bid submission at the due date or submitting on the due date without satisfying the project assessment parameters (Patil, Waghmare, & Gawande 2016). The aftermath can be inefficient utilisation of company time, considering that the parameters will be the tool for comparing prices of the competitive bidders (Ballesteros-Pérez, Skitmore, Pellicer, & González-Cruz 2015). It is accepted that time is significant while preparing the bid proposal; management influences can limit its realisation. At the achieved-bidding stage, the chances of winning can be ascertained with the management influences, then the negotiation phase and the construction phase. The main dynamics of product development in the built-environment is significant during the construction phase (Soliño & Gago de Santos 2016). The construction phase of a project is achieved for a specific purpose using the assigned deadlines and resource limitations.

The scheduling problem becomes creating a timetable for limited resources assignments to various tasks. Tremendous efforts are employed to satisfy the allocation of resources based on achieving optimal duration, budget, resources utilisation and

stakeholders satisfaction (Ansari, Makui, & Ghoddousi 2018, Dürr et al. 2018). In that case, constraints are the conditions imposed on the project resources, activities and accompanying decision-making. Amongst the limitations are capacity constraints, precedence constraints, time constraints and simultaneous constraints (de Miranda & Teixeira 2018). It can be a positive planning approach if the tender phase is integrated with the construction phase.

In consideration of the construction project characteristics, one of the main aspects of the integrated phase is planning and scheduling. The scheduling and planning system is a vital solution to the tight deadline challenges in construction projects (Memarzadeh & Pozzi 2016, S. Rostami, Creemers, & Leus 2018). It is accepted that the project escalations and overruns are the consequences of planning and scheduling problems (Ahiaga-Dagbui, Love, Smith, & Ackermann 2017). Notwithstanding the considerable value of the planning and scheduling in the construction project sector, it is subject to a range of problems, discussed previously. To tackle those problems, several studies (El-Abbasy, Elazouni, & Zayed 2016a, 2017, El-Abbasy et al. 2017, Francis 2016, G. Heravi & Eslamdoost 2015, Hsieh & Lin 2015, C. Huang & Wong 2015, Kerkhove & Vanhoucke 2017a, K. Kim, Walewski, & Cho 2015, H.-G. Lee, Yi, Lee, & Arditi 2015, H. Liu, Al-Hussein, & Lu 2015, Nazari-Heris, Mohammadi-Ivatloo, & Gharehpetian 2017, Pawan & Lorterapong 2015, Šetinc, Gradišar, & Tomat 2015, Shou, Wang, Wang, & Chong 2015, Su & Lucko 2016, Tran, Cheng, & Cao 2015, Verma & Kaushal 2015, Wauters & Vanhoucke 2017, L. Zhang & Wong 2015) have developed different technologies in other industries, including: optimisation, heuristics, metaheuristics, artificial intelligence, modeling and simulation-based, multi-agent based, and hybrid-based systems (Mostashari 2011). Most of the methods have conducted studies into one or more aspect of scheduling and planning.

The characteristics of the construction project system have clarified that the ideal solution is expected to consider all the components describing the features of the planning and scheduling system (Alvanchi, Lee, & AbouRizk 2011b). Hence, the holistic

integration of the system components is expected to create opportunities for enhancing the growth of the construction enterprise. The interest of the necessity to improve project management is evident in the growth of the construction industry, both local and international. In the global economy, construction and building projects have become one of the critical sources of nations' development and an increase in gross domestic product (GDP) improvement (NZCID June 2018, OECD 2018). The distinguishing features in Figure 1.2 are the productivity of the construction sector, which is not deterministic, despite its contributions to the global gross domestic product (NZ.Stats 2018) shown in 1.3.

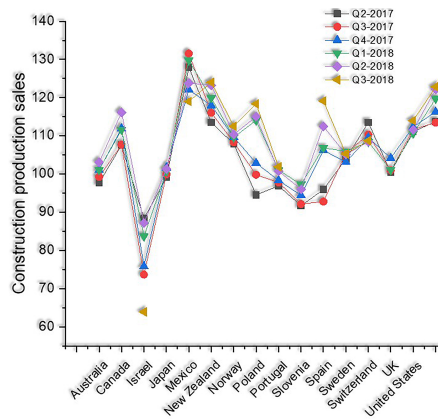


Figure 1.2. OECD global construction productivity. Data from (OECD 2018)

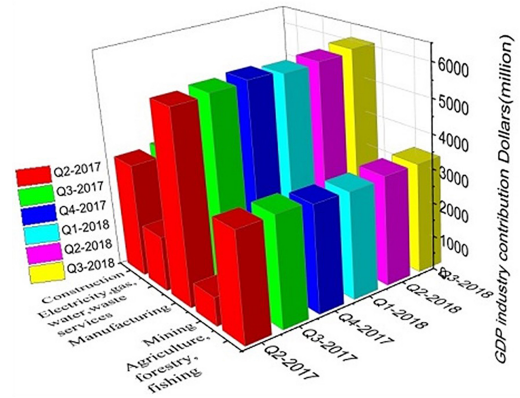


Figure 1.3. New Zealand industry GDP contributions. Data from (NZ.Stats 2018)

While Figure 1.2 shows the construction sector productivity from 2017 to third quarter of 2018, Figure 1.3 displays the gross domestic product contributions of the primary industries showing the construction including construction sector as the second largest contributor after the total manufacturing sector contributions. Notwithstanding that the figures displayed growth and the positive impact of the construction industry because of demand for infrastructures and housing, it can imply that the dynamics of the sector is not stable, and it is subject to uncertain features. Figure 1.4 illustrates a summary of the contributions and challenges of the construction sector (NZCID June 2018, OECD 2015, OECD 2016, 2018).

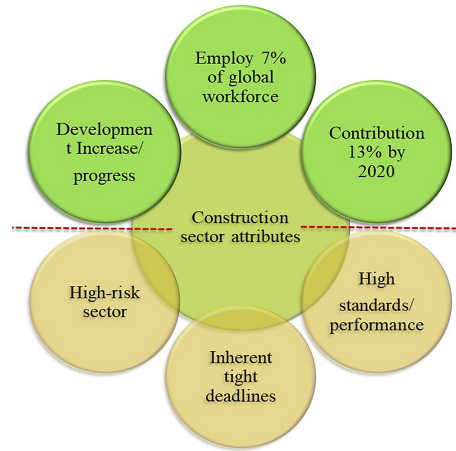


Figure 1.4. Summary of construction contributions and challenges

In the figure, while the upper circular shapes show the present and expected contributions of the construction enterprise, the lower circles below the red line are among the construction problems challenging the sector. The boundary of the figure with an open red line suggests that the contributions can be made to be a challenge. Likewise, the challenges are likely to be contributions if they are solved with novel techniques. The persistent time overrun in the construction industry with tight deadlines, overall, has been one of the challenges. For instance, construction projects have a tight deadline, especially caused by different factors such as fast return on investment, and planning to accomplish the due date challenge is an urgent need. Therefore, the tight deadline is one of the challenges which the research tackled through enhanced planning and scheduling system. Consequently, time overrun problem, which has not accomplished the tight deadline challenges, turned into a requirement for an innovative planning system.

The summary of the trends illustrate what we can see for the future of construction industry: 1) economy building towards construction sector and the urgent need for better planning system; 2) construction sector provides building and construction everywhere, helping in the healthy built environment and; 3) streamlining construction planning towards improving turnaround duration to customers and clients. There is

a bright future for the construction sector, albeit, is likely to depend on other related factors. Those figures described earlier, show that even though the construction sector contributes to the global economy, it has essential challenges, including planning and scheduling problems and application of the scheduling tools to unravel the scheduling problems.

1.1 Justification for the research

An effective planning and scheduling system is one of the vital solutions to the tight deadline challenge in construction project (PMI 2013). The construction project professionals accept that the project escalations and overruns are the consequences of planning and scheduling problems (Seboru 2015). A mix of strategic, tactical and operational variables influences the characteristics of the system (Goh & Ali 2016). The complex decision-making triggers the problems focused on activities precedence, resources constraints, scheduling heterogeneous-environment and different objectives (Swinerd & McNaught 2012).

From the project scheduling perspective, there is a consensus that deterministic schedule and planning are static without the consideration of risks imminent in uncertain project environment (W. Zheng, He, Wang, & Jia 2018). For instance, the Critical Path Method (CPM) and Gantt Chart are employed to plan, schedule and coordinate projects that lack the integration of uncertainties and project dynamics, even though it is a computer-aided. The implication is that resources and precedence infeasibility characterise the deterministic baseline schedule without stability in the schedule in different real-time events (Willems & Vanhoucke 2015). These risks are in terms of disruptions, known knowns, known unknowns, unknown knowns and unknown unknown (Herroelen & Leus 2005, W. Song, Xi, Kang, & Zhang 2018).

The deterministic schedule has been the basis of many novel approaches developed

after the birth of Gantt charts, including Agile Project Management and Building Information Modeling (BIM) (Chakraborty, Sarker, & Essam 2016, GhaffarianHoseini et al. 2017, Muriana & Vizzini 2017). It has been argued, for example, that because of the inability of baseline schedule to expect risks from disruption, it can be protected and optimised to change its deterministic nature (M. E. Bruni, Pugliese, Beraldi, & Guerriero 2018, Padalkar & Gopinath 2016a). Besides, other authors have pointed out that static baseline schedule only enhances resources allocation, the primary basis for planning, used for communicating and coordinating a plan for both projects functional and organisation structure (Davari & Demeulemeester 2017, Villa & Taurino 2018, Xiong, Leus, Yang, & Abbass 2016). The main drawback of deterministic baseline schedule is its inability and insensitivity to uncertainties as well as disruptions that characterise the real-world and dynamic project environment (Afshar-Nadjafi 2016, Davari & Demeulemeester 2018, Lamas & Demeulemeester 2016). The construction project implication is the development of a deterministic schedule method without considerations of variability and realistic project dynamic environment (Alzraiee, Zayed, & Moselhi 2015).

So, the deterministic schedule is limited in resolving several escalation issues and time overrun inherent in construction project planning environment. Static schedule inability to consider the information of the production facility constructed in terms of the implied technology constraints and operation sequences underpins the assertion (Tao, Wu, Sheng, & Wang 2018). But, the significance of the static project scheduling forms the basis for dynamic scheduling (H. Li & Womer 2015). With the advances in computer technology, it calls for a transformed approach capable of automating the entire scheduling systems in terms of interactive and integrated computer-aided systems for scheduling and rescheduling in disruptive and dynamic conditions. Furthermore, it encouraged this research in construction schedule that will integrate the variabilities.

Physical built-environment and the associated services are the outcomes of every construction project contract. Indirectly to the outcome is the project performance,

including stakeholders satisfaction, time, budget, cost, information management system database. The construction enterprise, to remain solvency specifically, is required to search for the best solution for a given activity to meet the success criteria. The best solution (optimisation) should be by trial, testing, performance, experimenting (simulation) on the failures and success, which is too risky and expensive to perform on the construction site. In a computer-aided system, which is risk-free and less expensive, the interaction of the project agents including their attributes, behaviour, cultural and physical environment can be experimented to eliminate failures and plan for success by creating collaborating support of the agents and the environment where they live. In construction, among the processes are the use of an agent-oriented and system dynamics approach, irrespective of the renowned process-centric analysis of construction processes.

The combination of the processes can integrate all the aspects of the system real-world components and environment at no cost or risks. The environment in which the construction industry operates is dynamic and uncertain. A project manager is aware that project planning is an understanding of activities scheduling, decision-making, contingency planning and also managing project buffers. The project team uses historical information to decide on scheduling management before the project. Even when the project manager is not optimistic, multiple planning estimates are generated as protection and to choose among the options during the uncertain event. Although a project has a plan and schedule, projects are unique. At present, there is no model available to inform the project manager, which of the estimates to choose, and danger in time overrun and project failures. Project management triggers dynamic actions based on dynamic signals of events, not pre-planned actions and signals. Though a proactive plan is a part of the dynamic planning approach, but the large scale of the actions is in real-time.

In construction project irrespective of the proactive plan by experienced project managers, events come in endogenously and exogenously as a result of decisions and

influences of states and transitions of the project systems. Even when the project team has a proactive plan, the available project data or characteristics at any point is inadequate to capture the states and causal effects of the interacting agents in the project process. The proactive plan is expected to be comprehensive, and this can only be achieved through experiments with the complex components. This is because, no matter the size of the project, many parameters collaborate either positive or negative on the project activities.

The present approach to planning and scheduling such as critical path method, stochastic networks, decision trees, PERT, ASTA, Primavera, and others assume that information is adequate, and all events can be anticipated. Though, in practice, there is no complete information on the project agents and influences. However, the project managers can obtain an adequate level of information to devise efficient planning strategy as well as an aid to recalculate the available information concerning the new data. As the new information is obtained, the project manager can accept the new data, adapt and modified and change the information in different forms. The project managers, mental judgement can be limited of attention, details, scale, interacting factors influences and feedback, memory, processing capability with insufficient best and alternative outcomes that characterise project complexity.

Every project has different levels of complexity. The complexity is a function of the dynamic nature of the project components and the environment. Project management can be inherently complex in terms of achieving desired and designed outcomes within the participating environments. The outcome results in non-linear relationships among the project system and subsystems. Non-linear systems are everywhere in every aspect of the project and characterise the natural project environment. The use of static tools in planning and scheduling by the company executing the system that relates to only mental linearity does not depict the real-world planning system.

The environment impacts the development of the project, leading to the observable

characteristics of the project outcome. The project team is expected to gain insight by comparing the different traits at different circumstances before and during the project execution to select the best alternatives. The approach to carrying out the comparison is through a risk-free system of modeling, simulation and optimisation. The agents' behaviours and attributes in the project setting are different as well as factors that influence them and the environment they are located, even though we know the process-centric activities to satisfy the agents' requirements. Again, capturing the differences requires a multi-modeling method that integrates units of the system, and the problem is how to integrate the system components. Accordingly, the thesis innovatively captured all the levels of details to generate the best plan and schedule.

The construction project environment is dynamic and operates in the unsteady state (Luo, He, Xie, Yang, & Wu 2016). There is a need for project planning and management systems to integrate real-time, continuous and discrete events, known to be the characteristics of the construction project. Although there is a wide application of dynamic scheduling in other fields of scheduling, namely computer and manufacturing, its use in construction is developing (Faghihi, Reinschmidt, & Kang 2016).

The planning and scheduling problems in a construction project system include the integration of the multi-components from bidding to the execution phase and the mechanism to integrate the multi-component. The problems also entail the method to describe the behaviours of each microscopic component in the real world to enhance capturing the points of influences towards variability and disruptions (Kerzner 2013). Similarly, the challenges of responding to the dynamic changes as they develop due to complexities (Luo, He, Jaselskis, & Xie 2017) for enhancing decision-making support can be pivotal to planning and scheduling success. It is of interest to have insights on possible options for planning and scheduling and the analysis of the accompanying risk for each choice in the complex environment.

The construction project utilises scarce resources to execute each activity, and the

optimisation of the limited resources and activities options from one contract phase to another is of great importance to ensure the best utilisation of those resources (Reddy, Nagaraju, & Salman 2015). The persistent time overrun in construction projects creates the need for continuous improvements in planning and scheduling as an integrated entity (Y. Olawale & Sun 2015). This research considers scheduling as a product of planning, and inefficient planning results in inefficient scheduling. Even though the integration of planning and scheduling systems is the reality, the research is of the view that the method of synthesis is a significant challenge.

Although earlier studies have evaluated those problems as a disjointed system (Fahmy et al. 2014, S. H. Lee et al. 2006, Padalkar & Gopinath 2016b, L. Wang, Kunc, & Bai 2017), this research interest is the urgent need to combine each component in the system as an entity. Furthermore, the dynamic nature and characteristics of construction project requirements can be evaluated with multi-systems. A multimethod framework can be an integration of system dynamics (SD), discrete-event simulation (DES) and agent-based systems (ABS) and optimisation, shown in Figure 1.5.

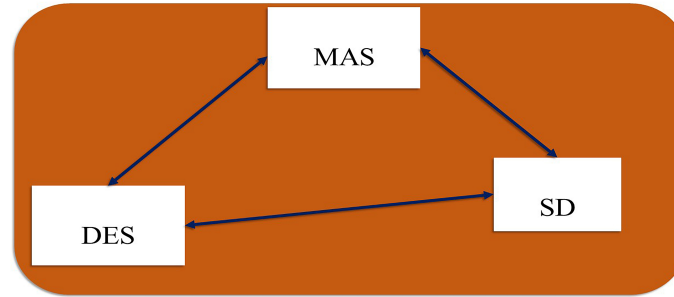


Figure 1.5. Multi-method structure

The figure depicts the possible hybrid interface of the multi-method based on the level of abstraction. The interaction of different models approach; DES, SD and ABS, depends on the paradigms communication channel and association interfaces. The ABS is utilised in the figure to ascertain the involvement of more than one agent in the system, multi-agent system (MAS). A various number of channel is likely to exist; however, the research applied a two-way communication protocol with different

interaction structure including a two-hierarchical structure and three-hierarchical structure including DES-MAS hierarchy, SD-MAS hierarchy, and DES-SD-MAS hierarchy. DES is at the lowest point of the hierarchy because it is the its core function for scheduling tasks and resources assignments. Discrete-time events from DES trigger statechart (state and transitions) of the MAS to intervene, which updates the operations. Likewise, continuous-time factors from SD triggers MAS, which in turn updates the stock. SD-triggered events on DES seeks for MAS to resolve and implement changes.

This can offer modeling and evaluation of complex multi-systems (S. Brailsford, Eldabi, Kunc, Mustafee, & Osorio 2018, Xu, Wang, Li, Huang, & Xia 2018). The figure shows possible structure and communication between each model paradigm. This means that even if the system components are modeled different, the models can communicate as an entity. The interaction of different models approaches depend on the paradigms communication channel and association interfaces (Goh & Ali 2016). The utilisation of the multi-method is a combination of systematic framework structures adequate to represent each component and the associated interaction channel that represents a complete model (Borshchev 2013a). Various channel combinations are likely to exist, including system dynamics (SD)-agent-based simulation (ABS) hierarchy, discrete-event simulation (DES)-agent-based simulation (ABS) hierarchy, and discrete-event simulation (DES)-system dynamics (SD)-agent-based simulation (ABS) hierarchy.

The investigation of the framework is a combination of literature review, in-depth case study analysis, and real data from a construction company to promote closing the gaps betwixt theory and practice and reduce time overrun. The integration of planning and scheduling system is implicit with merging theory and practice to derive the best output of the system. In this research and the thesis, the meaning of planning embraces scheduling, and both terms are a single term.

1.2 Research problem summary

The research is set out to study integrated construction project problems on road improvements project. According to the New Zealand construction report (Ministry of Business & Employment 2018), although constructions are planned for a specific value and timeframes, the planning processes are completely transformed into real construction as planned. The overall implication in the project characteristics and planning problems is the failures in project performance objectives, including time and cost overrun, low productivity, poor quality, litigations, claims and decrease in gross domestic product.

When uncertainties and changes distort the project, the duration increases, and resources requirements increase beyond the allotted amounts (Kaiser, El Arbi, & Ahlemann 2015). If the schedule is not controlled at that point, failures and overruns set in, and the disturbances can go through the entire project portfolio processes (Davies, Dodgson, & Gann 2016). Irrespective of the plan control as the uncertainties occur, there is the need for a system to integrate the lessons learned, historical project information and project scenarios either during the project bidding and or during the project executions. As far as construction planning is relevant, the current dynamic and real-time scheduling research are insufficient, with the necessity to consider the environment of the construction projects (Fahmy et al. 2014, Xu et al. 2018).

A wide range of planning and decision-making for construction activities have been conducted using human mental models (Sterman 2000). Even though mental models have the fundamental ability in processing the different number of data, they are faced with the inability to account for the complex characteristics delineated in Figure 1.4 and Figure 2.2. On the other hand, the mental model can handle the concerns under consideration, and the ineptness to propagate veracious results from emergence, interactions and communications among the components of the complex-systems

without errors is a significant challenge. Given the peculiarity of the construction project systems, specific problems are prompted in the integrated management of the phases.

The research, in its bounded aptitude, delved into one of the **problems**: how the project management system can represent and espouse the characteristics of real-world and complex systems. The idea of the posed problem depends on studying the performance of the system, likewise evaluating different bidding and construction phases while integrating planning and scheduling decision-making. This research endeavours to develop a real-time and dynamic solution to real-case construction project planning and time management with disruptions and complexities.

1.3 Research goals

The research aim is to develop and test a multi-method framework, concerning the implementation of integrated planning and scheduling system for a construction project, taking into account the associated system characteristics, components and influencing factors. The aim is explained with a dynamic and hybrid simulation model and optimisation. The multi-method integrates different parameters and factors of decision-support system for planning and scheduling.

The integrated model can be used to investigate the influences of factors affecting construction project time management, risk factors and impact of the interacting components of the planning and scheduling system. It is expected that the model will improve the quality of the construction project system and enhance the contribution of tight deadlines in reducing time overrun and improve project objectives. It is also believed that the developed hybrid model improves the proactive and reactive planning and scheduling during dynamic events and influences. To achieve the stated aim, the research has three key objectives and twelve numbers of research questions, which are

formulated to accomplish the research objective. The research aim, research objectives and research questions are combined as one interacting essential goals and depicted in Table 1.1.

In the table, the relationship between the research aim, objectives and research questions, as well as their presentation in the relevant sections of the literature review, results and discussion are set out. The research questions were developed throughout the literature and refined with the research case ([Chapter 2](#)) to guide the initial framework analysis and hybrid framework analysis and implementations ([Chapter 3](#)). The testing of the results is explained in ([Chapter 4](#)) as well as the discussion of the results ([Chapter 5](#)), while the evaluation of the research fulfilment of its aims, objectives and proposed questions is discussed in conclusion ([Chapter 6](#)).

Table 1.1

Research aims, objectives, research questions and their relationship

Aim	Objective	Research Question	Section
To develop multi-method framework, modeling and optimisation to strengthen the implementation of integrated planning and scheduling system for a construction project, taking into account the associated system characteristics, components and influencing factors.	A. To understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading to time overrun.	1. What is the current approach for static and dynamic planning in construction projects, and what form of the plan is produced?	2.7.2.1; 4.2; 5.3; 5.5.1
		2. How can the approach be categorised to identify its constraints to solving dynamic planning and scheduling problem?	2.7.2.2; 4.2; 5.3; 5.5.2
		3. What are the barriers to the utilisation of the current solutions for planning problems?	2.7.2.1; 4.2; 5.3; 5.5.3
		4. What are the expected strategies if pursued, positively influence the real-world planning system and improve system solutions?	2.2; 2.7; 4.2; 5.3; 5.5.4
	B. To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule.	5. What are the relationships between construction time management and influencing factors in construction projects necessary to gain insight about reducing time overrun in construction projects?	2.6; 4.3; 5.4; 5.5.4
		6. What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?	2.3; 4.4.1 - 4.4.7; 5.4; 5.5.5
		7. What mechanism can best integrate multi-decision support for planning and scheduling of construction projects?	2.7.3.2; 4.4.1 - 4.4.7; 5.4; 5.5.6
		8. To what extent can the model assure the flexibility to accept multiple inputs?	2.7.3.2; 4.4.1 - 4.4.7; 5.4; 5.6.7
		9. What are barriers that may be associated with the model integration, and how are they addressed?	2.7.2.3; 2.7.3.1; 2.7.3.2; 4.4.1 - 4.4.7; 5.4; 5.5.8
		10. How can the results of management influences be an efficient option for improving the project planning in tender/bidding phase?	2.7; 4.4.1 - 4.4.7; 5.4; 5.5.9
		11. How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?	2.3; 4.4.1 - 4.4.7; 5.4; 5.5.10
		12. What is the technique to present the model solution for application by the construction project team to improve the planning decision?	2.7.2.3; 2.7.3.1; 2.7.3.2; 4.4.1 - 4.4.7; 5.4; 5.5.11
		13. To what extent can the integrated planning solution aid the capability of construction project management?	2.3; 4.4.1 - 4.4.7; 5.4; 5.5.12
		14. How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?	2.7.3.4; 4.4.7; 5.4; 5.5.9
		C. To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.	

1.4 Research methodology

This section is the synopsis for the development of the initial framework on construction time management with dynamic Bayesian network (DBN) and the development of the multi-hybrid framework. It accounts for the validation and testing experiments and Gantt chart development to achieve the research objectives. The research presents a multimode input data system with a hybrid model for planning and scheduling integration to explore a real case study method. The case study is multi-cases-in-one case (Yin 2011) from one of the major road improvement projects in New Zealand. The methodological approach used in this study is a concurrent parallel mixed (triangulation) method based on the philosophy of pragmatism. The research utilised observation, informal interview and feedback review from the case study company to explore the solutions to the construction planning problem.

Reflecting on the construction planning and scheduling concerns, dynamic and real-time scheduling research is insufficient (Fahmy et al. 2014). The first phase began with the in-depth appraisal of existing knowledge and method in construction project planning. Since the case project is a megaproject, the definition of the case boundary enhanced the in-depth exploratory discussions of the business development team, and the project and construction management teams. The research data was collected through site observations, CSC documents and process, and informal discussions and meetings to refine the research objectives, research questions and framework development.

The entire construction project system at the tender and construction phases comprised different homogenous and heterogeneous components collaborating to ensure the actualisation of the objectives of the road improvement project (Manupati, Putnik, Tiwari, Ávila, & Cruz-Cunha 2016). The observations and process data collected informed the refinement of the initial supposedly framework, while capturing the main interacting components of the construction project system in the second

framework. Although, in the second phase, the first framework was refined into a new framework that captured multi-components of the construction project system. The multi-components, as a result, were pursued with varying paradigms of the model to describe the construction project system. A multi-hybrid framework and modeling were conceptualised at this phase to answer the research questions while accomplishing the research objectives. The development of a framework is one challenge, and the validation and testing to achieve the research objectives is another problem. In this phase, the developed framework was validated and tested to accomplish the research objectives using hybrid simulation and optimisation. The data collected from CSC and state-of-the-art literature review facilitated the achievement of the phase result.

1.5 Contribution to knowledge

This study has attempted to develop two unique frameworks while contributing to the body of knowledge: 1) a decision support framework to explore the relationship between construction schedule and the influencing factors at different project phases and; 2) a multi-hybrid framework selected for the construction project system components and characteristics. Earlier studies have presented the relationship between schedule or time factors impact on project management based on descriptive statistics and equation modeling, that are static.

In this research, a framework premised on dynamic Bayesian network (DBN), was developed and tested for modeling and conducting computer-aided experiments on time management for construction project and associated influences at different contract phases. The application of the experiments can enhance explorations of the relationship between construction project time management and factors causing time overrun in those phases, as well offer intuitive insight for decision-making.

Although the dynamic Bayesian network supported the development of the dynamic

framework. The research conducted an in-depth study to combine a significant number of the characteristics and components of construction project systems. This idea was to ease the accomplishment of the research objectives. In that regard, a multi-hybrid framework of agent-based-discrete event-system dynamics-discrete rate simulation and optimisation was developed, validated and tested to generate real-time plan and schedule for the construction project.

Literature review affirmed that hybrid models have been developed mainly on frameworks (Alvanchi et al. 2011b, Borshchev 2013a, Fahmy et al. 2014, Goh & Ali 2016, S. H. Lee et al. 2006, Swinerd & McNaught 2012). The features of those frameworks include combining a few construction project components and are not tested and validated. Furthermore, the frameworks lack the ability to consider the tender phase, construction phase and influences as an integrated unit. Likewise, the frameworks are not adequate to develop and update schedule as a product of planning, related influences, "what best" and "what if" in one implementation platform. (Arditi & Pattanakitchamroon 2006). So, the research endeavours to develop a real-time and dynamic solution to real-case construction planning and scheduling problems and objectives on complexities and variability through hybrid simulation and optimisation technology. The research answered the research questions and satisfied the research objectives.

1.6 Guide to the thesis

The process from the research implementation to results realisations encompasses unique parts. The complete structure of the research takes the form of six chapters. For a sustainable insight into the flow of the research elements, this section introduces the logical guide of the thesis: an overview of the thesis structure. The overall thesis flow diagram is represented in Figure 1.6.

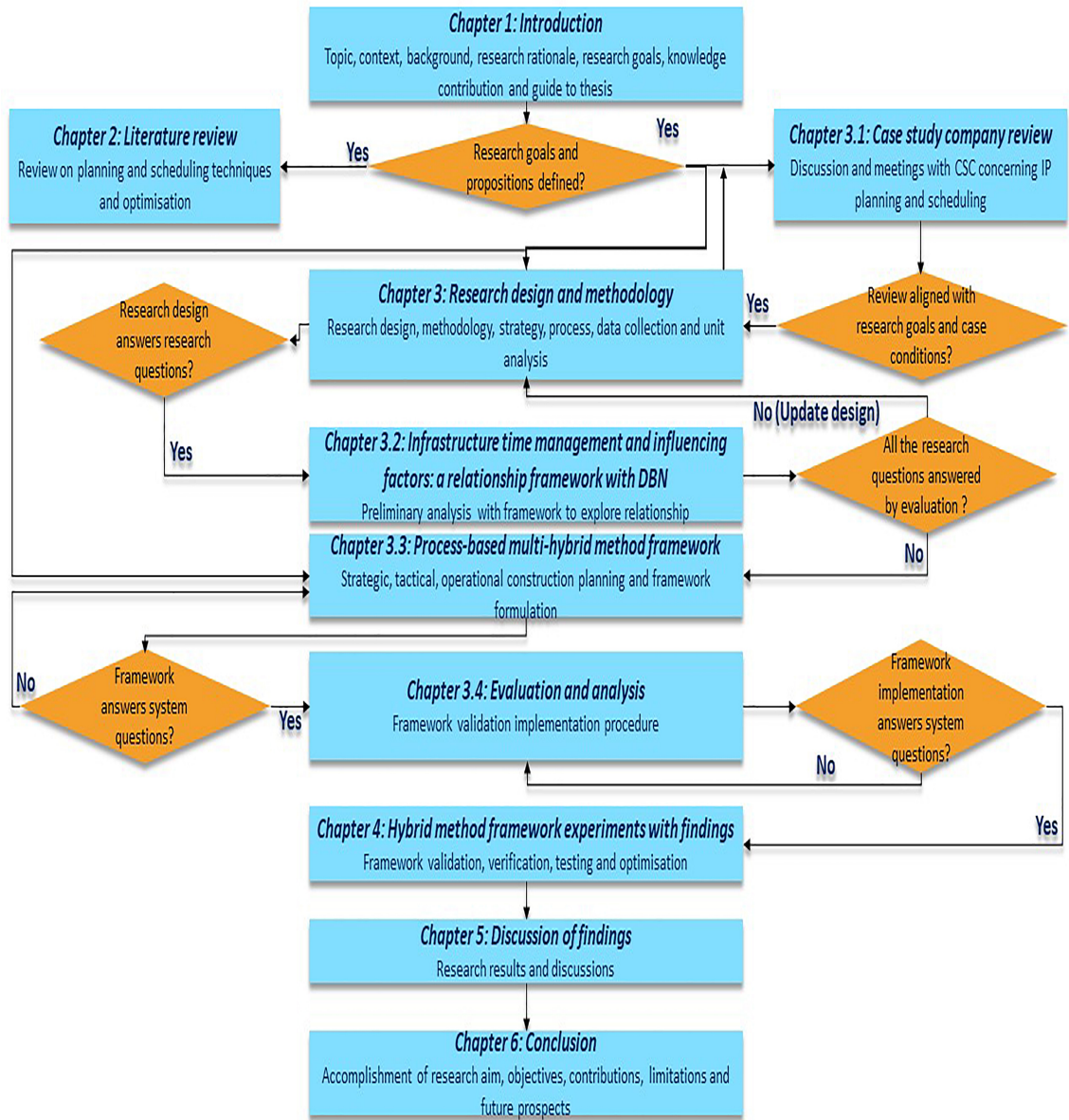


Figure 1.6. Guide to thesis

Chapter 1 begins by setting up the research context and the justification for the research. While presenting brief literature related to the research questions, it identified and discussed the research problem. The chapter also explained the research goals, including the research aims, objectives and research questions as well as the relationships with the relevant sections in the literature review, results and discussion. In the chapter, a brief synopsis of the research design and methods are discussed, and after, the contribution to knowledge stating the value of the study with construction project planning and scheduling to mitigate time overrun. Finally, the thesis structure is presented to guide the report comprehension.

The literature review on scheduling and planning in construction project is discussed in **Chapter 2**. In the chapter, an evaluative and expository study on existing distinct aspects of construction planning and scheduling are reviewed and discussed including planning environment, state-of-the-art scheduling technologies, hierarchies in planning and scheduling, historical perspectives, barriers and opportunities. The literature review, together with the case study company (CSC) meetings, the gaps that formed the aim, objectives and unanswered questions were ascertained as the fundamentals of the study. So, the state-of-the-art of multimethod planning is emphasised in the interest of entire research, centred on agent-based simulation, discrete-event simulation, discrete rate simulation and system dynamics framework and modeling.

In **Chapter 3**, the study method are extensively explained with more focus on construction project and literature. The technique for assessing real project cases, in the form of a case study, is adopted for the research. The benefits of that approach are explained and utilised to give insight into the influence of construction project time on construction time management that formed the initial problem formulation. A further in-depth study resulted in a process-based multi-method analysis and evaluation in hierarchical planning to enhance decision-making. The strategy for data collection was discussed and evaluated because of the problem statement on the road improvement project.

Taking into account that the planning and scheduling in the research case are concentrated on time, an initial problem formulation was presented to understand the relationship between schedule and the influencing factors. The initial framework discussed the factors that affect the schedule, established a dynamical model, adapted dynamic Bayesian network (DBN) to evaluate the outcomes of the influence, as a support package to help project managers to make valuable decisions. The process-based multi-method: agent-based simulation (ABS)-discrete-event simulation (DES)-discrete rate simulation (DRS)-system dynamics (SD) with scatter search optimisation was presented with the design of analysis and evaluation.

The research has emphasised the need to consider the integrated planning and scheduling system that encompasses the strategic, tactical and operational phases of the construction project. In this regard, an in-depth examination with frameworks and models for strategical, tactical and operational planning in the construction system was assessed that delineates an extensive framework for construction hybrid modeling.

The results of how the concepts in chapter 3 are utilised to enhance construction planning and scheduling were illustrated in [Chapter 4](#). The chapter presented and evaluated each modeling framework as well as the integration of the distinct frameworks for construction planning and scheduling as a decision support package (DSP). The results were the outcomes of chapter 3 implementation to elaborate on the models and framework experiments, risk analysis, validations and statistical analysis. The chapter utilised the developed framework and the real case data collected from CSC to set up the viability of the framework to achieve the research goals.

In [Chapter 5](#), each facet of the research outcomes is discussed to affirm the holistic solutions of the research project. The discussion took each research question and mapped it into the results and findings. It examined the findings, affirmed answers to the posed questions. Furthermore, the discussion of the findings presented arguments on the accomplishment of the research objectives and aims. The discussion demonstrated

the research contribution to knowledge with the results and findings. Finally, **Chapter 6** is the research conclusion, which articulated the research contributions, limitations and prospects for future developments.

1.7 Summary

This research is set out to develop and test a multi-method framework, concerning the implementation of integrated planning and scheduling system for a construction project, taking into account the associated system characteristics, components and influencing factors. This chapter presents the overview of critical elements that drive the entire research including 1) the main topic (construction project planning and scheduling); 2) related literature on the subject; 3) statements on the state of affairs of the topic; 4) significance of the research; 5) research problems; 6) research goals; 7) research contributions to knowledge and; 8) the thesis structure.

Consequently, as a product of this chapter, the next chapter (Chapter 2) conducts a state-of-the-art literature review centred on the research goals and research problems. Moving on to discuss the key ideas and theories that have been established for the understanding of real-time planning in the construction project, in **Chapter 2**, a range of relevant themes are discussed. Those themes include construction project management, construction project time management, construction project influencing factors, the relationship between construction project time management and construction project influencing factors, construction project characteristics, construction project hierarchical planning, and construction project scheduling technologies.

Chapter 2

Construction project planning and scheduling: literature review

2.1 Introduction

The interest in project success in a construction project has triggered a wide-ranging effort to reduce the intensity of time and schedule overrun. Scheduling and planning are considered the essential strategy towards the reduction of time overrun for a successful construction project. The overrun, generally, is as a result of influencing factors. The relationship of the construction project time influencing-factors with construction project time management is of importance in defining the effectiveness of the whole project life cycle from the resulting impact, especially the resultant effects of the influence on time management due to the relationship. As a support to one of the objectives of this research is to integrate planning and scheduling as a unit. Hence, in the sections of the overall thesis either planning or planning and scheduling is recognised as one theme. The layout and contents of this chapter are presented in Figure 2.1 to ease the process flow.

This chapter provides a holistic review on the state of the art of dynamic planning techniques and various relevant ideas within construction projects, namely construction project management, associated characteristics, time management, and influencing factors. It includes the discussions on the relationship between project time management and influencing factors, hierarchical planning, planning technologies and their timelines, methods comparisons, and advantages.

The ever-increasing demand for building and infrastructure accounts for the contribution of construction enterprise to global economic growth. Aiming consistently on the growth requires outstanding approach and persistent improvements. One of the main success drivers for those projects is the delivery timeline: a significant concern for stakeholders (Laursen & Svejvig 2016). For instance, a project with time overrun is a determinant for unsuccessful project leading to uneconomical growth (Shehu, Endut, & Akintoye 2014).

According to (H. Jin, Shen, & Wang n.d.), the astounding implication of the time driver is its intuitive and embedded association with other success drivers including cost, quality, risk, function and profit. The dominant issue is not the construction project itself instead of the plan and schedule pivotal to achieve the delivery time, which drives other success components. There is a construction project in different parts of the globe, necessitating an effective and a dynamic plan and schedule for realising the purpose for those projects (Locatelli, Invernizzi, & Brookes 2017).

Planning and scheduling is the crucial technique embraced to manage and control projects to meet the due date delivery as well as one of the vital solutions to the tight deadline challenge in a construction project (Viradia & Rao 2018). Time management is a dominant feature in the construction project management domain, and either effective or ineffective planning determines its outcome (Marshall & Cowell 2016). It is a management strategy to enhance the performance of time in a construction project, though associated with influencing factors. The implication is on the influences of project characteristic and environment to the project outcome.

It is possible that the integration of planning with consideration of project characteristics and environment can aid the reduction of time overrun. In that case, dynamic and stochastic planning with risk analysis is expected to capture the project features (Cuppen, Bosch-Rekveltdt, Pikaar, & Mehos 2016). The planning requires the investigation of the dynamic system as a strategy and technique for meeting the

needs of a construction project in a complex, real-time event and disruption that characterise it (Mok, Shen, Yang, & Li 2017). Since those conditions are natural for construction project contract and environment, the events can be categorised as client-related, design-related, consultant-related, resources-related, contractor-related, and external-related (Lessing, Thurnell, & Durdyev 2017).

In support of the literature sources, the real-time categories are the unexpected breakdown in resources, variations in process and methods, delay, traffic conditions, weather conditions, adverse environmental conditions, and many others (G.-X. Chen, Shan, Chan, Liu, & Zhao 2019). The events are among the factors responsible for the influences and variabilities in the construction project. The dynamic planning aided with the ability to accept the system, tactical and operational changes while optimising construction project plan is likely to be the way forward to static planning challenges.

Any planning technology with the insensitivity of the influences is not expected to be effective since the project operates in a combination of deterministic and non-deterministic environment (Al Nasser, Widen, & Aulin 2016). The technology is deemed to capture the opportunity to explore the relationship between influences and time management. The insight of the relationship, which can be examined with a likelihood approach such as dynamic Bayesian network is likely to enhance decision-making to ameliorate time overrun.

Over the years, static scheduling, known to be deterministic, unpredictable and unreactive to disruption events, is one of the techniques widely utilised to manage and control construction project (Sing, Love, Edwards, & Liu 2016). For example, from the baseline schedule, resources, duration, precedence relationships involving start times and finish times are known before the project commencement, contrary to the realities in the construction project.

According to (Collier & Lambert 2018), real-time events disruptions always occur in a construction project. It is the main reason for many of the failures in the schedule.

In the same vein, over the past century, the level of project failure resulting from disruptions has increased with companies experiencing an average 45 percent overrun in time (PMI 2016). The disturbances can lead to finishing 31 percent of the project on the due date (KPMG 2017). Although the widespread application of static (deterministic) planning has alleviated issues in time overrun and infeasible schedule to an extent, the dynamic (non-deterministic) plan is expected to discuss complexities and variabilities in the construction project.

In that case, simulation modeling, what if analysis and optimisation can be the methods to enhance the evaluation of dynamic planning. Moreover, the dynamic technology requires an approach to integrate the system characteristics, influences and the multi-components causing the variability (Furlong, De Silva, Guthrie, & Considine 2016). One of the issues of dynamic planning is the method for bridging the gap between theory and practice (Herroelen & Leus 2005), while investigating the system components and characteristics.

The planning method is not only expected to mimic real construction project strategies, operations and activities; but, the understanding of the dynamic performance of the plan is vital (Gerami Seresht & Fayek 2018). Because the construction project has different phases, successful construction project planning is expected to be hierarchical and commences from the tender stage. At this investment decision phase, a significant part of the planning is of the essence. The phase is strategic decision-making either to bid or not to bid, even if the decision to bid enhances the opportunity to carry out the project after contract award stage (Jarkas, Mubarak, & Kadri 2013). Without the mitigation policies for construction project plan and schedule challenges, the operational and system concerns in managing construction project are expected to increase (El-Sabek & McCabe 2018).

Although there have been essential tools in the field of steady-state scheduling and simulations (Ballesteros-Pérez, Smith, Lloyd-Papworth, & Cooke 2018) to generate

different near-optimal base-case plans and schedules, there are a few research studies in dynamic and real-time scheduling relating to construction project management (Xu et al. 2018). Even with the earlier studies, there is a need for improving and devising different strategies to tackle complex construction project challenges, orchestrated by continuous time overrun and schedule escalations (Whyte, Stasis, & Lindkvist 2016). Nevertheless, the process to develop the approach requires a firm understanding of the management of the construction project. In the next section 2.2, the researcher presented the construction project management context, importance and characteristics to support the research questions raised in this study.

2.2 Construction project management

Construction projects require best practice to ensure the fulfilment of the stakeholders' objectives as suggested by (Zedan & Miller 2018) involving monitoring and controlling of project tasks and resources (D. H. Walker 1995): the basis of construction project management (Shadid 2018). The interpretations of recent trends in the construction industry illustrate the growth of construction projects. There is increasing investment in the construction project resulting in significant growth in the industry (OECD 2019). The explanations confirm the overarching contributions of construction project management in the field of built-environment product development. A construction project is managed by planning, scheduling, evaluation, and controlling of project activities through effective use of the allocated resources, managing the issues involved to set up the projects (D. Hu, Mohamed, Taghaddos, & Hermann 2018).

The management of projects demands professional service that applies effective techniques from inception to completion as outlined by (Demirkesen & Ozorhon 2017). Similarly, construction project management integrates the project life cycle (Mäki & Kerosuo 2015, Styre 2017) with new ideas to drive construction project (M. E. Murphy, Perera, & Heaney 2015). In the same vein, construction project management is a tool

for identifying, analysing and mitigating risks (X. Zhao, Hwang, & Low 2013) and the minimisation of project waste to satisfy stakeholders objectives (Sacks 2016).

The project delivery method has become one of the dominant processes of achieving construction project success (Shrestha, O'Connor, & Gibson Jr 2011). Interestingly, the core of success criteria in construction management is central to the entire method. Irrespective of project size and complexity, construction projects involve construction time management (CTM) functions, namely planning, scheduling, evaluation and monitoring (Al-Nady, Al-Hawary, & Alolayyan 2016). The implication of this is the need to organise requirements, plans, and resources to carry out the project aim (Eizakshiri, Chan, & Emsley 2015). The construction project management, compared with other product development technologies in manufacturing and information technology and business developments, is fundamental to the built environment and infrastructure development that contribute to economic growth (Stevens, Neelankavil, Mendoza, & Shankar 2012)

Construction project management enhances better control of plan and schedule (Solís-Carcano, Corona-Suárez, & García-Ibarra 2015). It varies somewhat across different construction life cycle for time and cost saving. Henry Gantt (Pollack, Biesenthal, Sankaran, & Clegg 2018, Toffel 2016) is the origin of the development of better project planning and controlling approach. What is notable on this recognition is the application of "bar" chart as a schedule management tool in construction projects. Despite that, the Gantt chart method is easy to understand and apply to simple projects with few activities (Sawalhi & Enshassi 2012); but, it cannot be applied in complex and dynamic project conditions (Maylor 2001).

Likewise, the communication framework underlying the management of construction project systems can be used to automate various communication functions across the project lifecycle (Khan, Flanagan, & Lu 2016). Moreover, the same study provides evidence of how the Internet of Things and related standards can contribute to such an

improvement. Compared with the improvement, many studies (Doloi, Sawhney, Iyer, & Rentala 2012, Fu, Lau, & Varakantham 2015, Masmoudi & Hait 2013) have reported that there are complex and uncertain interactions and actions of tasks and resources in construction project (Mir & Pinnington 2014). The steps are design, decisions management and production of the facility on site, project close-out, rehabilitation and maintenance of existing facilities.

The execution of the project activities, sometimes, are extraordinarily complex and diverse. Construction project execution activities are executed by the effectiveness of time and resources allocation as well as utilisation on complex and distinct activities (Reveliotis 2016). It is usually believed that project complexities cause several project escalations (J. Zhu & Mostafavi 2017). A vital strength of the management of construction project is the application of robust processes and procedures to resolve many of the issues generated by complexity and uncertainty (Maylor & Turner 2017). A construction project is known to involve complex evaluations at different stages (Yun, Choi, de Oliveira, & Mulva 2016), and the aftermath of this can be the associated influencing factors prevalent at the various stages that further compound the real complexities.

As a result of that, the management of those complexities becomes significantly difficult in terms of satisfying the main activities competing for resources (Parvaneh & El-Sayegh 2016). Similar to the complexities, the implication is the existence of relationships between the CTF and project performance criteria (Doloi et al. 2012), and the need for a comprehensive understanding of the complexities and the associated CTF challenges. One of the new issues to learn from those concerns is the significance of identifying the CTF first and then evaluating their relative association with CTM. Then, the analysis can be with sets of strategies for time management before embarking on construction activities.

Those identifications, assessments and evaluations pursue an enormous opportunity for

enhancing the development. Notably, is the application of an adequate strategy to mitigate, control and manage the construction project time influencing factors (CTF) for the successful execution of the project within the defined time-cost-quality triangle (Hussain, Fangwei, Siddiqi, Ali, & Shabbir 2018, PMI 2013). The utilisations of construction management techniques to resolve a wide range of projects complexities, uncertainties, and CTF require the role of a skilful and experienced construction manager (Durdyev, Ismail, & Kandymov 2018), construction management best practices and stakeholders' support (A. Heravi, Coffey, & Trigunarsyah 2015). In spite of these issues challenging construction projects, the construction manager is expected to deliver high-quality buildings and structures on time. Even with the completion of the project on time, the realisation of the stakeholders' requirements is essential (Saunders, Sherry, & Gale 2016).

The allocation of constrained resource and time to achieve project success tends to be the responsibility of the project and construction management team (Durdyev et al. 2018). The team is expected to carry out a construction project within schedule, budget and technical performance (Volden 2018). The project manager and construction manager are expected to guide the cross-functional teams to accomplish the project responsibilities (M. L. Martens & Carvalho 2017). The methods and processes of combining the various construction actions and interactions to either produce or alter buildings and construction project are part of his task (Koops, van Loenhout, Bosch-Rekvelde, Hertogh, & Bakker 2017).

Due to the varying sizes of construction project and companies having branches in different parts of the globe, the need for efficient management tools becomes paramount. As regards to this, construction management and information sharing across functions and locations are enhanced by employing relevant information management tools and software (Berente, Baxter, & Lyytinen 2010). Project execution time performance can be dependent on the team's experience to manage project issues and resolve problems using the relevant tools and techniques. In other words, those tools are among the

strategies that enhance the management of the project challenges (Saidi, Kattan, Jayasinghe, Hettiaratchi, & Taron 2018). So, the effectiveness in time management is a key priority for a successful outcome in construction projects. The ability in the time management can be evaluated by exploring the construction project as a system. The understanding of the system is expected depending on the system behaviour and characteristic, which is the main discussion for the next section 2.3, validates the concerns of the research question 4 that asks:

4. What are the expected strategies if pursued, positively influence the real-world planning system and improve system solutions?

2.3 Construction project characteristics for planning and scheduling integration

The emerging problems from the dynamic and complex nature of a construction project are dynamic and complex (Fujiwara, Morita, & Suwa 2016). A system capable of recognising those features and resolving the main problems is expected to begin with either any or all of the characteristics including uncertainty, complexity, dynamicity (Alvanchi, Lee, & AbouRizk 2011a, Davies et al. 2016, Ford & Sterman 2003, J. Park & Cho 2017, M. Park, Kim, Lee, & Han 2011), ambiguity (Akhund, Khoso, Memon, & Khahro 2017, Pich, Loch, & Meyer 2002, D. Walker et al. 2017), productivity (Chalker & Loosemore 2016, Choudhry 2017, Sarhan, Xia, Fawzia, Karim, et al. 2017), large-scale (Patanakul, Kwak, Zwikael, & Liu 2016, X. Song, Xu, Shen, Peña-Mora, & Zeng 2017), competitively (Loosemore 2016, Oyeyipo, Odusami, Ojelabi, & Afolabi 2016, Semaan & Salem 2017), and sensing (Akanmu, Olatunji, Love, Nguyen, & Matthews 2016, Omar & Nehdi 2016, K. Yang, Ahn, Vuran, & Kim 2017). It also includes multi-environment (Petri, Beach, Rana, & Rezgui 2017, Thomé, Scavarda, Scavarda, & de Souza Thomé 2016), collaborations such as linear and non-linear feedforwards and feedbacks (Bygballe, Swärd, & Vaagaasar 2016, B. Liu et al. 2018, M. Lu, Cheung, Li, &

Hsu 2016, Qazi, Quigley, Dickson, & Kirytopoulos 2016), tangible and intangible data (Alvanchi et al. 2011b, Işık & Aladağ 2017, Parvaneh & El-Sayegh 2016). Amongst the characteristics stands the need to defragment planning and scheduling as an entity for construction project management (Dave, Kubler, Främling, & Koskela 2016). While Table 2.1 shows the characteristics of the construction project and their descriptions, the characteristics are subject to the entities, sub-entities and sub-sub-entities constituting the system (Oppong, Chan, & Dansoh 2017).

The discussion supports the research question **6** that asks:

What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?

Table 2.1

Construction project characteristics

	Characteristics	Description
1	Uncertainty (S.-J. Guo, Chen, & Chiu 2017, Hellström, Wikström, Gustafsson, & Luotola 2016)	System variable may be unknown, originates from multiple sources, and initiates other factors.
2	Complexity (Hou et al. 2017, Shadid 2018)	Increasing number of system components causing the emergence across project phases with risks.
3	Dynamic (Adam & Lindahl 2017, Alasad & Motawa 2015, Alzraiee et al. 2015)	Construction system changes overtime: time-varying factors leading to risks and complexity.
4	Ambiguity (Ebrahimian, Ardeshir, Rad, & Ghodssypour 2015, Naderpajouh & Hastak 2014)	Lack of clearness, imprecision and information adequacy on construction systems.
5	Productivity (Azman, Hon, Skitmore, Lee, & Xia 2019, Karimi, Taylor, & Goodrum 2017, Mirahadi & Zayed 2016)	Construction system generating output with input-environment interactions.
6	Non-linearity (Rashki, Miri, & Moghaddam 2014, Shadid 2018)	The construction systems having parallel and random interaction of system inputs and environment.
7	Competitive (Ballesteros-Pérez, González-Cruz, Pastor-Ferrando, & Fernandez-Diego 2012, Ghoddousi, Eshtehardian, Jooybanpour, & Javanmardi 2013)	Choosing the scarce variable among several alternatives.
8	Sensing (Osman 2012, Vahdatikhaki & Hammad 2015)	Sensing of the variables on system behavior either using technologies that require interventions decisions.
9	Multi-environment (Löwstedt & Räisänen 2014, Phua 2013)	The construction system is a synergy of multi-facets data, information and variables.
10	Collaborations (Pensel & Widén 2011)	Interrelationships, exchange and interfaces among the linear and non-linear system variables.
11	Tangible and intangible data (Bresnen & Harty 2010, El-Diraby & Osman 2011)	The constructions system inputs, environment and output in the form of physical and abstract knowledge.

Those characteristics can be either a part of the input to the system or emergent from the system due to the interaction between inputs, the system environment and the inherent characteristics resulting to complexities (Havenvid, Holmen, Linné, & Pedersen 2017, Love, Edwards, & Smith 2016, J. Zhu & Mostafavi 2017). The generic representation of a system applied to illustrate the emergent system characteristics, and complexities of a planning system are demonstrated in Figures 2.2.

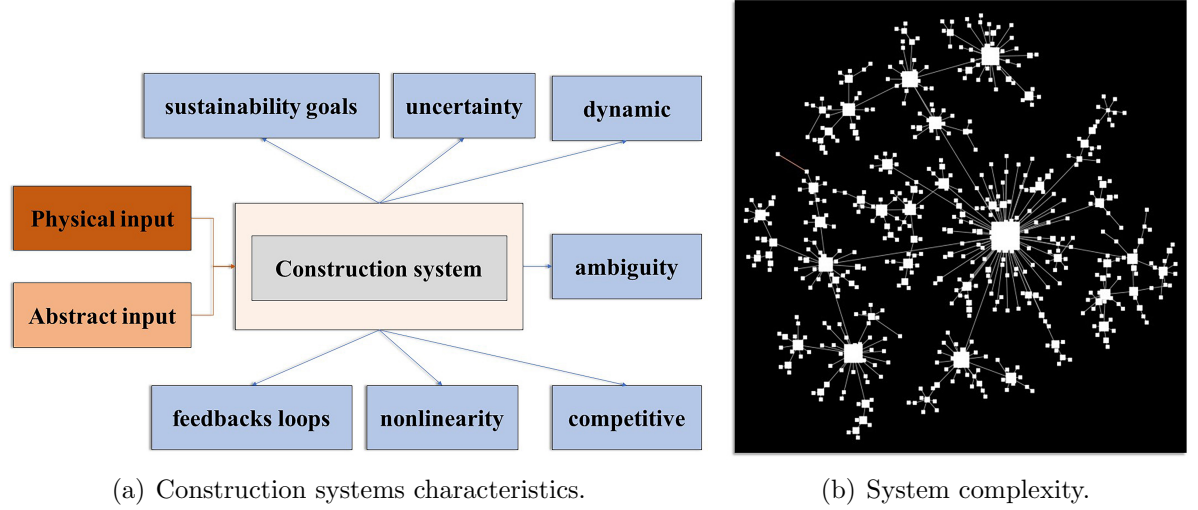


Figure 2.2. Construction project system emergent characteristics and complexity.

From the discussed ideas and theories on construction system characteristics, the figures are developed to couple the insight showing the construction project system with inputs, output and complexities. The concepts of the entire project portfolio at every stage can be described with entities, sub-entities and sub-sub entities. The aggregation of the objects, which are a combination of diverse data compositions is the source of the complexities (Dao, Kermanshachi, Shane, Anderson, & Hare 2016, de Blois, Lizarralde, & De Coninck 2016, Mujumdar & Maheswari 2018, Qazi et al. 2016) leading to a specific project outcome. A sensing of the results guides the conclusion of whether a project meets the outcome or in the region of overrun (Behnam et al. 2016). Though human decisions handle complexities using mental models; but, the strength of the model is likely to deteriorate when the components of the construction project begin to increase

in number (Perera, Sutrisna, & Yiu 2016, Sierra, Yepes, García-Segura, & Pellicer 2018, Sterman 1992).

The inability to handle the incremental entities aggregation and their characteristics can add to overrun in time and other project drivers. The insight on the natural environment of a construction project including the features is likely to be the beginning of a solution to solve the planning problems (Luo et al. 2016), so the usefulness of the technology. Thereby creating an inquiry on the research question **11** that asks:

How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?

Due to the limited and scarce project resources, the planning problem is motivated by the complex decision-making for allocating the resources to the tasks over time (Artigues, Leus, & Nobibon 2015). The main issue to planning problem is the need to satisfy the project performance objectives given the resources and task characteristics, planning environment and constraints (Artigues et al. 2015, M. E. Bruni, Beraldi, Guerriero, & Pinto 2011, Davari & Demeulemeester 2017, Herroelen & Leus 2005). The real-case of construction projects is influenced by several uncertainties and complex variables that lead to similar uncertain problems in the planning and scheduling (Arashpour, Wakefield, Lee, Chan, & Hosseini 2016, Asiedu & Alfen 2016). The accomplishment of the objectives means that scheduling problems centre on the planning environment, resources, tasks constraints and plan objectives, which supports the research question **13** that asks:

To what extent can the integrated planning solution aid the capability of construction project management?

The dynamic planning problem, its accompanying responses and the related variables are continuous and stochastic in the form of probabilistic distribution (Altaf, Bouferguene, Liu, Al-Hussein, & Yu 2018, Alzraiee et al. 2015, Ghasri, Maghrebi, Rashidi, & Waller 2016, Gouda, Hosny, & Nassar 2017, Taillandier et al. 2015). As

shown in Figure 2.3, the first level consists of the main events, and the second level comprises the sub-events or subcomponents.

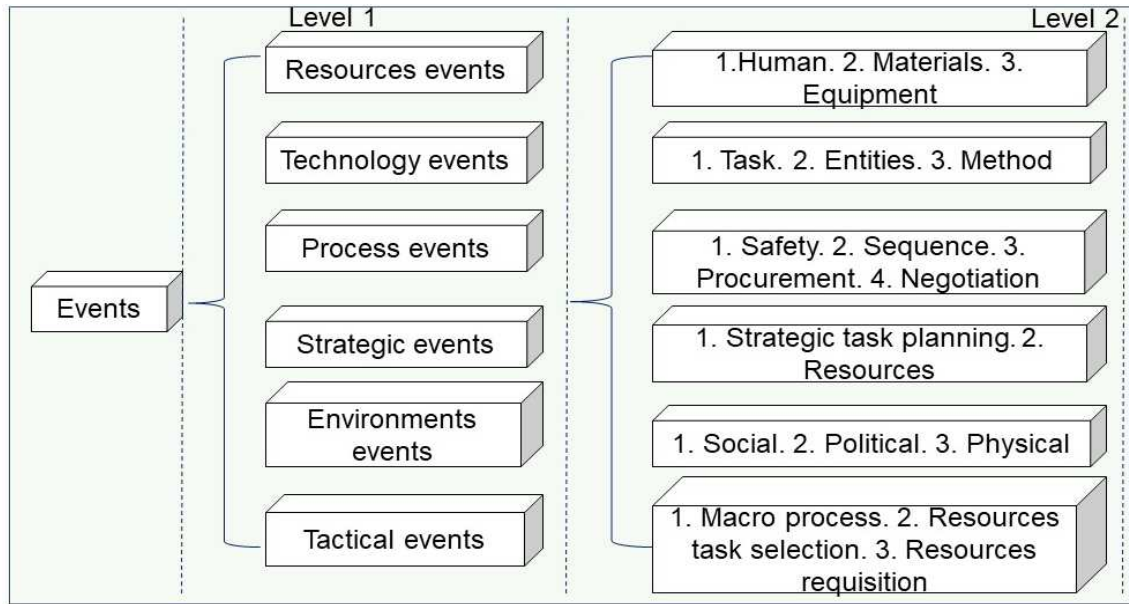


Figure 2.3. Deterministic project requirement (Herroelen & Leus 2005)

So, dynamic planning problems entail objects, entities, and agents' with real-time events that emerge due to the entities and agents characteristic (Deblaere, Demeulemeester, & Herroelen 2011b, Goh & Ali 2016). Since the entities and agents are of homogeneous or heterogeneous behaviours, in the figure, different entities are identified with different events (M. Ahmadi, Behzadian, Ardeshtir, & Kapelan 2017a, A. Rostami & Oduoza 2017, Y. Wang, Han, De Vries, & Zuo 2016) relating to their characteristics. The next section, Section 2.4 evaluates time management of a construction project because the study has analysed the construction characteristics.

2.4 Construction project time management

Two main terms are utilised to analyse time management and associated influencing factors. In this research, the terms 'CTM' and 'CTF' will be used in their broadest sense to refer and correspond to construction project time management and construction

project time influencing-factors, respectively. With the discussion of the concepts in managing construction projects, the construction project is expected to have a specified duration agreed upon for its completion. The organisation and management of construction projects can be of less significance without an understanding of time management (Morris & Geraldi 2011). CTM typically consists of the following elements: activities definition; sequencing of activities; estimation of activity resources; estimation of activity durations; and schedule development and control (PMI 2013). What is notable in this statement is that it captures the essential features of CTM. To achieve a construction project within the stipulated time, for instance, means many workflow tasks may be developing or changing over time.

In the preceding explanations, time is of fundamental value in the success of built environment product development. The success criteria include time, cost, quality, scope, function, safety, and contractors and contractors profit. Earlier studies have highlighted a range of significant benefits of CTM (Benila 2016, Enshassi, Kumaraswamy, & Al-Najjar 2010, Jorvekar Shreyas & Sushma Shekhar 2015, Y. A. Olawale & Sun 2010, Ramanathan, Narayanan, & Arazi 2012, Wong & Vimonsatit 2012, Yousefi, Yakhchali, Khanzadi, Mehrabanfar, & Šaparauskas 2016). The actualisation of the benefits can be a standard measure of project success (Ortiz, Pellicer, & Molenaar 2018) and critical performance indicator (Lam, Chan, & Chan 2007). Moreover, those advantages are more likely to depend on the following criteria: robust and fit for purpose design, result-oriented construction team, and stakeholders' commitment (F. Y. Ling & Khoo 2016, G. Wu, Liu, Zhao, & Zuo 2017). One of the fundamental concerns of built environment product development is to derive maximum return on investment and competitive advantage (Morita, Machuca, et al. 2018). The objectives are a function of the time of product availability in the market and maximising the favourable outcomes when construction projects are efficiently and promptly completed.

How the CTF affect CTM can be assessed and explored using relationship frameworks

as outlined by (Chaturvedi, Thakkar, & Shankar 2018) and models confirmed by (Durdyev et al. 2018). The use of frameworks to show relationships of variables is among the approaches in project management. CTM is a critical components in construction project management and can vary depending on its interrelationship with the CTF. Because of the dependency of project success on time, the management of construction time requires a process for exploring the interrelationship (Ameh & Osegbo 2011). The idea of CTM relationships with CTF can either be modeled in many different perspectives, calculated based on workflow or an investigation with a simulation experiment (Alsaqqa 2015).

Reasoning in that perspective, for instance, the evaluation may be applied to measure the approach to improve construction time performance (Vanhoucke 2010). The time relationships calculation and modeling are techniques that tend to facilitate efficient time management. Often, construction managers claim that the construction projects are completed on time, on budget and to the required quality. In contrast, a variety of studies has proved that often what is demonstrated to be a successful project are less likely to meet the stakeholders' specified expectation (Gardiner & Stewart 2000). There is a unanimity that poor or inadequate CTM is the cause of the delayed project completion (Memon, Rahman, Abdullah, & Azis 2011) and contractual disputes (El, El Nawawy, Abdel-Alim, et al. 2017). The consequence can lead to an adverse effect on the construction project outcome.

The expected construction time performance can be enhanced by construction team competence and shareholders' commitment. Correspondingly, the engagement encouraged the flexible exploration of a wide range of construction alternatives (Janani, Chakravarthy, & Raj 2018). This can be facilitated further by the contractors' management ability (O. Aje, Odusami, & Ogunsemi 2009). The construction team that lacks time resources is comparable to a low productive team and is likely incapable of meeting the critical requirements of efficient CTM (Tabassi, Ramli, Roufechaei, & Tabasi 2014). The productivity of the construction team can be a measure of its

effectiveness on time usage.

CTM needs constant evaluation needs redefinition (Eduardo Yamasaki Sato & de Freitas Chagas Jr 2014) due to the project dynamic environment. It is vital that new approaches and instruments are continuously developed to manage construction time. Sometimes, the construction team overlooks the application of the relevant procedures and tools (Sawalhi & Enshassi 2012). It may be because of inadequate experience and level of complexity inherent in the approaches. This section has reviewed CTM and presented that the stakeholders' goal is to achieve the prompt completion of projects, despite the associated CTF. Likewise, a positive notion in time management yields a corresponding construction management success (Sha'ar, Assaf, Bambang, Babsail, & Fattah 2017). Research findings and applications have shown that the CTF influencing time management can impact on cost and quality management (Y. J.-T. Zidane & Andersen 2018).

Relying on the discussed insights and what CTF is to CTM, a constant search for an improved strategy to show their relationship is a significant effort in the expected direction. The search for the insight is likely supported further by the uncertain and imprecise nature of construction projects, and based on that idea, a part of the research objectives and questions are formulated in terms of relationship framework between CTF and CTM. The factors from the project scope, construction method (Kelly & Ilozor 2019), client and project team relationship (Xiao & Proverbs 2002) are the CTF affecting time performance. Furthermore, social objectives (Nonis, Teng, & Ford 2005) and the procurement system can influence the outcome of time performance. Before proceeding to develop the framework, it is worthwhile to present a brief discussion on the CTF.

This research is of the opinion that if the construction project is completed at the planned due date, then planning problems and the resultant outcomes on the project success are likely to be insignificant issues. In the real construction project, time overrun

and the associated results often have been the reality, meaning that several factors are the root cause of the planning failures. The next subsection, Section 2.5, appraises the factors affecting the time management of the construction project.

2.5 Construction project time management influencing factors

CTF variables are among the factors that determine the outcome of construction projects. The understanding and the knowledge of how they influence the outcome of CTM can be of important concern and analysis. Among a range of studies in different contexts (Baloi & Price 2003, A. P. Chan, Scott, & Chan 2004, Y.-M. Cheng 2014, Naoum 2016, Nkado 1995, Pal, Wang, & Liang 2017, Y. J.-T. Zidane & Andersen 2018) have assessed and evaluated CTF significance in construction management. Even though it has been the case for CTF, the project escalations resulting from their impact have created the need to evaluate and explore how they influence CTM.

One of the significant problems that cause time escalation in the construction projects is poor time management (Adam, Josephson, & Lindahl 2017, Ansah, Sorooshian, & Mustafa 2016, Vahdani, Mousavi, Mousakhani, & Hashemi 2016) and further affected by unsystematic and unpredictable CTF. Time problems occur with the disparity between the real progress and planned schedule of a construction project. Completing the project on time without time overrun is a measure for project success and value creation accepted by the stakeholders (Ralf Müller 2016). Apart from time problems, other resulting challenges include cost overrun, disputes, litigation and abandonment of projects (Ahmadabadi & Heravi 2019), and the adverse outcomes could cut across interrelated activities. One of the most problematic issues in construction projects is the CTF since they adversely affect CTM (Amusan, Afolabi, Ojelabi, Omuh, & Okagbue 2018, Lindhard & Larsen 2016). The need to understanding the

uncertainties caused by CTF has resulted in their categorisation into internal or external factors (Le-Hoai, Dai Lee, & Nguyen 2013).

The CTF are differentiated into seven main categories: (1) tender stage; (2) design stage; (3) pre-construction stage; (4) procurement and subcontracting stage; (5) construction stage; (6) post-construction; and (7) operation. The sub-category can be divided into seven main classes of CTF: client, contractor, and subcontractor, supplier, design and consultant, construction project related, material and labour and equipment, and external, whereby the subcategories encompass the CTF. Besides, the CTF evaluation can be dependent on the inputs from the construction management team. While there are CTF that can have huge impacts, others can have fewer effects (Bagaya & Song 2016, Kadry, Osman, & Georgy 2016, Yousefi et al. 2016).

The concepts of the approaches entail that the solutions to poor CTM cannot be suggested unless the problems are investigated via a thorough understanding of CTF, and it can be based on different contexts (Aziz & Abdel-Hakam 2016, Zarei, Sharifi, & Chaghoei 2018). The different contexts are location, industries, company sizes, respondents' demographic data, sample size, and sample location (T. Liu, Wang, & Wilkinson 2016). Despite those factors responsible for the outcomes of time performances, the insight on their relationship with time management in different phases of construction projects is of great significance for CTM. The next section, Section 2.6, explores the relationship.

2.6 Construction project time management relationship with influencing factors

Construction time management (CTM) enhances construction time performance and is a vital instrument in delivering construction projects as planned (Louis & Dunston 2018, Winge, Albrechtsen, & Mostue 2019). The effectiveness of construction time

performance accounts for the increasing number of construction projects produced at the due date because of implementing time management best practice (Proverbs & Holt 2000, Raj & Wadsamudrakar 2018). Time, cost and quality performances are utilised as the main drivers for the assessment and evaluation of construction projects (Hamta, Ehsanifar, & Sarikhani 2018, Mahamid 2016, Tripathi & Jha 2018). This is because of their significance in project economics (Badewi 2016). CTM is interrelated with construction cost performance and quality performance if the influence on one criterion has a direct relationship and impact on the other criteria (Brown, Adams, & Amjad 2007, M.-Y. Cheng & Tran 2016).

Since in construction projects, the understanding of CTM-CTF relationship is required to analyse the influencing factors and their impact on schedule. In this direction, different studies have evaluated CTM-CTF relationship. Ranking indices, including Criticality Index (CI), Frequency Index (FI), and Relative Severity Index (RSI) are among the analytical techniques used to explore the CTF impact on CTM. For instance, (B.-G. Hwang, Zhu, & Ming 2016) evaluated the criticality index to assess the likelihood, impact of factors that impede to the productivity of building construction and can be used to monitor schedule escalations (X. Hu, Cui, Demeulemeester, & Bie 2016a). The criticality index generated quantitative values to measure the magnitude of the factors. Though is given insight about the size of the factor, the quantitative values are deterministic and meaning that it is insensitive to real project scenario.

(Santoso & Soeng 2016) presented another analytical solution on the evaluation of of CTF and CTM based on frequency and average index, whereby the factors are ranked based on their frequency of occurrence. In frequency index (FI) analysis, different factors responses from the respondents are analysed to obtain their occurrences. The average index can be used as the relative importance index of the categories to figure the factors affecting project performance and success. Similar to the method and values generated by (B.-G. Hwang et al. 2016), it is analytical and has no consideration the complexities at the different stages of the project, which as a unit

determines the frequency of the index. (Hanna, Ibrahim, Lotfallah, Iskandar, & Russell 2016) calculated relative importance index of CTF on CTM to determine the relative importance of different factors to generate their rankings and compare them among different groups. The analytical method and statistical approach utilised by the authors is insensitive to emergent characteristics of CTF during any phase of the project. In the analytical methods by those studies generated the index as output that links the input through a simple formula. The formulas expressed only static dependencies between the CTF and CTM variables, which is not adequate to describe the system behaviour.

In those statistical and analytical investigations, samples are gathered from different professionals in the construction both in qualitative and quantitative forms to represent the population sampled in terms of their demography (Durdyev & Ismail 2016). The samples are pre-tested in the questionnaire design using the qualitative inputs of experts before being distributed. The factors' influence and pair-wise comparison of different factors are then tested to find the significance and intensity of the factors (Arashpour, Abbasi, Arashpour, Hosseini, & Yang 2017a). At least 30 samples are utilised for analysis and to scale the factors in terms of risk probability (Forcada, Gangoellis, Casals, & Macarulla 2017).

Different studies conducted by (Radziszewska-Zielina, Śladowski, & Sibiela 2017) and (M. Ahmadi, Behzadian, Ardeshir, & Kapelan 2017b, Osei-Kyei & Chan 2017) on CTF and CTM relationship established the use of a hybrid of statistical and fuzzy method as an advanced technique applied for risk calculation of CTF, whereby fuzzy set theory identifies the causes of the schedule overrun. In the evaluation, expert respondents information were collected on the factors that cause delay and severity of each factor. The outcome is implemented to proffer mitigation measures with the aid of fuzzy set theory to determine delay probability. The Fuzzy can handle ambiguity, complexity, uncertainty and decision making using linguistic variables and membership function. Even though a technique evaluates static and dynamic CTF-CTM-IM exploration, the method is simple and has ease of analysis.

However, the realisation of the primary success criterion is hindered by CTF because of various imposed challenges (Proverbs & Holt 2000). Still in the CTF's presence, over the decades, the construction industry is changing towards contributing to the increasing economic growth and gross domestic growth (D. W. Chan & Kumaraswamy 1996, González, González, Molenaar, & Orozco 2013, Y. A. Olawale & Sun 2010). The implication of CTF may be the need for continuous research efforts towards developing and improving the approach to understanding the relationship between CTF and CTM. This creates insights of the resulting impact on the overall stakeholders' objectives. In contrast, managing the execution and control of projects in the construction sector is one of the most significant challenges that require devising improved decision-making systems relating to construction success — the performance criteria, even in the presence of project risks factors and uncertainty.

A growing body of literature suggests that time, cost, quality, safety, scope, function, and contractors profit are contributing components necessary to meet the demands of productivity in construction projects (Akanni, Oke, & Akpomiemie 2015, Lam et al. 2007, Nassar & AbouRizk 2014). The deviation from the criteria is almost certain to incur significant failure in construction project scope and objectives. Among those components, time is sometimes the most critical aspect. A primary concern of time component in construction management is the concept of CTM. Time is among the essential factors for a successful construction management (Cheong Yong & Emma Mustaffa 2012, Koops et al. 2017). Over the past century, it has been emphasised that most projects have time overrun that prevents the achievement of expected project outcomes, with the connotation that managing time can be of the essence for project outcomes. A typical view of the study conducted by (Cheong Yong & Emma Mustaffa 2012, D. Walker 2018) has shown that time management success is impacted by a wide range of factors called CTF. The CTF emanate at different phases of the construction project life cycle and delivery systems (Pheng 2018).

In that context, the stages involve project proposal, preliminary design, procurement,

design, bidding, construction, transfer, and operation. The insight of CTF variation from project to project and the in-depth evaluation of the CTF by the stakeholders' are fundamental to successful project delivery (M. Bragadin 2018, Doloi et al. 2012, Forcael, Morales, Agdas, Rodríguez, & León 2018). CTF is know-unknown or unknown-unknown with different degree and category of impacts on the success of the project schedule. CTF has been found to affect CTM, and this has been explored in several studies (Chaturvedi et al. 2018, Enshassi, Mohamed, & Abushaban 2009, Nkado 1995, Y. A. Olawale & Sun 2010). The studies confirm that construction projects are generally subjected to different time escalations. In the same way, a range of researches over the past decades has given different terminologies to the resultant impact of CTF (Issa 2013, Koushki & Kartam 2004, Mahamid, Bruland, & Dmaidi 2011, G. J. Sweis 2013a). Among the terminologies are time overrun, delay, time risks, time variations and time impact. Because of the CTF, either construction project can be delivered on time or its completion delayed after the due date (Yap, Abdul-Rahman, Wang, & Skitmore 2018).

The examination presented the dependency of timely delivery of construction projects on the knowledge of the influencing factors that request for the answer to the research question 5 that asks:

What are the relationships between construction time management and influencing factors in construction projects necessary to gain insight about reducing time overrun in construction projects?

The association of CTM success with CTF in construction projects has documented a significant amount of literature (Ahmadabadi & Heravi 2019, Antwi-Afari, Li, Pärn, & Edwards 2018, Bond-Barnard, Fletcher, & Steyn 2018, D. W. Chan & Kumaraswamy 1996, Ghannadpour, Noori, & Tavakkoli-Moghaddam 2014, Kavishe & Chileshe 2018, S.-Y. Kim, Tuan, Do Lee, Pham, et al. 2018, Ochieng, Hughes, Ruan, Price, & Egbu 2013, Tezel, Koskela, & Aziz 2018, Y. J.-T. Zidane & Andersen 2018). The effectiveness of contractors' management, for instance, impacts on project

time performance (O. Aje et al. 2009, Olubimbola 2018), likewise, the complexity and ambiguity in construction time management (A. Ahmadi & Golabchi 2013). The understanding of time management complexity is important in showing the relationship between CTM and CTF. The insight can be true because project complexity has relative effects on project duration, and it is likely to be the underlying reason for project time escalation. The relationship can be explored in different ways. A relationship framework is likely to be one method to describe the relationship. To avoid construction time delay and budget overrun, it is necessary to keep time control at the heart of construction projects (Y. Olawale & Sun 2015).

The relationship between CTM and CTF can be conceptualised at different contract stages including bidding, design, preconstruction, procurement, construction, post-construction and operation expected to represent the factors at the primary category levels. The categories are used in the method section 3.7.1.1 to illustrate the categorisation. There is no specific approach to explore the correlation between CTM and CTF. In the same vein, some studies have utilised the conceptual framework to investigate a variety of relationships at different project phases (Z. Jin, Deng, Li, & Skitmore 2013, Rosenfeld 2013). Therefore, this research aims to examine the CTM and CTF relationship at different stages and provide a conceptual model to explain the impact of the relationship. The construction project planning occurs in phases. In the next section, Section 2.7, hierarchical planning is examined to drive further discussion on different planning levels, planning stages, planning methods and planning technologies.

2.7 Construction project hierarchical planning

The system for accomplishing the procurement of construction project are lineated procurement (Bing, Akintoye, Edwards, & Hardcastle 2005, Hueskes, Verhoest, & Block 2017, Plantinga & Dorée 2016, Regan, Smith, & Love 2011, X. Zhang & Kumaraswamy 2001). Along the line are different phases initiated from tender phase to

post construction stage (Levitt & Eriksson 2016, Naoum & Egbu 2016). Those projects characteristics are inherently complex and dynamic. There is a requirement to create a sequential process (Heeres, Tillema, & Arts 2016, Moore & Elliott 2016) to enhance their planning and management, including capacity planning, system influences and the detailed schedule.

Hierarchical planning is an approach to handle uncertainties, complexities and variabilities in activity times and duration (Hans et al. 2007). This is because activity durations are stochastic and non-deterministic (Browning & Yassine 2010). Hans points out that in contrast to the traditional planning and scheduling methods where durations of the work packages are specified in advance, the activities sequences and durations in the real construction project need analysis on a dynamic basis.

The hierarchical planning is divided into the strategic level, tactical level and operational level (Alvanchi et al. 2011b, Hans et al. 2007, S. H. Lee et al. 2006, Meifort 2016, Montoya-Torres, Muñoz-Villamizar, & Vega-Mejía 2016). Because of the vast management activity in construction projects, operational level planning and scheduling have embraced high acceptance and formed the core of most project planning and scheduling (Albrechts 2006, Shenhar 2004). Many commercial project management tools are majorly developed on the operational practice of planning in construction (Papke-Shields & Boyer-Wright 2017). Besides, planning in terms of uncertain time distributions are expected to be improved in most of the tools and a requirement for stochastic simulations concerned at both the tactical and strategic levels (Florichel, Michela, & Piperca 2016, Moret & Einstein 2016).

The explanations presented in this section suggest the research question 4 asking:

What are the expected strategies if pursued, positively influence the real-world planning system and improve system solutions?

The question is posited to improve the planning of construction projects and validated by the subsections of this section. Each level of the hierarchical planning are discussed in Subsections 2.7.1 for strategic-tactical level and 2.7.2 for operational-tactical level.

Table 2.2 shows the levels of details at different hierarchy. The table describes the characteristics of the different levels of planning.

Table 2.2

Levels of abstractions

Variables	Abstraction level
Operational:	Detailed scheduling and network-based including activities, precedence relationships, activities duration, resources allocation, task sequence, constraints.
Tactical:	Flexibility, optimal resources management, schedule robustness, due date setting, replanning rules, milestones, operations and activity management, constraints and multi-objective management, decision-making, technology interactions, productivity management, policies implementation, procurement and sustainability.
Strategic:	complexity, material/energy information, dynamic programming, exploration and evaluation variables, decision rules, goals, success factors, team motivation and project capability.
Reference sources from : (Bennett & Ormerod 1984, Betts & Ofori 1992, Choi & Bae 2009, El-Sheikh & Pryke 2010, Hans et al. 2007, S. H. Lee et al. 2006, Love, Holt, Shen, Li, & Irani 2002, R. Murphy 2013, Peña-Mora et al. 2008, Rodrigues & Bowers 1996, Russell, Tran, & Staub-French 2014, Sterman 1994, Verheij & Augenbroe 2006)	

Each level of the hierarchical planning are discussed in Subsections 2.7.1 for strategic-tactical level and 2.7.2 for operational-tactical level.

2.7.1 Construction project strategic-tactical planning

Construction project enterprise involves productivity and growth from both the client and contractors' perspectives. The construction project is aligned towards the business goals (Anvari, Angeloudis, & Ochieng 2016, Karunasena, Rathnayake, & Senarathne 2016, PMI 2013). Therefore, strategic planning aims to link the business objectives holistically with the discrete activities needed to achieve the goals. Different approaches have adopted strategic level to investigate the dynamic and complexity features in the construction project. Strategic and operational levels, as well as tactical level, are

employed to plan and control dynamic projects in collaborative environments (S. H. Lee et al. 2006), although without hierarchical consideration of the construction phase that begins with tender and bidding.

(Choi & Bae 2009) suggested that the system requires inputs, outputs, internal models and assumption, whereas (Love et al. 2002) suggested that it as a platform for strategic simulation of changes in a dynamic project environment to enhance project performance. The baseline and master schedules integrate buffer to protect the activities against uncertainties (Carvalho, Oliveira, & Scavarda 2016, Ghoddousi, Ansari, & Makui 2017, J. Zhang, Song, & Díaz 2016). The assignment of buffer during scheduling of events and buffer size requires a system to investigate changes of the buffers on activities (Balta, Birgonul, & Dikmen 2017, J. Zhang, Jia, & Diaz 2018).

In relation to buffer amounts, (S. Lee, Peña-Mora, & Park 2006) applied strategic simulation to determine the impact of buffer changes on project performance for a dynamic and complex project process towards maximising project productivity. The integration of strategic and operational elements modeled as a unit enhances the decision support and actions for project management (Davies & Brady 2016, Peña-Mora et al. 2008, Y. J. Zidane, Johansen, Hussein, & Andersen 2016). Strategic planning can be applied at the tender phase to investigate and manage risks and changes for large complex projects (Banihashemi, Hosseini, Golizadeh, & Sankaran 2017, Biruk, Jaśkowski, & Czarnigowska 2017, Rodrigues & Bowers 1996). A construction project is well-known to be influenced by changes and uncertainties and can be protected with strategic planning and system analysis (Plantinga & Dorée 2016, Wilker, Rusche, & Rymsa-Fitschen 2016).

Even though there is a global acceptance of strategic planning, yet the application on construction projects faces many constraints (Abu Bakar, Yusof, Tufail, & Virgiyanti 2016, Betts & Ofori 1992, Oyewobi, Windapo, Rotimi, & Jimoh 2016). These include: 1) strategic ideas are emerging; 2) technology and approach are developing; 3) lack

of attention to strategic planning; 4) misunderstanding between strategy and strategic planning and; 5) construction has little opportunity for the application of strategic planning. Since construction project is in phases and planning and control at one phase affects the next phase, real-time dynamic control for the procurement and construction of a new construction project is expected to begin with tender and bid phase.

In the tender phase, the management of the planning process for the expected project ascertains the need to integrate a high percentage of the process in that phase (Adafin, Rotimi, & Wilkinson 2016, Towner & Baccarini 2012). Irrespective of the fact that the phases are required, the dynamic and stochastic duration investigations and analysis are necessary to support the dynamic and sophisticated features of the construction system (Mendoza, Rousseau, & Villegas 2016, M. Ning, He, Jia, & Wang 2017). For hierarchical planning, the choice of the planning level employed for modeling and simulation is expected to be dependent on the construction procurement phase.

Many strategic decisions are made during the construction phase, which is likely to be a misnomer because project appreciation and decision to commit to a construction project begins from the procurement stage where the business opportunities are analysed with the company vision (Olatunji, Aje, & Makanjuola 2017, Shokri-Ghasabeh & Chileshe 2016b). The construction project product needs to stay competitive and drive growth. The sub-processes, process, subsystems, a central system for achievements in a complex and dynamic environment are influenced by risk factors that hamper the project performance to uncertainty (Bakhshi, Ireland, & Gorod 2016, Demirel, Leendertse, Volker, & Hertogh 2017). Strategic planning enhances risks identification, assessment and management towards attaining success on the competitive procurement process (Alwan, Jones, & Holgate 2017, D. H. Walker 2016). Strategic planning can vary with changes as the construction project is executed. Hence it requires a tactical process to actualise the strategic goals.

The definition of business goals and objectives is one part; a process for linking the

goals with the actual activities is another. While a successful project goal requires the process as a collaborative interface between what the business wants and what is employed to achieve those wants, the tactical plan transforms strategic planning into project plan (Y. J. Zidane et al. 2016). Sometimes, a large part of the process is embedded in the activities to achieve the want. Tactical level planning is a process that takes the strategic planning components into project implementation (Carvalho et al. 2016). It is considered for both short-term and long-term by linking and comparing the implementation with the strategic objectives of the businesses.

The two ends of construction project planning, strategic and operational, have rigid attributes by their internal accomplishment and the project remains static if no planning level negotiates and embraces that inflexibility (Drake, Starkey, Owusu, & Burke 2019). The required flexibility and negotiation are attained through the tactical level. The flexibility of the tactical level is the driver of workflow (Verheij & Augenbroe 2006) and value delivery derived from the operational level to the strategic level (Barima 2009). It executes the non-deterministic impact of strategic and operational variables (Alzraiee et al. 2015). The tender and bidding phase is central to the implementation of the strategic objectives.

The efficient and effective approach employed at the tender and bidding phase can be one of the determinants of success in the procurement and execution of construction project management. For instance, the information at the tender phase is vital for decision-making at the planning and construction phase (Vu, Wang, Min, Mai, & Nguyen 2016). Contracting Companies make bid/no bid decisions for the project to satisfy the project mission. In the process of appreciating the proposed project, the company weighs the organisation philosophy in assessing the opportunities and threats (Chisala 2017, Sonmez & Sözgen 2017). The aim is accomplishing client requirements and submission of the bid before the deadline as well as sustain the business through the project with contract profitability (Chisala 2017, Utama, Chan, Gao, & Zahoor 2018). Among the needs of the tender from the client is the due date delivery of the

projects, which is a function of other related specifications and requirements, including each activity execution method.

The strategic level of planning requires the bidding process to receive the top management commitment (Semaan & Salem 2017). Even when it is the accepted expectations of the company to bid for the project, winning the bid is a challenge (Mathisen 2016). The questions are: 1) what is the strategy for bid/no-bid decision? 2) how do the company transform its business goals to secure the project? 3) how much insight does the company have that the contract shall be executed as agreed and planned? and, 4) what is the approach to generate a practical strategy for robust execution of the project?

The tendering/bidding phase, given the answers to those questions, stands out as a key to hierarchical construction project planning and execution to satisfy the business objectives (Thunberg & Fredriksson 2018). The management influences and actions are likely to impact the bid submission and the system output. The investigation of interaction among the project objectives, execution, project planning, resources requirements, decisions on alliancing and management influences, then, is a part of the strategical-tactical planning. The collaborations are required at those hierarchical phases of the contract with the awareness of the project complexities. The management influence is a result of the interactions between the company business units leading to the research question **10** that asks:

How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?

Concerning one of the main motivation of the study, which is appraising dynamic and static planning systems, the characteristics and the construction system are further explored independently given the deterministic (static) and non-deterministic (dynamic) planning concepts. In Subsection 2.7.2, while the Section 2.7.2.1 analyses the static planning concepts, the Section 2.7.2.2 presents ideas and concepts for dynamic

planning.

2.7.2 Construction project operational-tactical planning

Efficient planning is unlimited to strategical-tactical level. The processing of each activity to achieve a complete project product is dependent on the operational-tactical phase. The management of constructions projects, particularly in scheduling, has motivated this part of the review. Scheduling enhances the delivery of construction projects at the defined schedule and within allocated resources constraints, irrespective of the inherent, predictive and reactive risks in a dynamic construction environment. Though scheduling is the outcome of effective planning, this section will present understanding and ideas on static and dynamic planning, focusing on construction activities requiring resources and durations. The present status of construction project scheduling, including the state of the art technologies for construction scheduling, the level of research efforts and essential themes are assessed in the review to strengthen the purpose of the proposed research.

2.7.2.1 Construction project deterministic planning characteristics

From the initial construction scheduling perspective, there is a consensus that baseline schedules, including Gantt chart, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Line-of-Balance (LOB) and Earned-Value Management (EVM) (Abdul-Rahman, Wang, & Muhammad 2011, Daniel & Daniel 2018, Kokkaew & Chiara 2010) are deterministic. The schedule generated using those methods do not consider several risks imminent in uncertain project environment (Al Nasser et al. 2016, M. E. Bruni et al. 2018, Giran, Timur, & Bekdaş 2017). The deterministic schedule assumes that project will finish at the planned duration (12 days) and resources (12 units). This is a change of the schedule from an amber colour to green colour, as shown in Figure 2.4.

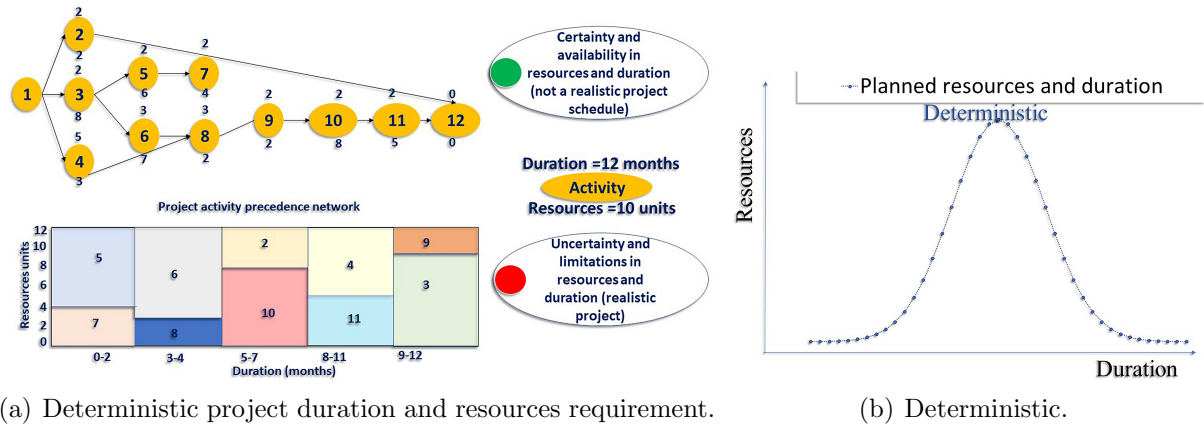


Figure 2.4. Construction project system deterministic characteristics and nature.
Data source: (Coelho & Vanhoucke 2011, Herroelen & Leus 2005)

In the real construction environment, this assumption is invalid because there are no sizes of changes considered in the schedule resulting in a change of the schedule from amber to red (Alvanchi et al. 2011b, Demeulemeester & Herroelen 2011, Gaspars-Wieloch 2017, Nesmachnow 2016). Because of the examination, research developed a question 3 that asks:

What are the barriers to the utilisation of the current solutions for planning problems?

In contrast, baseline schedule has been the basis of several novel approaches developed since Gantt charts. Similarly, it aids in the rescheduling to enhance the flexibility and performance criteria of construction schedule in static mode (Kuo, Tsai, & Kang 2011). It has been argued, for example, that despite the inability of baseline schedule to expect disruption risks, it can be protected and optimised to change its deterministic nature (Palacio & Larrea 2017). Besides, other authors have pointed out that the baseline schedule only enhances resources allocation. It is the fundamental basis for planning used for communicating and coordinating a plan for both project functional and organisation structure (Davari & Demeulemeester 2017). The main drawback of deterministic baseline schedule is its inability and insensitivity to uncertainties as well as disruptions that characterise the real-world and dynamic project environment (Afshar-Nadjafi 2016, Artigues et al. 2015).

Static schedule inability to consider the information of the production facility that is being constructed in terms of the implied technology constraints and operation sequences underpins this assertion (H. Liu et al. 2015). The significance of the static project scheduling forms the basis for dynamic scheduling (Brafman & Shani 2016, Feylizadeh, Mahmoudi, Bagherpour, & Li 2018). With the advances in computer technology, it calls for a transformed approach capable of automating the entire scheduling systems in terms of interactive and integrated computer-aided systems for planning in variability and complex conditions. Furthermore, technology development has encouraged this research on construction project planning that will integrate the dynamic characteristics, analysed in Subsection 2.7.2.2.

2.7.2.2 Construction project non-deterministic planning characteristics

Compared to the manufacturing industry, the significance of solving planning and scheduling problem in construction project motivates the development of a range of approaches in various research. Real-time dynamic scheduling changes and events consist of known and unknown strategies: known, as foreseen uncertainties and unknown, as unforeseen uncertainties (Herroelen & Leus 2005). For known unknown, the method of analysis is categorised into entirely/stochastic scheduling, proactive scheduling and reactive-predictive scheduling (Artigues et al. 2015, Herroelen & Leus 2004, Lambrechts, Demeulemeester, & Herroelen 2008a). The unknown unknown method is grouped into learning and selectionism that considers the network of activities as decision variables (Pich et al. 2002).

The construction project environment is dynamic and operates in the unsteady state (Y. Huang, Zou, & Zhang 2016, Kaveh, Khanzadi, & Alipour 2016, Walecdzik, Manadziuk, & Zadrozny 2014). There is a need for construction planning and management systems to integrate real-time, continuous and discrete events, which are the characteristics of the construction project (Elbarkouky, Fayek, Siraj, & Sadeghi

2016, J. Zhu & Mostafavi 2016).

Although there is a comprehensive application of dynamic scheduling in other fields of scheduling, namely computer and manufacturing, its utilisation in construction is developing (Fahmy et al. 2014). An implication of this is the possibility of construction scheduling systems and research that have been developed in a steady state. This is one of the most influencing factors that has subjected the construction project to time and cost overrun (Love, Sing, Wang, Irani, & Thwala 2014).

Dynamic scheduling is emerging as a capable alternative for generating construction schedules in an efficient and real-time response (Francis 2016, Khan et al. 2016, Poshdar et al. 2016). Construction teams often ignore the significance of understanding the dynamic nature of the construction environment. The project is finished within the deadline with the compromise on project quality (M. Park, Kim, Yoon, & Nepal 2010). Similar to the manufacturing industry, dynamic changes, transient and unpredictable events, complexity, scale, uniqueness and set objectives are among the characteristics of the construction project.

Dynamic scheduling responds to uncertainties and risks and makes decisions to support the stability of the schedule. The risks are in terms of disruptions, known knowns (K K), known unknowns (k unk), unknown knowns (unk k) and unknown unknown (unk unk) (Herroelen & Leus 2005, Howell, Windahl, & Seidel 2010, Jones, Gibb, Goodier, & Bust 2017). The risk diagram in the region of k and unk, depicted in Figure 2.5, can be considered as phases showing limiting conditions of the risk components.

An investigation into the project environment is expected to explore opportunities from the start into the different phases. In the phase diagram, a particular risk might be unclear even when we expect it to be known, leading to more complexities (Arashpour, Abbasi, Arashpour, Hosseini, & Yang 2017b). A technology that has the features of exploring the phase regions and checking that what we know can be the possible solutions to deterministic project events is expected to be valuable.

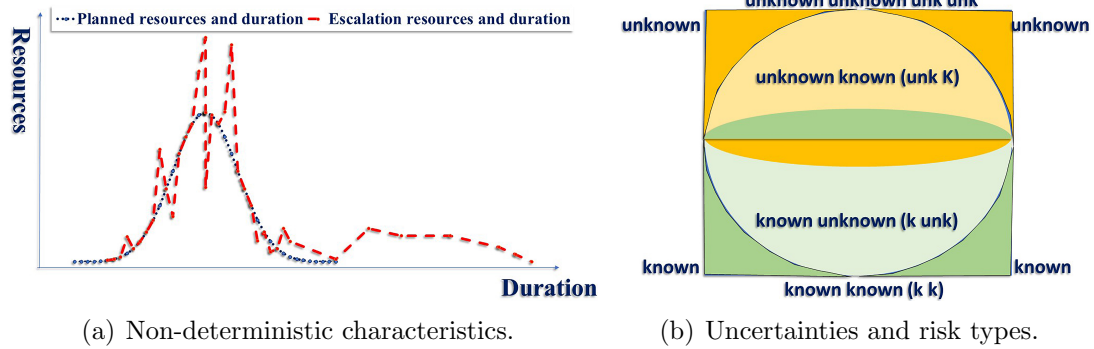


Figure 2.5. Construction project system non-deterministic characteristics and nature. The pictorial representation is based on these sources (Baker & Trietsch 2013, Baldwin & Bordoli 2014, Herroelen & Leus 2004, 2005, Jones et al. 2017, Lambrechts, Demeulemeester, & Herroelen 2008b, PMI 2013, Shen, Minku, Bahsoon, & Yao 2016)

Irrespective of the inherent characteristics, for planning and scheduling technology, even if it integrates those features, there are other salient features required for the applicability of the developed tools (Matar, Osman, Georgy, Abou-Zeid, & El-Said 2017). According to (Bonnie 2015, El-Sabek & McCabe 2018), construction scheduling tools is expected to satisfy the conditions depicted in Figure 2.6. The figure shows the

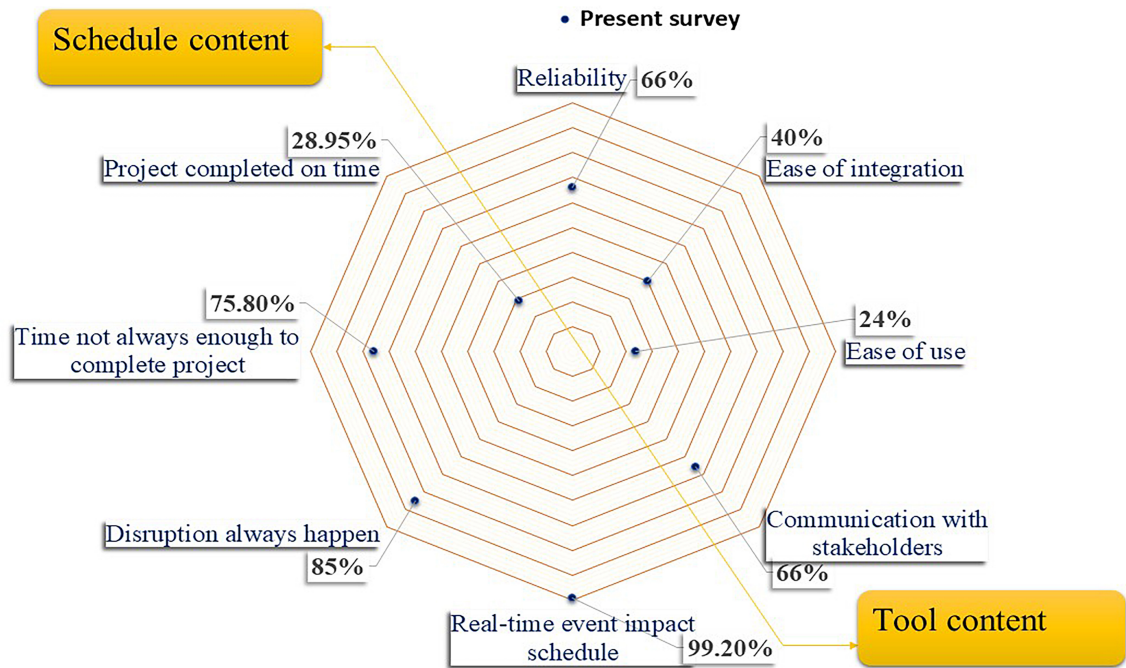


Figure 2.6. Operational scheduling technology features

expected attributes of planning and scheduling systems.

Although the figure shows the state of the planning tool, an improvement is required to enhance the applicability of the tools. The literature review explains that the efforts to solve scheduling problems can be divided into reactive scheduling, predictive-reactive scheduling, robust-proactive scheduling, learning and selectionism. In the sections under this subsection, the theories of the three classifications are reviewed. Therefore, this section, in addition to the pieces of evidence so far, supports the research question **1** that asks:

What is the current approach for static and dynamic planning in construction projects, and what form of the plan is produced?

2.7.2.3 Completely reactive scheduling

In this type of scheduling, no baseline schedule is developed. The method; however, uses the scheduling and multi-decision policies, and strategies at different decision point (Möhring, Radermacher, & Weiss 1984, 1985, Stork 2000). It is based on the priority rule to determine the tasks for execution based on admissibility constraints (Herroelen & Leus 2005). Among the various strategies, completely reactive scheduling, has the strength to update and reschedule the construction schedule to meet the deadline (S.-S. Liu & Shih 2009).

In this approach triggered by disruptions:

1. the schedule is first generated;
2. rescheduling strategy and policies define when and how to reschedule;
3. rescheduling method is established; and
4. then the updating and rescheduling completed based on either complete or partial rescheduling.

Sometimes no initial schedule is generated but uses dispatching heuristics rule to execute the tasks with the highest priority in resources utilisation (Petrovic, Petrovic, & Burke 2011). The dynamic reactive rescheduling includes sets of technologies involving rescheduling management and optimisation. The completely reactive scheduling, set out in Figure 2.7 is concerned with the application of scheduling policies to handle uncertain events and to guard against overrun in duration.

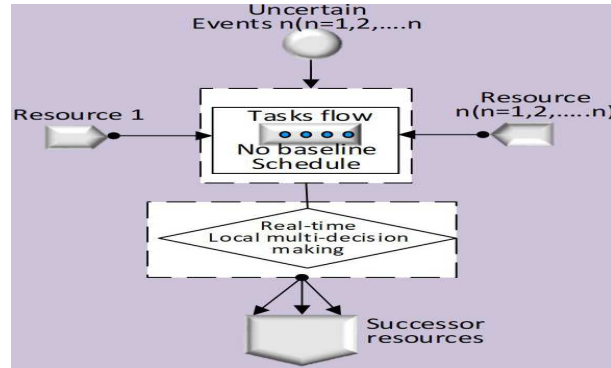


Figure 2.7. Completely reactive scheduling

2.7.2.4 Robust proactive scheduling

The robust scheduling, shown in Figure 2.8, is known to be predictivity-uncertainty absorber.

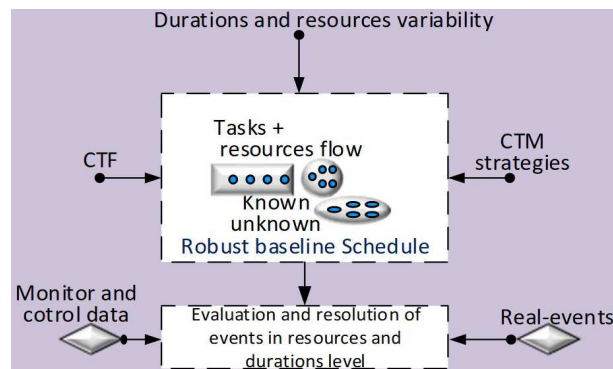


Figure 2.8. Robust proactive scheduling

This method focuses on absorbing a specific level of uncertainty, performs the maintenance of the offline predictive disruption, and insensitive to changes in uncertain

conditions (Herroelen & Leus 2004, Jensen 2001, Schatteman, Herroelen, Van de Vonder, & Boone 2008, Van de Vonder, Demeulemeester, Herroelen, & Leus 2005). Robust scheduling anticipates for several variabilities in duration and resources. It employs the past project issues, challenges, construction time influencing factors (CTF) and construction time management strategies (CTM) to make the schedule robust and predictive for any uncertainties. Afterwards, the schedule is updated using project monitoring to control data in an uncertain event.

2.7.2.5 Predictive-reactive scheduling

The scheduling strategy focuses on schedule repair, rescheduling, contingent scheduling, activity crashing and sensitivity analysis (M. Bruni, Pugliese, Beraldi, & Guerriero 2017, Ibadov 2018). There are many studies related to this scheduling approach found in (Lambrechts et al. 2008a). In schedule repair, a quick intervention strategy is applied to restore any breakdown in resources and activities relations without re-sequencing the tasks (Alipouri, Sebt, Ardeshir, & Zarandi 2017). Schedule repair tackles minor repairs, while rescheduling intervenes by carrying out full scheduling of the remaining activities (Moparathi, Sagar, Ramya, & Chaitanya 2018). Instability and discontinuities are the attributes of proactive-predictive scheduling, as presented in Figure 2.9.

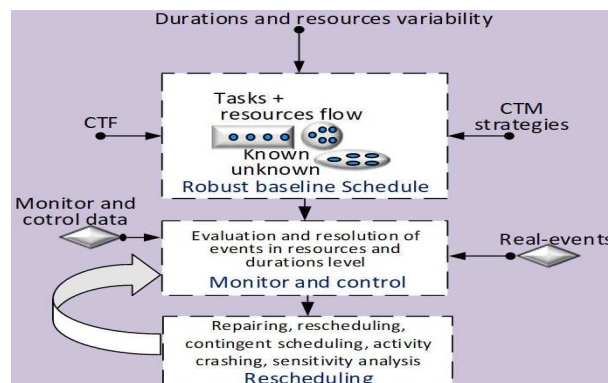


Figure 2.9. Predictive-reactive scheduling

2.7.2.6 Learning and selectionism

Project teams always encounter information inadequacies during project execution generated from unforeseen uncertainties and variations (Herroelen & Leus 2005, Howell et al. 2010). The schedule planner is available to respond to an uncertain signal by updating the schedule in the uncertain conditions leading to new scheduling solution. This approach searches for the unknown unknown in the existing strategies and adopts new policies to respond to the new changes (Lenfle 2011, Pich et al. 2002).

The new uncertainty can occur at any level of the schedule. Learning technique is the preferred choice when the project management team accepts that improvement is one of the options to handle unforeseen events (De Meyer, Loch, & Pich 2002, Geraldi, Maylor, & Williams 2011). Tasks and resources allocations can be re-planned to capture unaccounted changes, and the learned improvements in the past are then applied to resolve the current changes, as shown shown in Figure 2.10.

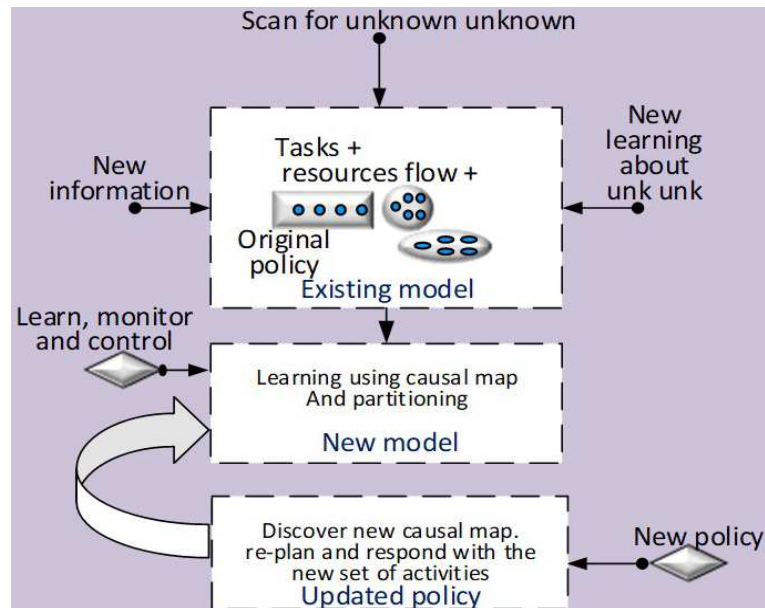


Figure 2.10. Learning scheduling method for unknown unknown

The major challenge for learning approach is time-consuming involving a high level of flexibility among the team members (Bosch-Rekvelde, Jongkind, Mooi, Bakker, &

Verbraeck 2011, De Meyer et al. 2002). Furthermore, it requires a more empirical test to validate the approach, and if validated, helps project management team adopt a project characteristics-based strategy to enhance planning and scheduling (Thamhain 2013). Selectionism is an extension of the learning approach, whereby there is a search for optimal possible solutions in the neighbourhood of multiple solutions (Brady & Davies 2014). It entails adapting to new policies as well as modifying the existing policies to capture and tackle uncertainties. Most often, the change signals are too costly for the project team to learn from and may not yield best within the search spaces. In this case, the team make policies and observe the outcome and behaviour of the policies (Davari & Demeulemeester 2017, Habibi, Barzinpour, & Sadjadi 2018, Herroelen & Leus 2005). Furthermore, as presented in those studies, the strategies evaluate the policies against future known uncertainties and prediction of the uncertainties.

The examination shows that the dynamic scheduling problem is generated during construction execution. The project execution process directly influences the solution quality to the problem. The solution technologies of a dynamic scheduling problem for the construction project are scarcely available. In different researches where the solutions are available, the bridging of the gap between theory and practice is a significant problem. In the same vein, scheduling solution issues are pointed out in different research, although the research efforts are in manufacturing. The next subsection 2.7.3 presents the concepts of different approaches for dynamic systems and the technologies to evaluate their complex and variable attributes, namely trade-off analysis, hybrid frameworks and simulation modeling, and optimisation.

2.7.3 Planning and scheduling system and technology

Construction scheduling is developed during the bidding phase as a baseline to high-level scheduling during the project execution to manage and control time (Guevrement & Hammad 2019). The concern is the development of a scheduling system that generates

feasible, optimal, robust, and alternative schedules within the certainty and uncertainty domain subject to the specified resources (X. Hu, Cui, Demeulemeester, & Bie 2016b).

Though scheduling technologies take a fraction of the cost, it can be utilised to plan, manage, control time, and maximise the project profit (A. M. Elazouni & Metwally 2005). This can be achieved through deriving insight from the construction system characteristic, whereby scheduling systems require inputs, interacting processes and entities, system boundaries and outputs (Tsehayae & Fayek 2016). The analysis of a scheduling system for a real case project is expected to integrate the sub-processes and sub-systems, again leading to the complexities and dynamic emergence that characterise the system (T. Williams 2017, G. Wu et al. 2017).

A system has boundaries, which specify the system objectives, limitations, constraints, assumptions and initial conditions (M.-Y. Cheng & Tran 2016, Elbeltagi, Ammar, Sanad, & Kassab 2016). A holistic approach to a scheduling system enhances the decision-support for the management of the system (Kerzner 2013). Even though there is a clear understanding of the system components, the tools and method to analyse the system are the key aspect, if the insight is expected to be useful (Zavadskas, Govindan, Antucheviciene, & Turskis 2016). The system analysis in a complex environment is an important challenge with varying concerns. It is the reason for the wide range of tools and method developed for complex and dynamic systems, which can be applied to construction project scheduling and planning (Bakhshi et al. 2016). The complexities and computational difficulties of the analysis method have enforced different efforts on the parts of the system, but not the holistic system (J. L. Ponz-Tienda, Salcedo-Bernal, Pellicer, & Benlloch-Marco 2017). This has resultant issues and challenges on the analysis method and technology, which is illustrated in Figure 2.11 (Kang & Choi 2013, Zhang & Mostashari 2011).

The insight gained from those challenges and their integration into the technology and analysis method may be of aid in improving the evaluation. Furthermore, it can



Figure 2.11. Complex systems real-time challenges

enhance the accompanying results from the dynamic and complex planning system in the management of a construction project. While Figure 2.11 depicts the main challenges, the description of the associated challenges and summary mechanisms are tabulated in Table 2.3.

Overall, this section indicates that there are challenges to complex system analysis and integration that generated the research question 9 asking:

What are barriers that may be associated with the model integration, and how are they addressed?

In general, the practical implication is likely to be the consideration that a construction project is a system with multi-input, multi-output and multi-component interactions with the surrounding environment. Moreover, irrespective of the system definition, the characteristics of the system and the interactions requires a holistic evaluation in one platform. In this case, it suggests that a method capable of demonstrating those features can strengthen the development and updating, and optimisation of the planning system as an entity. So, the table and figure presented in this section form the basis for reviewing the analysis method and technological processes examined in Sections 2.7.3.1 to 2.7.3.4. The main analysis methods and technological processes selected for in-depth examination and relevant to this study, are trade-off analysis, simulation modeling and framework, and optimisation

Table 2.3

Solution challenges in dynamic scheduling

Challenges	Description
1 NP-hard problem	Exponential growth of solution with problem.
2 Multi-constraints	Simultaneously satisfied variables and conditions.
3 Multi-objectives	Several conflicting performances.
4 Solution convergence	Huge computation and solution space.
5 Solution quality	A solution in terms of performance measures.
6 Scale	Huge decision-making from many activities and limited resources.
7 Implementation	Practical implementation of solution and usage.
8 Environmental interactions	Interact with many variables.
9 Schedule and planning integration	Scheduling executed planning separately.
10 Strategy for system characteristics	Unforeseen unknown, lack of system interactions awareness.

(Artigues et al. 2015, Asta, Karapetyan, Kheiri, Özcan, & Parkes 2016, Baccarini 1996, Deblaere et al. 2011b, Faghihi et al. 2016, Fahmy et al. 2014, Ghoddousi et al. 2013, Herroelen & Leus 2005, Jarboui, Damak, Siarry, & Rebai 2008, Kang & Choi 2013, H. Liu et al. 2015, M. Lu, Wu, & Zhang 2006, Pich et al. 2002, J. Ponz-Tienda, Salcedo-Bernal, Pellicer, & Benlloch-Marco 2017, Zhang & Mostashari 2011, S. Zhang, Boukamp, & Teizer 2015, X. Zhu, Ruiz, Li, & Li 2017)

(”what best analysis”). Since simulation modeling embodies ”what if” experiments, sensitivity analysis is not discussed independently. The analysis method is presented in Table 2.4,

Table 2.4

Complex system technologies

Uncertainty	Certainty
Trade-off analysis	Linear programming
Modeling and simulation	Network models
Sensitivity analysis	Integer and mixed-integer
Optimisation	Nonlinear programming
	Line-of-Balance

Data source from the following references: (Doolittle, Dranichak, Muir, Wiecek, et al. 2016, Köbis 2015, Mostashari 2011)

2.7.3.1 Trade-off analysis

One of the challenges involved in complex and dynamic systems is multi-objectives on project outcomes. The objectives include time, cost, quality, function, safety, profit and other project-specific goals (Anvari et al. 2016, Chawla, Chanda, Angra, & Chawla 2018, Kerkhove & Vanhoucke 2017b, Ozcan-Deniz & Zhu 2017, Trivedi & Singh 2017). A balance and conflicts between the outcomes are necessary to link the project and the strategic objectives (Aminbakhsh & Sonmez 2016, Golzarpoor, González, Shahbazpour, & O'Sullivan 2017, Salimi, Mawlana, & Hammad 2018a). In construction projects, the team managing those projects are challenged to execute it using specified and limited resources and other constraints (Alhumrani & Qureshi 2016, Christodoulou 2016, A. Martens & Vanhoucke 2017). The accomplishment of the projects requires decision-making on available alternatives for time, cost and quality. Also, projects have multi-stakeholders with different goals that need to be attained (Henjewe, Fewings, & D. Rwelamila 2013, Leung, Chan, & Olomolaiye 2008, T. H. Li, Thomas Ng, & Skitmore 2015, olde Scholtenhuis, Hartmann, & Dorée 2016, X. Song, Zhong, et al. 2017). In most cases those goals are not likely to be achieved, then a balance between the interdependent goals from the stakeholders is expected to be the possible option in a complex and dynamic project environment (Eshtehardian, Afshar, & Abbasnia 2009, M. Ning et al. 2017).

Trade-off analysis is one of the critical technologies to access the possible alternatives among the options and the search for optimal balance in time and cost (Alsayegh & Hariga 2012, Kalhor, Khanzadi, Eshtehardian, & Afshar 2011). (Q. Chen, Li, & Zhuang 2009) suggested that this could minimise the adverse impact of the outcomes within the project constraints. In Figure 2.12 the timeline and efforts that have utilised meta-heuristics to analyse trade-off in the construction project are set out, including the mechanism and objectives.

The understanding from the examination of trade-off analysis proves that the

construction project is known to have multi-objectives. As a result of its complex and dynamic nature, often the complete objectives are not achieved simultaneously (Alavipour & Arditi 2019). The objectives, in consideration with the stakeholder's goals, are giving preference with other objectives while seeking quality solutions of system problem via this specific analysis method (Kannimuthu, Raphael, Palaneeswaran, & Kuppuswamy 2019). In the figure, the critical studies on trade-off analysis are presented describing the mechanism, method and result of each study. The trade-off analysis can be between a range of factors. It can be a combination of time, cost, resources levelling, construction method and outcomes acceleration strategies (Bakry, Moselhi, & Zayed 2014, El-Abbasy et al. 2016a, Ghoddousi et al. 2013, Leu, Yang, & Huang 2000, Salimi et al. 2018a, H. Zhang & Xing 2010).

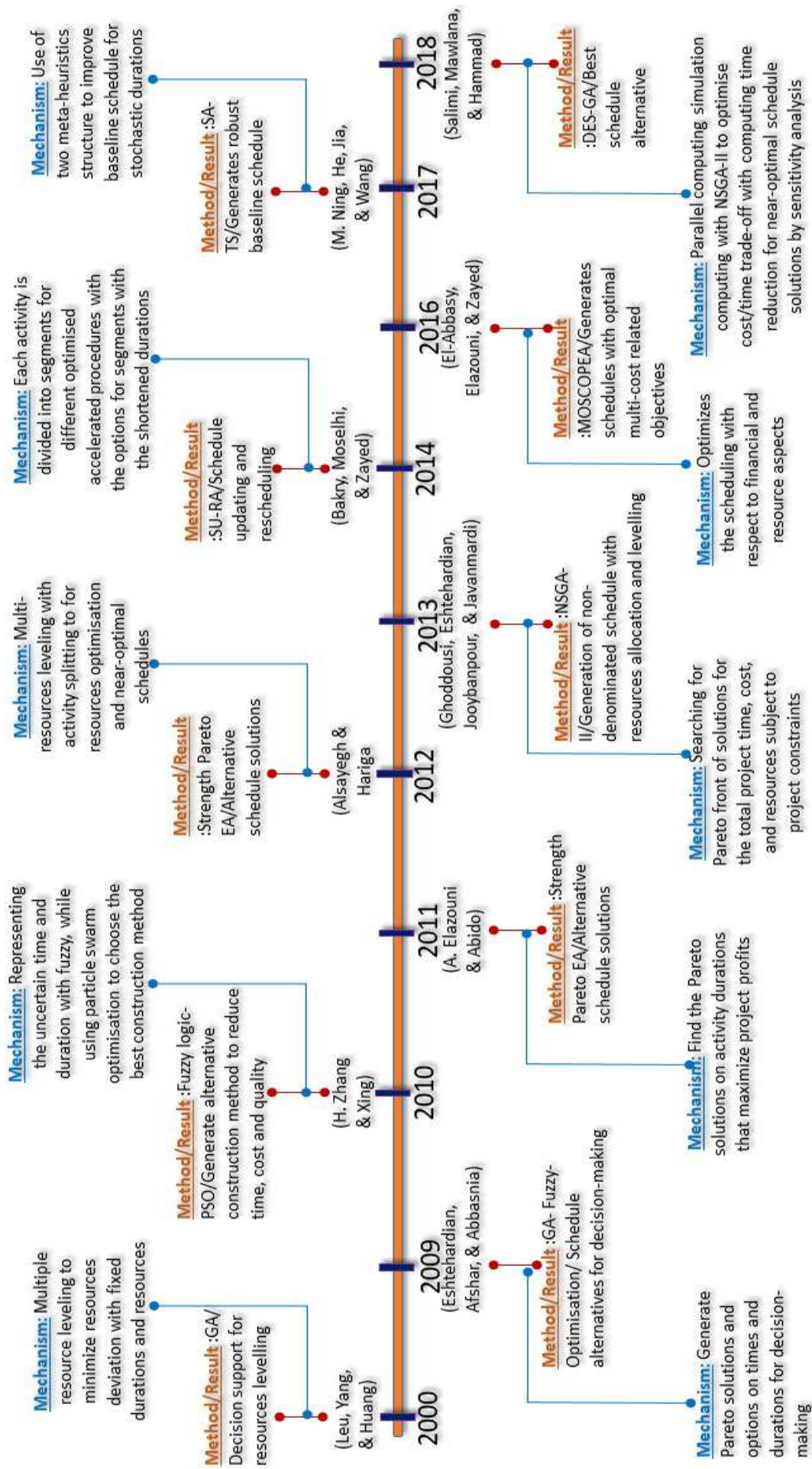


Figure 2.12. Key research efforts timeline of trade-off analysis

It can be between profit values, credit, cash flow and strategic benefits of multi-projects (A. Elazouni & Abido 2011). Alternatively, it may be between computational time and practical solution in the course of other trade-offs since large-scale is one of the characteristics of the construction project (Tirkolaee, Goli, Hematian, Sangaiah, & Han 2019). The method applied to analyse the trade-off in the uncertainty of the project often takes an aspect of the entire features of the construction project. Heuristics, meta-heuristics and mathematical programming are the methods for investigating trade-off analysis (Leyman, Van Driessche, Vanhoucke, & De Causmaecker 2019, W. Li, Nault, & Ye 2019).

The outcomes are interdependent, and there is a trade-off among the outcomes, thereby selecting the outcome that maximises the objectives. Although the heuristics method is a system analysis method, the trade-off analysis uses certainty of data (Eshtehardian et al. 2009). Eshtehardian presented the disadvantages of the heuristic methods, which are not reliable considering the uncertain nature of construction time-cost-quality analysis. The need to consider the uncertainty in scheduling and planning systems has enhanced the application of meta-heuristics. The Meta-heuristics method is applied to develop a continuous curve while providing an ample search space based on the Pareto front solution (Eshtehardian et al. 2009, Ghaeli & Sadi-Nezhad 2019).

This research promotes the approach that can evaluate the complete planning system as an entity at any level of analysis. Again, even though the trade-off technology is an analysis method for a complex system, it demonstrates the ability of the system as a disjointed and discarded sets. Whenever the system is defragmented for specific component analysis, an opportunity to integrate the defragmented components is of global significance than discarded parts of the system. For instance, the cost is preferred to time, or time is preferred to cost as well as other possible combinations of the objectives without consideration of the facet of the complete complex system. In the next section, Section 2.7.3.2, this study discusses another analysis method, simulation modeling and related framework.

2.7.3.2 Simulation modeling and framework

In a complex and dynamic environment, the analysis of the construction system and the quality scheduling is expected to seek for a method that provides insight into the behaviour of the system components. The application of analytical and human analysis is known to be limited for evaluating complexities of a system about the system objectives, constraints and assumptions (Daniel & Daniel 2018, Fang, Zhao, & Zhang 2016, Luoma 2016, Sterman 1992). One of the scientific methods explored for handling and mitigating the limitations of analytical and human techniques for complex and dynamic systems is simulation modeling (Leite et al. 2016, Mesa, Molenaar, & Alarcón 2016, Y. B. Moon 2017, Mostafa, Chileshe, & Abdelhamid 2016, Mostashari 2011). It comprises applying computer-aided experiments to present the behaviour of construction systems (AbouRizk, Halpin, Mohamed, & Hermann 2011, S.-M. Chen, Chen, & Chang 2013). It can be a preferred option for understanding the complexities in planning, scheduling and controlling of construction operations. Though it is a widely applied science in many fields, its application in construction is developing (Jabri & Zayed 2017), as depicted in Figure 2.13. The understanding from the evaluation of simulation analysis proves that the construction project is known to be dynamic and complex with real-time activities. Hence, the review discusses the strength of simulation modeling for alternative experiments on the plan in real-time as well as mapping the model with real case data. In the figure of timeline studies for simulation analysis method, the important studies on simulation modeling are presented, and describing the mechanism, method and result of each study. In construction projects, simulation aims to offer and enhance decision-making tool for performance improvements (Alvanchi et al. 2011b, M.-Y. Cheng & Tran 2016, Ozcan-Deniz & Zhu 2016, Z. Wang, Hu, & Gong 2018).

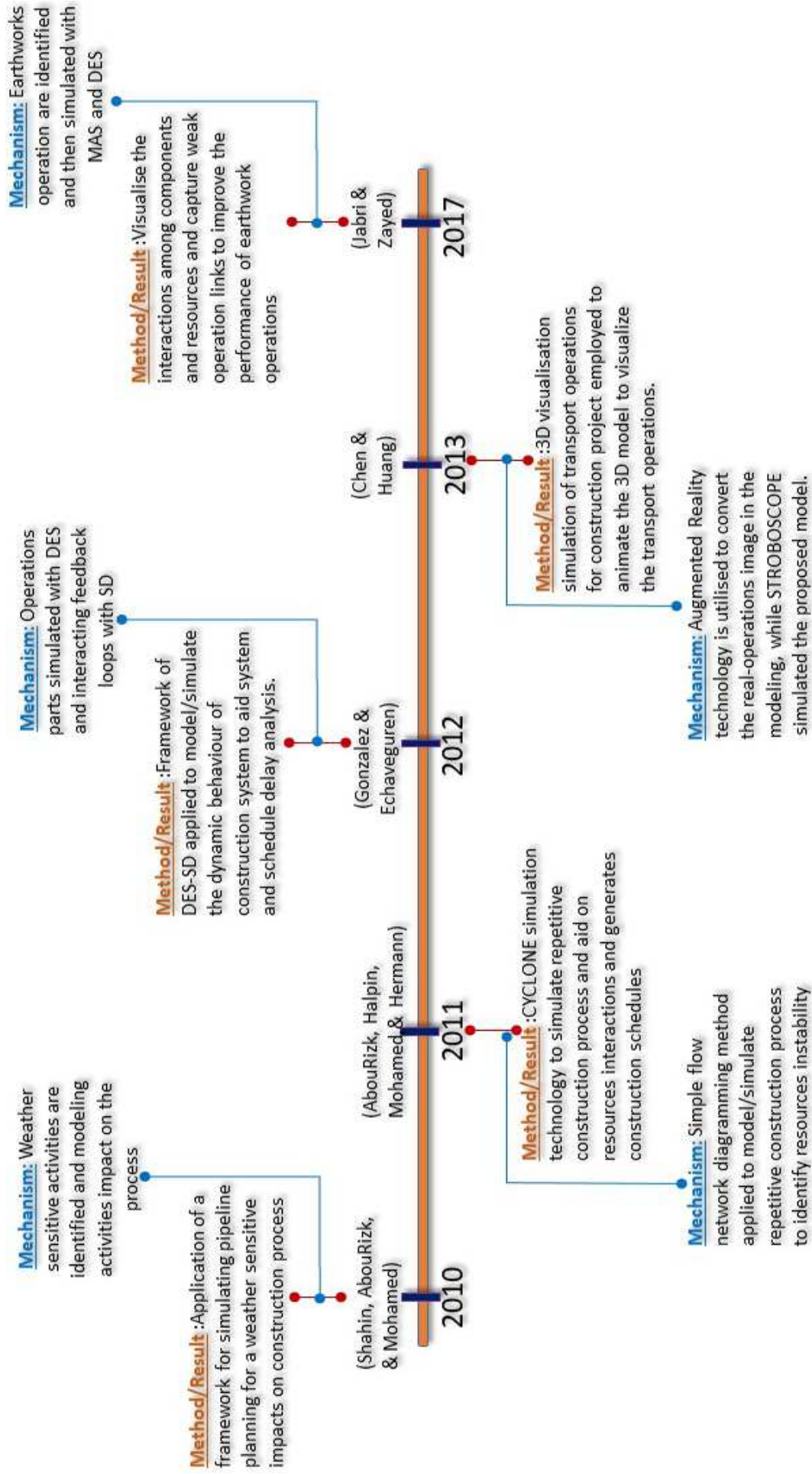


Figure 2.13. Key research efforts timeline of modeling and simulation

In the case of planning and scheduling systems, simulation methods use uncertain durations in virtue of probability distributions and statistical analysis of model output for decision-making (Ben-Alon & Sacks 2017, Marzouk & Abubakr 2016, RazaviAlavi & AbouRizk 2016). Similarly, with simulations, various computer-aided experiments are performed such as "what-if" and "what best analysis" (Dehghanimohammadabadi & Keyser 2017, Groesser & Jovy 2016, Turner, Hutabarat, Oyekan, & Tiwari 2016). Computer-aided experiments form the main anchor to simulation designs (de Salles, Neto, & Marujo 2016, Kevrekidis, Gear, & Hummer 2004, C. Wang, Zhang, Du, Pan, & Xue 2016). The challenge that remains is the need to generate the relevant system constructs expected to represent the scheduling system, in the form of process models. With the evidence of successful implementation of simulation technology in other fields with multiple entities, construction project systems simulation is likely not to be different. The system challenges are the understanding of the complete process in real time, simulation components and applicability of the tool (AbouRizk et al. 2011, Akhavian & Behzadan 2013, 2015). Similarly, modeling framework, time advance and communication architecture are challenges to the simulation of construction systems (Gonzalez & Echaveguren 2012, S. Lee, Behzadan, Kandil, & Mohamed 2013, Leite et al. 2016, Lopez, Chong, Wang, & Graham 2015, Shahin, AbouRizk, & Mohamed 2010). Although it is ideal for analysing the sub-components of the entire system, a process that integrates the individual sub-systems into a complete system with ease of applicability can aid the simulation modeling to mitigate the challenges limiting its range of application in construction. Scheduling problems are generated due to the varying project conditions. The Solution to the problems requires a system capable of mimicking project different and varying conditions that map out the real world case into a model (H. Liu et al. 2015).

In simulation modeling, sensitivity analysis can be applied to explore the robustness of the generated output and experiments by performing "what if scenarios" (Herroelen & Leus 2005, Hsu, Weng, Cui, & Rand 2016). It can identify the parameter that has the

most significant effect on the output (Gálvez & Capuz-Rizo 2016) and compare different alternatives and control options (Bisogno, Calabrese, Gastaldi, & Levialdi Ghiron 2016, Mishra & Parbat 2012). Over the years, discrete event simulation (DES), discrete rate simulation (DRS) and system dynamics (SD) modeling are employed in construction planning and scheduling. The agent-based simulation (ABS) is one of the new techniques based on object-oriented modeling (Borshchev 2013a, H. Kim, Shen, Moon, Ju, & Choi 2016). The planning and scheduling system supported by this research is based on the method proficient at integrating different aspects of the system as an entity.

The appraisal of the simulation modeling method so far has identified the capabilities of a different simulation method for complex and dynamic systems. Since the simulation methods (SD, DES, DRS, ABS) are different (Martinez-Moyano & Macal 2016, Rondini, Tornese, Gnoni, Pezzotta, & Pinto 2017), each simulation method has peculiar features applied to evaluate a specific part of complexity and variability within the system. The present review explained that simulation modeling can provide and enhance flexibility on the complex and variable system. Besides, interest in the integration of the different simulation method is likely to support the gathering of different aspects of the system as an entity. So, the challenge is on the method to integrate the simulation methods, and an analysis of the integration aptitude is discussed in Section 2.7.3.3. The evidence provided in this section suggests that there are challenges to complex system analysis and integration that generated the research question **9** asking:

What are barriers that may be associated with the model integration, and how are they addressed?

2.7.3.3 Simulation modeling hybrid structure

Hybrid or multi-method modeling and simulation strategy is the integration of various individual modeling methods to extract their natural features (Goh & Ali 2016)

that have been underutilised (Ivanov 2017). In this sense, the three core simulation models namely SD, DES, and ABS can be integrated to derive the benefits and strengths of the individual models into one paradigm for more correct and realistic results (May & Siebers 2015, Nasirzadeh et al. 2018a). The main characteristics of multi-paradigm include flexibility, straightforwardness, paradigm non-differentiation (S. C. Brailsford 2015), continuous state evaluation and recording at discrete times (Ivanov, Sokolov, Solovyeva, Dolgui, & Jie 2016) as well as the behavioural system components (Barra Montevechi, Silva, da Costa, de Sena, & Scheidegger 2015).

The benefits of combining different models have been emphasised due to the need to solve, real, complex and multi-system problems. It can investigate system event and responses, whereby the causality feedback loop is constructed by the controller to respond to the system, and a programmed control to respond to intervals between events (Ivanov et al., 2016). It enhances modeling complex systems (Nasirzadeh et al. 2018a), dynamic systems, large-scale (Djanatljev, Bazan, & German 2014) including the various levels of abstraction in a real-world problem. It creates an opportunity for the flow of one model information, from one paradigm to another that are naturally linked together with the concern of system limits and constraints (Brailsford, 2015).

There is limited research using hybrid simulation in construction research. Hybrid simulation-based planning approach is suggested and discussed by researchers as the expected prominent for detailed planning and scheduling for construction operation because its capability to integrate different aspects of system components. In this regard discrete event simulation, system dynamic simulation, discrete rate simulation and agent-based simulation can mimic construction project operation as it is in the real world. (Goh & Ali 2016) utilised a mix of ABS, SD and DES to model earthmoving construction activities. The study proposed a hybrid simulation framework demonstrated using hypothetical case study aimed at facilitating the integration of safety management considerations into construction activity simulation. In the technique, the entities and resources in the traditional discrete event simulation are

replaced with agents. While the agents carried out the process-centric activities, system dynamics was utilised to capture the social behaviours of the agents and the DES is the core of simulation of the construction process. The intention of the DES-ABS-DES combinations is the need to capture the naturalness and complexities in the system. The analysis was demonstrated using sensitivity analysis and factorial experiment. Though the method investigated system complexities for planning, it does not integrate the constructions operations of different phases. The study can help defragment the components; however, there is no evidence of considering the phases of construction as a unit and the components of the phases, which again does not integrate plan with schedule.

The impact of working hours on construction activities was introduced by (Alvanchi et al. 2011b, Nasirzadeh, Khanzadi, & Mir 2018b) using ABS-SD to obtain the benefits of the two methods. The study used the SD simulation to capture the influencing factors and the ABS to simulate the behaviour of the interacting agents. The two proposed simulation is combined into one model framework to analyse the safety behaviour of the working groups. The realities of the construction project are the need to include a reasonable number of abstractions to enhance the representation of the system modeled, which is not applied in the research and different from integrating different construction components and more levels of abstractions.

(Peña-Mora et al. 2008) developed a DES-SD simulation-based to improve decision-making system to increase productivity by evaluating the combination of managerial and operation process. The study carried the study to enhance project management planning and control at both strategic and operational levels. One of the process of controlling a project is the use of construction schedule; however, does not integrate planning with scheduling as well as taking construction project outcome as the function of the interactions of different phases.

(Alzraiee et al. 2015) suggested that DES and SD models can be integrated to

examine the operational and strategic variables in one communication platform and single computation platform. The expected results generated realistic project schedule networks. The model was tested and verified using different cases without any optimisation platform to generate best even when there are various solution alternatives. Again the level of details utilised does not show a conviction that the result is expected to represent the examined construction system.

(RazaviAlavi & AbouRizk 2016) proposed a simulation model for investigating the impact of the size of a construction facility on a construction project. This model integrated schedule and cost items using a hybrid simulation model of DES and continuous stimulation (CS) to improve material management. The study examines the dynamic interactions of the construction system in the construction operation based on state transformations. However, it does not consider the time the agents' communication in terms of time lag during agents' message sending and receiving and other related agents in the system, which is essential in the construction project planning and scheduling.

(Xu et al. 2018) established a hybrid simulation technique using a computer-aided system to integrate the dynamics and uncertainty of schedule risk analysis. The system applied SD and DES model to investigate the impact of risks on the schedule performance, but it requires considerable integration of the agents that also make a decision to change the state of the scheduling system. It does not consider the risks of the other phase and it is expected not to represent the schedule performance. Besides, the study conducted a sensitivity analysis that cannot generate quality solutions without optimisation analysis.

In an attempt to improve the accuracy of a model for calculating activity, durations and consideration of real-life resources constraints cases, (Jabri & Zayed 2017) suggested an agent-based simulator for earthmoving operations (ABSEMO) model. The research used the interactions of the agents to calculate accurate activity durations with resource

handling and resource constraints. However, in the construction project creating alternatives, experimenting on the alternatives, optimising the alternatives in the presence of influencing factors is among the important aspects the study does not investigate. The results are compared with the existing model, which is not adequate to confirm the results because the construction system is unique with ad hoc methodology when it is simulation modeling with ABS.

Despite the inherent advantages of the hybrid paradigm, it has several challenges that affect its applicability. These include variability of the hybrid model, lack of the integration of multi-concepts of the hybrid models (Alvanchi et al. 2011b). The absence of applicable and straightforward framework and time advancing can be solved using a fourth-order Runge-Kutta method and communication architecture. The concepts and ideas of each simulation modeling are described and summarised in Table 2.5.

Table 2.5

Summary and concept of simulation modeling

<i>Theme</i>	<i>SD</i>	<i>DES</i>	<i>ABS</i>
<i>Origin</i>	To apply dynamic systems in in social and business by Jay Forrester in 1950.	The need to model operation sequences by Geoffrey Gordon in 1961.	Necessity to predict the interactions of conscious entities and agents by von Neumann and Morgenstern in 1940.
<i>Focus</i>	Continuous, policy making system and influences.	Events changes overtime.	
<i>Components</i>	Stocks, flow polarity, delay, differential equations	Flow chart with source, entities and resources block and sink, iteration, constraints.	Knowledge base communication of participating agents for complex problems and benefits.
<i>Main features</i>	Causes-and-effects dynamics, complex, feedback loops, high level of abstraction, continuous, deterministic, dynamic, aggregation, non-linearity.	Process-centric, high details required, low level of abstraction, discrete, stochastic and dynamic.	Heterogeneous agents with different learning, behaviour, rules, continuous, stochastic and dynamic.
<i>Fundamental principle</i>	Based on accumulation vector with a set of parameters and nonlinear vector.	Dependent on the principles of automata theory.	Dependent on the principles of automata theory.
<i>How it works</i>	Based on basic law and equations conservation of mass for open system, numerical method, accumulation, depletion and parameters flow.	Sequential analysis of effects of operational level variables and extraction of event-driven objects.	Agents interact with knowledge base with to make goal-orientated decisions.
<i>Advantages</i>	Planning and control of complex systems.	Planning and control of complex and real objects.	Variables and bottom-up modeling.
<i>Disadvantages</i>	Homogeneous and aggregation of variables.	Not suitable for modeling dynamical systems and complexity.	Validation problem.
<i>Application in construction</i>	Relatively applied in construction operations	Widely applied and suited for construction simulation.	Relatively applied construction.
<i>Application</i>	Stakeholders engagement and non-trivial implementation.	Modeling framework, time advancing, communication architecture.	Interaction structure, computational inefficiency, non-trivial implementation
<i>Challenges</i>			

(Altaf et al. 2018, Alvanchi et al. 2011b, Borshchev 2013a, Borshchev & Filippov 2004, Copeland et al. 1945, Forrester 1958, Goh & Ali 2016, Gordon 1975, Mahdavi & Hastak 2014, Martinez 2009, Mostashari 2011, Ogunlana, Li, & Sukhera 2003, Pena-Mora & Dwivedi 2002, Ren & Anumba 2004, Rodrigues & Bowers 1996, Rumeser & Emsley 2016, Sterman 1992, Wenzler & Günthner 2016)

In the table, the main themes of each method are presented to enlighten fundamental ideas and capabilities on each method, facilitating the development of the hybrid framework and simulation. Most importantly in complex and dynamic analysis, even if the simulation methods are skilful in the exploration and evaluation of the systems as well as "what if" analysis is the decision on the best alternative amongst different solution options.

The answers for the second and partly the first and third research objectives and associated research questions are derived from the integration of the simulation methods:

- 1) ABS;*
- 2) DES-DRS and;*
- 3) SD to form ABS-DES-DRS-SD simulation modeling and framework.*

Thereby supporting the research question on the need for a pertinent role of simulation modeling with the research questions *7, 8, 9* that ask:

7. What mechanism can best integrate multi-decision support for planning and scheduling of construction projects?

8. To what extent can the model assure the flexibility to accept multiple inputs?.

9. What are barriers that may be associated with the model integration, and how are they addressed?

The next section, Section 2.7.3.4, examines different optimisation methods, where they have been applied and frequency in the utilisation of the method.

2.7.3.4 Optimisation of complex and dynamic system

The construction project systems are characterised with complexity and uncertainties (Danesh, Ryan, & Abbasi 2018). The interactions among the system components emerge with linear and non-linear collaborations, feed forward and feed backward loops (Grieves & Vickers 2017, R. J. Yang, Zou, & Wang 2016). Similarly, different options are explored to generate the best solution, and the optimisation method is broadly known for exploring and searching for the best option amongst a large number of alternatives (Fletcher 2013, Rao 2016). In complex and dynamic systems, the non-linearity outweighs the linearity entities of the system (Rezvani et al. 2016). One limitation of deterministic scheduling and planning is its operations within the linear range of the system without consideration of the non-linearity, which is a dominant feature of complex systems (Khan et al. 2016). In the planning and scheduling optimisations, mathematical programming optimisations are prominent for analysing the linear compositions of a system (Shafi, Elsayed, Sarker, & Ryan 2017).

System optimisation, "what best analysis", is a strategy to minimise, maximise or optimise either some or all the system outputs – optimal resources allocation, project goals and stakeholders' satisfaction (Kyriklidis & Dounias 2016, X. Ning, Ding, Luo, & Qi 2016, Y. Zhang 2016). The optimum analysis is subject to the system inputs, environments, uncertainty and stipulated constraints (El-Abbasy et al. 2017). In the effort to integrate the non-linearity and complexities that characterise the construction project systems, different optimisation methods have been developed to offset the limitations of linear and straightforward heuristics optimisations. In construction, the significant applicable optimisations are heuristics, meta-heuristics, and black-box. The methods can be applied to optimise the output functions of the construction systems (Laguna 1997).

Several simulation-optimisation based planning tools have been developed to date, including linear programming, heuristics, meta-heuristics, swarm optimisation, fuzzy

systems, and multi-agent heuristics optimisation. (H. Liu et al. 2015) developed BIM-based process simulation integrated with particle swarm optimisation for automatic generation of optimised activity level schedule, but it does not capture the level of details required at each phase of the construction project to generate best-case schedule and the system components interactions including the other agents in the construction project and factors that are likely to change the dynamics of the construction resulting in scheduling risks and uncertainty. Similarly, (M.-Y. Cheng, Prayogo, Wu, & Lukito 2016) presented their work of hybrid harmony search (HHS) algorithm to solve discrete truss structure optimisation problem by combining global-best particle swarm optimisation search and neighbourhood search. The optimisation solution, compared to other methods, demonstrated the optimum solution and the convergence.

(Arashpour, Wakefield, Abbasi, Lee, & Minas 2016a) used optimisation-based meta-heuristics to minimise changeover time for offsite construction. They applied the optimisation to gain insight on the dynamics of the limited resources utilisation among different activities and the tasks sequence. Although the results are expected to increase the productivity of the construction system, the other components of the system are not considered. The study enhances the defragmentation of construction system, an expected system for productivity performance requires the holistic analysis of the system.

Multi-objective optimisation of construction schedules has been successfully adopted by engineering researchers because of its capability. (El-Abbasy, Elazouni, & Zayed 2016b) introduced Evolutionary algorithm method for optimising time and cost in construction projects. The result is expected to help contractors to generate schedules that have optimum trade-off capacity; however it is based on heuristics that do not consider the interactions of the system components that can change the scheduling system in real-world scenario, especially where the project events are emergent to the construction project conditions.

(Salimi, Mawlana, & Hammad 2018b) showed their interest in using parallel Genetic Algorithm for optimising cost-time relationship in construction projects. By creating a high computing performance architecture, they established that the computing system is not only capable of reducing computation time especially for bridge construction that has large entities and complexities but enhanced the planning of the infrastructure project. They also carried out sensitivity analysis to identify the best system configuration for GA and the level of performance with the GA; which does not generate optimum schedule.

(Arashpour, Kamat, Bai, Wakefield, & Abbasi 2018) introduced their integer and probabilistic optimisation models to integrate time and cost of shared resources to enhance planning calculations. In their research, they defined an objective of minimising the cost incurred in multi-skilled resources utilisation for off-site construction. However, construction project has multi-resources and influences that are required as part of the constraints in the resources minimisation. Moreover, the analysis is not completely dynamic to capture the system components in real-time, and considering only resources variability and availability is not adequate to define the entire system.

(H. Lu, Wang, Xie, & Wang 2018) presented genetic algorithm (GA)-based simulation optimisation solver to include supply logistics and site logistics challenges in the allocation of limited resources. They developed policies that enhanced the integration of resources allocation management to improve time and cost performances, although it does mimic real-life conditions that characterised the construction system considering non-real networks utilised in their analysis.

(García-Nieves, Ponz-Tienda, Ospina-Alvarado, & Bonilla-Palacios 2019) developed an algorithm that used mathematical linear programming for multi-objective scheduling in construction project. The proposed mathematical method was designed to aid construction project team solve resources, allocation and resources-constrained scheduling and cost management. The approach is likely not to represent realistic

scheduling because repetitive activities and resources alone are not adequate constraints and considerations when analysing resources allocations. It does not capture the approach to analyse the influences of decisions on resources allocation.

In an attempt to integrate large components of the construction system, (S. H. Lee et al. 2006) suggested a framework of a detailed construction system. They classified the construction system based on strategic, tactical and operational levels. The approach is realistic because it considers different categories of dynamic construction planning that generates a construction schedule with visualisation. However, despite multi-communication channel of the entire system, the level of details consider mainly the project tasks. Moreover, clear communications of agents and optimisation of the generated alternatives are not defined.

For heuristics, the representation of the objective function is in linear forms, although dependent on the system constraints (Liang, Shen, & Bu 2016). The objective function of the linear system can be analysed with simple heuristics and is represented in a canonical matrix forms with linear equality and inequality constraints (Prayogo, Cheng, Wong, Tjandra, & Tran 2018). On the other hand, to address the linear nature of heuristics method, metaheuristics, tabu search, black box and scatter search are optimisation methods developed to offset the linearity and non-complex system dependencies of the heuristics (Bouajaja & Dridi 2017, Tran, Cheng, & Pham 2016). The metaheuristics and tabu search are upskilled heuristics, memory-based structures and neighbourhood search to offset the limitations of the heuristics and linear systems (Sörensen, Sevaux, & Glover 2018). Similarly, while black-box is a context-dependent metaheuristics algorithm, scatter search is a population-based and combination metaheuristics (X. Guo, Liu, Zhou, & Tian 2016). Irrespective of the fact that those methods are applied to non-linear and complex systems, they have different mechanism and superiority over one another (Z. Li, Kucukkoc, & Nilakantan 2017).

The metaheuristics algorithms combine iterative procedures with strategies for

exploring search space to generate feasible solutions, which may not be a global solution with a specific optimisation problem (Amaran, Sahinidis, Sharda, & Bury 2016, I. Ismail & Halim 2017, Savsani, Tejani, Patel, & Savsani 2017). On the same dispositions, black-box procedure evaluates the objective function as a black box with problems of specific structure and context. Correspondingly, scatter search applies solutions from subset generation, combination, improvement and reference set update (Sarakhsi, Ghomi, & Karimi 2016). It also an extension to integrate the tabu search to enhance the quality solution for complex systems (Amaran et al. 2016, Laguna 1997). While metaheuristics generate a real-world solution which is context dependent compared to the heuristics, the scatter search with extension to integrate tabu search generates high-quality solutions, treats multi-objectives without much computer time consumption compared to metaheuristics (Geng, Cui, & Gu 2016).

In relation to other optimisation approaches presented in trade-off analysis, (Arashpour, Wakefield, Abbasi, Lee, & Minas 2016b) used optimisation-based metaheuristics to evaluate schedule. As a result of this, the changeover time is minimised as a function of resources utilisation and production output, which is dependent on the optimal activities sequence to enhance productivity. Similarly, (Said & El-Rayes 2013) applied a genetic algorithm (GA) and approximate dynamic programming based on shortest path algorithm to generate feasible and global solutions for site layout facilities. The appropriate optimisation methodology is expected to provide solution speed for implementing the analysis of the multi-component system and visualisation of the system during experiment runs.

Different optimisation methods are developed in the effort to derive the best solution in the domain of alternatives within the search space and solution convergence for a complex system, different optimisation methods are developed. The applicability of each optimisation technology depends on the extent to tackle the challenges as presented in Table 2.3. The frequency of utilisation of the technological processes in solving uncertain, dynamic and complex system from 2010 to 2017 shown in Figure 2.14.

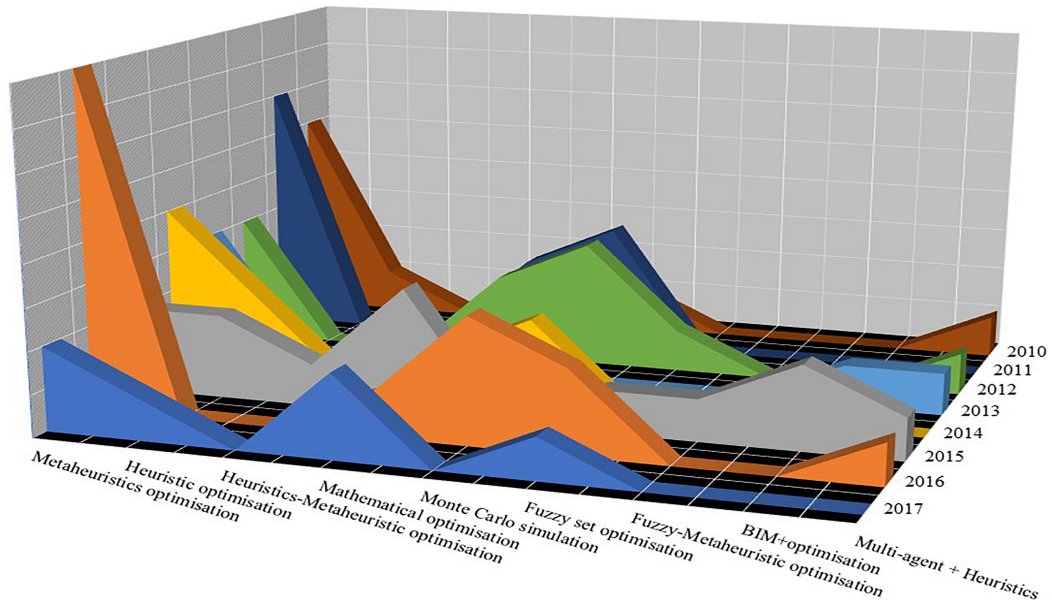


Figure 2.14. Scheduling technology process and frequency of utilisation based on literature review

It also contains the technologies used in the years before 2013 as reviewed in (Zhou 2013). The figure shows that the meta-heuristics, a hybrid of simple heuristics, is widely used compared with other technologies. The ideas, concepts, background and references from the literature review are employed to summarise the focus, essential components, advantages and limitations of the optimisation methods set out in Table 2.6.

Table 2.6

Optimisation methods summary and concepts

Method	Application/focus	Basic components	Advantages	Limitations
Optimisation	Discrete, non-continuous, static, dynamic, stochastic, and deterministic. Dynamically searching all feasible solution in search space.	Objective functions and constraints.	Effective strength for optimal or near optimal scheduling solutions.	Small scale scheduling problems. The high cost of computational efficiency. Poor quality solution. Single -criteria problems and objectives. Sluggishly to dynamic systems.
Heuristics	Focus on discrete, non-continuous, deterministic, static, dynamic, stochastic. Based on some defined rules.	Objective functions and constraints, rules.	Combining priority rules to hybrid rules for optimisation. Simple, easy to use. Can withstand changes.	Limited scope in decision rules and local search based. Not fit for all-purpose. Solutions Inflexibility. Insensitivity to changes. No contextual variables. Sluggishly to dynamic systems .
Meta-heuristics	Discrete, continuous, deterministic, static, dynamic, stochastic, use domain filtering, variable fixing, and tree search.	Objective functions and constraints, rules, search.	Efficient and flexible than heuristics. High-quality solution close to optimum and fast convergence. Solves complex and multi-mode problems. Sufficient literature.	Contextual variables in scheduling not integrated. Collapses if objective function unknown. Reacts sluggishly to dynamic systems, local search based.
Agent system	Dynamic, continuous, stochastic. Non-linear, variables and agents with benefits seeking, learning and behaviour transformation.	Multi-agents, system variables, goals, learning.	Interactions among variables and heterogeneity agents for complex decision-making. Multi-objectives and multi-problems considered.	System behaviour determined by initial assumptions. Insufficient literature. Unreliable Computational efficiency.
Fuzzy	Stochastic, discrete, deterministic.	Event, decision, and probabilities.	Events and decision affect modeling over an extended period. Capable of different what-if scenario analysis.	Unconcerned with system structure and dynamics. Poor linking with other models and simulation.
System dynamics	Deterministic, dynamic and continuous. Processes accumulation, generation, depletion with a large causality feedback loop.	Accumulation flows, causality feedback loops.	No prior knowledge of variables. Sophisticated sensitivity analysis, calibration and validation. Established literature. Simulates activities and resources delay in time.	Combines system dynamics. Incompatible with heterogeneous variables. Validation difficulties. Difficulty in quantifying operational and contextual variables.

Data source from the following references: (Bakry, Moselhi, & Zayed 2016, Deblaere, Demeulemeester, & Herroelen 2011a, El et al. 2017, El-Abbasy et al. 2017, Jarboui et al. 2008, Louis, Dunston, & Martinez 2014, M. Lu et al. 2006, H. Moon, Kim, Kamat, & Kang 2013, Tserng, Ho, & Jan 2014)

Construction scheduling problem like other scheduling problem is known to be non-deterministic polynomial (NP)-hard problem involving real-world (Lamas & Demeulemeester 2015a, Mostashari 2011). The implication of the NP-hard problem is the massive number of solution space combinations leading to combinatorial explosiveness (Kang & Choi 2013). It is not feasible to explore all the solution space, therefore, scatter search is amongst the sequential strategies that relaxes a large number of combinatorial decision problems and reduces the solution space while generating an optimal solution (Aka 2019, Amevi 2016, Borodin, Bourtembourg, Hnaïen, & Labadie 2018, Laguna 1997). OptQuest is an optimisation tool embedded in AnyLogic and is developed on scatter search. The platform employed for the hybrid simulation is AnyLogic software, University version, developed by AnyLogic company.

It is essential to create a platform with methods that assure solution possibilities, and AnyLogic has the features. Therefore, because of the review and feasibility of the method implementation while solving the dynamic and complex system, scatter search is selected among the optimisation algorithms for optimum plan and schedule in this study. The selection of the scatter search optimisation is because of its benefits for quality optimisation solution, hybrid-meta-heuristics, in-built in the AnyLogic analysis software and its proficiency to adapt to any model. Taking together, this section, a critical question emerges and aligns with the research question 14 that asks:

How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?

2.8 Summary

A complimentary range of technologies has been considered by diverse researchers to reduce time overrun targets in construction projects. The technologies include optimisation, heuristics, metaheuristics, artificial intelligence, simulation, BIM-based, multi-agent system, fuzzy set theories, system dynamics and Critical Path Method. To

explore how complex and uncertain scheduling problems are tackled, the literature review demonstrated that real-world dynamic planning had not been addressed sufficiently in the related earlier researches. This is for both known unknown or unknown unknown problems. It is noted that hybrid systems form a portfolio of technologies that can solve construction-scheduling and planning problems, but hybrid systems, in practice, are not yet broadly applied.

The research has reviewed various approaches, methods, technologies and issues related to dynamic scheduling problems, real-time scheduling responses, dynamic scheduling events, solution challenges and classifications. The choice of a specific planning and scheduling technology significantly relies on the solution quality, scheduling objectives, scheduling problems, constraints, complexity and scale. Metaheuristics are the most prominent technology for exploring planning and scheduling solutions because of its high computational efficiency and solution quality. Although the issues are related to scale, the transformation of theory to practice hinders technologies application to real-world problems. The best choice for real-time planning and scheduling relies on a variety of factors, triggered by disruptions, including

1. Size of complexity, ambiguity, and uncertainty integrated;
2. Degree of computational efficiency to generate solutions;
3. Scale of projects it can tackle (e.g. multi-objectives, multi-problems, multi-constraints);
4. Planning integration with schedule;
5. Solution deployment to construction software;
6. Integration of solution with visualisation;
7. Volume of data it can accept; and
8. The extent of automation of the process, especially in data extraction and acquisition.

Hybrid simulation and sequential search procedure can be a practical solution if an integration framework is efficiently formulated because of the enormous and potential ability to aggregate the attributes of the individual components for optimal solutions.

Although the economic feasibility of using a mix of technologies has not been adequately demonstrated for construction scheduling, the growing interests and efforts in computer and information technology can transform the potential to reality.

The literature review and consultations with the case-study company, to find the real planning challenges, enhanced the determination of study aims and objectives. The construction scheduling system is a significant concern for the construction industry. Several scheduling technologies described in this proposal have been developed so far; nevertheless, none of the reviewed research has addressed a range of those system characteristics presented as an entity. The dynamic and real-time complex project conditions have not been resolved yet with those techniques.

There is a need for an improved system, and in the same vein, the technologies have not solved the real-time dynamic scheduling and optimisation problems that are focused on integrating the combination of operational and contextual variables. A significant number of existing technologies have utilised only operational variables and optimisation. The capabilities of the experiment method are expected to include developed modeling framework, extensive simulation, validation, comparing runs, sensitivity analysis and optimisation.

This research explored the new and extensive range of planning solutions to learn whether the integration of the three paradigms is enhanced with scatter search optimisation. It is outlined that the integration of *agent-based simulation (ABS)-discrete event simulation (DES)-discrete rate simulation (DRS)-system dynamics (SD) method and scatter search optimisation* has not been majorly and comprehensively evaluated in construction planning. Even for the related themes, approach and input to be utilised are distinct. Therefore, this vindicates the originality of this research. The implication is that this chapter is pivotal to the research objectives:

- (A) *To understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading*

to time overrun.

- (B) *To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule.*
- (C) *To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.*

Having defined and established the feasibility for answering the research questions and achieving the research objectives, it is now necessary to explain and discuss the strategy, method and process for responding to the research questions in **Chapter3**. The chapter gives an account of how the research was conducted based on the research questions and the accomplishment of the research objectives.

Chapter 3

Research methodology

3.1 Introduction

Within the context of complexity and uncertainty of construction projects, simulation modeling and optimisation are recognised as priceless components to planning and scheduling problem. The fundamental aim of this chapter is to present the principles and procedures of the process applied to accomplish the research objectives and answer the research questions shown in Table 3.1.

Table 3.1

Research questions

Research Questions	
Question <i>Q1</i>	What is the current approach for static and dynamic planning in construction projects, and what form of the plan is produced?
Question <i>Q2</i>	How can the approach be categorised to identify its constraints to solving dynamic planning and scheduling problem?
Question <i>Q3</i>	What are the barriers to the utilisation of the current solutions for planning problems?
Question <i>Q4</i>	What are the expected strategies if pursued, positively influence the real-world planning system and improve system solutions?
Question <i>Q5</i>	What are the relationships between construction time management and influencing factors in construction projects necessary to gain insight about reducing time overrun in construction projects?
Question <i>Q6</i>	What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?
Question <i>Q7</i>	What mechanism can best integrate multi-decision support for planning and scheduling of construction projects?
Question <i>Q8</i>	To what extent can the model assure the flexibility to accept multiple inputs?
Question <i>Q9</i>	What are barriers that may be associated with the model integration, and how are they addressed?
Question <i>Q10</i>	How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?
Question <i>Q11</i>	How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?
Question <i>Q12</i>	What is the technique to present the model solution for application by the construction project team to improve the planning decision?
Question <i>Q13</i>	To what extent can the integrated planning solution aid the capability of construction project management?
Question <i>Q14</i>	14. How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?

The chapter examines the research approaches and, the theoretical framework that embodies the overall study namely:

- (1) *Research requirements* on the main parameters that drives the choice of the implemented methodology;
- (2) *Research paradigm* such as the philosophical views that govern the research nature and methodology emanating from decades of different inquiry into new or existing topics in different fields. The strategy is centred on the discussion and views of postpositivism, positivism, constructivism, transformative, and pragmatism;
- (3) *Research process* the product of the research paradigm, which is the process flow and lens for implementing the remaining facets of the research approach. It has emphasis on research design and method implementation, analysis to generate the research results, related discussions and conclusions;
- (4) *Research ethical framework* that documents the concepts of morals and ethical considerations for the overall research;
- (5) *Research case background* illustrate the context and understanding of the case selected for the research project;
- (6) *Research design* including the approach embraced in this study as a result of the factors influencing the various beliefs that guide the research, centred on qualitative, quantitative and mixed method design;
- (7) *Research method* explain the techniques employed by this research to gather, analyse, interpret and validate the data;
- (8) *Research design analysis* for example methods employed to gather the data

to answer the research questions and;

- (9) *Research design analysis implementation* for instance how the CTM and CTF are related using dynamic Bayesian network analysis and how hybrid multi-method was implemented with the collected data.

The items 6 - 7 are demonstrated into two categories: (a) initial problem formulation of influencing factors on construction time management to answer research Question *Q5* and (b) an in-depth research problem formulations with the multi-hybrid model to answer the remaining research questions. The methodology in listed (b) is explored to provide insight on multi-method analysis and evaluation in hierarchical planning to enhance decision-making and the data gathered from the case study company based on the road improvement project. Furthermore, the unit analysis, data analysis and validation are examined by reviewing, categorising, synthesising, and interpreting the collected data as well as the method of analysis and implementation. This entire chapter, with its layout and contents are shown in Figure 3.1. It provides the theoretical backup and practical strategies to confront time and planning problem in complex construction project aided by the developed frameworks and analysis. The next section, Section 3.2, re-establishes the guide to this chapter concerning the aims and research questions.

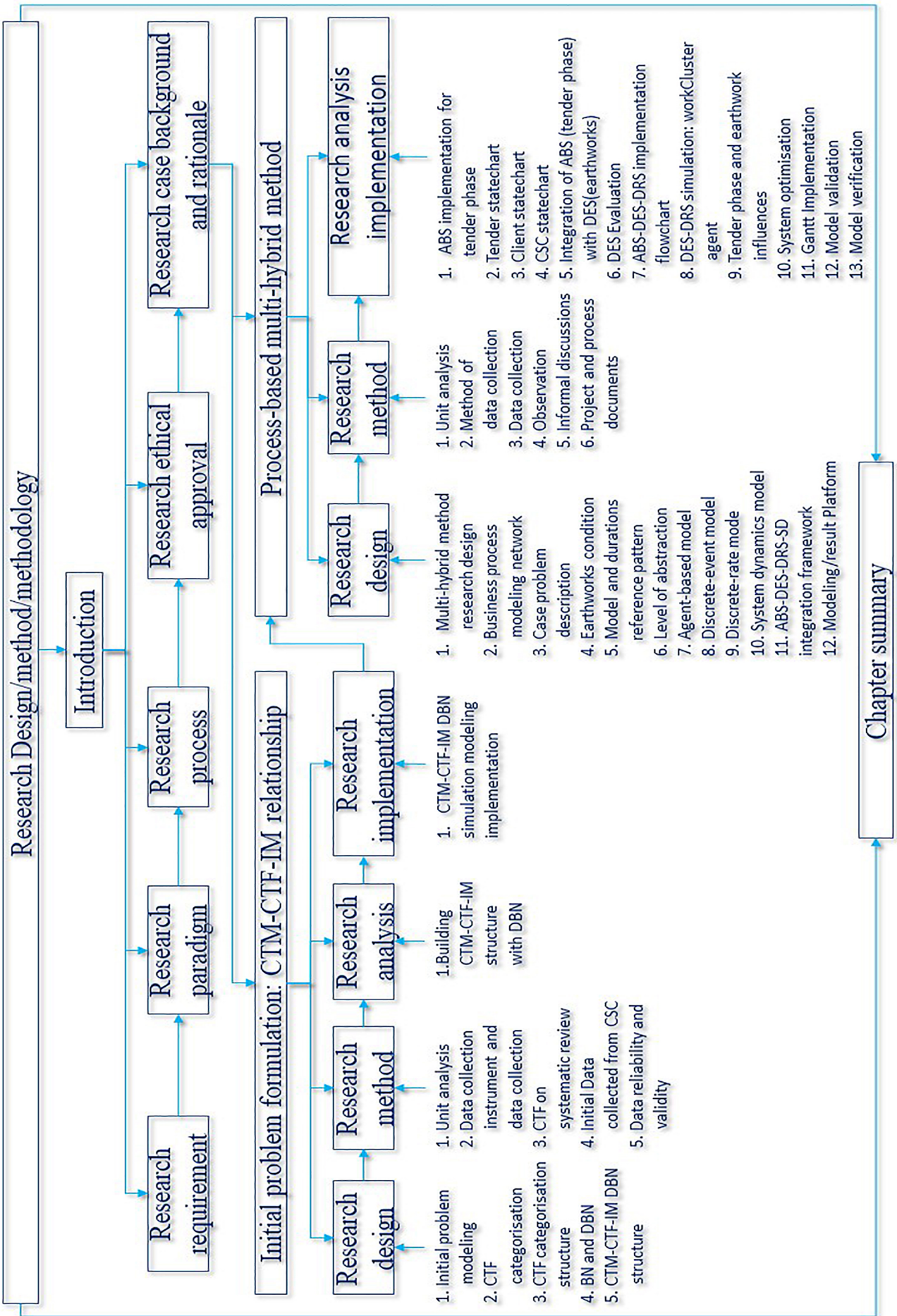


Figure 3.1. Chapter 3 layout and content

3.2 Research requirements

Central to the investigation, analysis and use of the methodology, design and method applicable for the implementation of the research is the aim established to:

The research aim is to develop and test a multi-method framework, concerning the implementation of integrated planning and scheduling system for a construction project, taking into account the associated system characteristics, components and influencing factors..

In order to achieve the aim are the key objectives including:

- (1) *A. To understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading to time overrun ;*
- (2) *B. To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule and;*
- (3) *C. To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.*

The research objectives include the need for the research to model reality with real data, map the real world with the model. This considered different aspects of planning, generate schedule from the developed plan, integrate influences to observe the impacts. The experiments on the dynamic nature and associated variabilities of the construction system focusing on planning and scheduling problem is examined in the next section, Section 3.3.

3.3 Research paradigm

The research paradigms generate views on different approaches necessary to tackle research problems and are classified into four main themes namely postpositivism, positivism, constructivism, transformative, and pragmatism (Creswell & Creswell 2017, Valiela 2009), which is described in Table 3.2.

Table 3.2

Research philosophy

Postpositivism (hypothetic-deductive)	Constructivism
Determination	Understanding
Reductionism	Multiple participant meanings
Empirical observation and measurement	Social and historical construction
Theory verification	Theory generation
Transformative	Pragmatism
Political	Consequences of actions
Power and justice-oriented	Problem-centred
Collaborative	Pluralistic
Change-oriented	Real-world practice-oriented

(Creswell & Creswell 2017, Valiela 2009)

The research in construction management is required to proffer a solution to an underlying problem. The solution is expected to resolve a particularly challenging problem. The problem can be the approach to analyse the problem. Through the approach, theory-building and theory-testing are formulated. The research paradigm is the philosophical understanding a researcher utilises to answer the research question for investigation. The successful implementation of research is a function of the research paradigm (Luck, Jackson, & Usher 2006), which without it, the research problem will only be a problem statement without a solution. The entire research has input and output; the research paradigm is the underlying fundamental principles the researcher embraces to decide, the research input, the settings that relate the research input to the output (Seymour, Crook, & Rooke 1997). The researcher conceptualises the

problem that confronts the environment, creates knowledge about the problem which is possible based on the rules, concepts, tradition, religion, dogma, reason, constraints, values about the inquiry among other bases (Creswell & Creswell 2017, Wing, Raftery, & Walker 1998). The approach selected and assumptions made by the researcher to mirror the surrounding, which is when investigated, inform the outcome of the research (Raftery, McGeorge, & Walters 1997).

The implication is that the significance of the research paradigm is the main dimension that enhances the researcher view of the realities that confronts the surrounding. Theory building and testing require strategy and procedures to logically and sequentially arrive at a given conclusion and aid the researcher to draw process of implementation of the research (Fellows & Liu 2015a). The implementation involves what method to use, what type of data to collect, where to obtain the research samples and what is the evidence that can help convince the research output and the implications to the world, where the concepts are developed within the epistemological assumptions (Gelfand & McCusker 2017). The researcher has different options to view the world; however the analysis of the strengths and weaknesses of each approach is paramount to the specific philosophy selected for the investigation (Golafshani 2003). Because the central point to all research is knowledge, the research paradigm is the epistemological nature of the research. It relates to the philosophy of real-world problem, the researcher interactions with the world to identify the existence of the reality and the sequences of rules and procedures to attain the knowledge and build theory. This means that the type of philosophical approach is the beginning of embarking on the research journey to study the world. In this regard, this research discussed different philosophical approaches that enhanced the insight gain in making a decision on which research paradigm is applicable to solve the world problem. The research paradigms generate views on different approaches necessary to tackle research problems (Bryman 2006). The epistemological perspectives include postpositivism, positivism, constructivism, transformative and pragmatism.

3.3.1 Postpositivism

Postpositivism methodology integrates subject and object, whereby the researcher knowledge about the surrounding is a function of the outcome from the surrounding and the method utilised by the researcher as a lens for the analysis the world (Panhwar, Ansari, & Shah 2017). The implication is that there are other possible solutions to any object of social inquiry, because, in every inquiry, future or untested inquiry is possible for the theory under study (Fluck 2017). In this approach, the solutions generated depends on using expert means to weigh the possibilities of all evidence and solutions. The validity of the solutions is determined by the ability of the research to adopt intelligent research design and method (Dedeurwaerdere 2018). The postpositivism epistemology is of the view that human perception can be biased concerning reality, which is the result of criticisms of positivism, whereby the reality of the world can be explained objectively (Nietzsche & Vico 2017). Postpositivism is of the view that there is cause to every effect based on the inherent biases of the researcher irrespective of the objectivity (Grigoriev 2019). The postpositivism allows the researcher to embrace as many divergent observations on the inquiry building and test theory, instead of relying on one analysis or observation, not free of errors, to explain the reality (Faraj & Othman 2018). The various and different experiments are integrated with an attempt to capture the observations close as much to the world problem (Tumele 2015). In this case the triangulated approach of one experiment weakness can be supported by the strength of the other experiment, and the use of multiple methods to assess relationships with a critical examination on the problem. In postpositivism, the assumption of the world as intersubjective enhances the researcher to reveal the knowledge of reality (Thanh & Thanh 2015). The only approach to achieve the reality is by positioning the researcher with the research subjects in an environment that allows real interactions including observations, conversational analysis, interviews, focus group and case studies, which is the benefit of the philosophy (Antonio et al. 2015).

Application of postpositivism and mapping to research case This section presents the application of the research paradigm to justify the decision components for the research case. The positivism and postpositivism are associated with experiment, reductionism (components analysis), theory testing and examination, casual relativisms using quantitative research design (Nestel & Bearman 2015). It involves social interactions to gain experience to build and analyse the worldview in terms of casualty and effects. It tackles reality confronted with complexities, triangulation of data from in-person interviews, multiple sources of data, secondary data, feedback mechanisms, content analysis and surveys with multi-trait methodology of experiments (D'Cruz, Noronha, & Lutgen-Sandvik 2018). It supports that all factors and system components are required to be combined to make a conclusion related to the case (L. Li 2015). It is of the view that construction of reality is possible with the aggregation of different pieces of evidence (Abreu Pederzini 2016). While the positivism campaigns for the use of research methodology in natural science; however, in business and management research, multiple variables are utilised to make decision requiring multiple methods and acknowledging limitations of bias. Positivism is of the view on the use of qualitative approach to research problems, but research involving organisational and business studies requires appreciating the strategic, operational and tactical variables (Pillay & Hoque 2015), which this research conditions. The research involved the interaction of the researcher and research construction in conducting a critical examination of the system, by being part of the system in order to observe the approach to the system investigation through experiments, knowledge establishment and generating real-life practical results (Cassell & Symon 2015).

3.3.2 Positivism

Positivism describes and explains the reality with objectivity and generalisations (Easterby-Smith, Thorpe, & Jackson 2015). The philosophical stance that governs the paradigm is that positivists believe that nothing is important except empiricism

including observation and measurement (Joullié 2016). In this case, the analysis of measurements and observations follow the science of logic and statistical method whereby the hypothesis is accepted or rejected subject to the research data. The level of biases based on the fact of human sensing, attributes, behaviour and beliefs concerning the environment can limit the paradigm (Hasan 2016). By the nature of the positivist, knowledge is developed by the perception and patterns of the reality, which is inductive and deductive because of shared experience, living and interacting in the same world (T. W. Kim & Donaldson 2018). So, objectivity is treated in isolation to individual perceptions, and any phenomena are significant only when it can be observed directly or indirectly (Whetsell & Shields 2015). Positivism believes that theory is confirmed through the building of verified facts by empirical testing, and during the theory building and testing, the researcher is not allowed to take for granted the acceptance of any particular values (Zait et al. 2015). In this research case, there is need for both subject and object, which limits applying the research paradigm to dynamic and real-world research.

3.3.3 Constructivism

Another epistemological stance is constructivism or interpretative. In constructivism, external reality has no significance; however, the insightful interpretations on the power of theory are demonstrated using scientific experiments, unlike the perceptions of positivism that theories are powerful instruments to build objectivity on reality (Sutton & Austin 2015). Social, individual, technological and semantic traditions are contributions to constructivism, which questions objectivism (Chipangura, Van Niekerk, & Van Der Waldt 2016). The contributions encompass various fields of learning in education, psychology, psychiatry, and anthropology, and the researcher interpretations of the reality during the interactions with the environment is based on subjective events (Barouch & Ponsignon 2016). The emphasis on subjectivity makes scientific investigation in constructivism to encompass concept generation, explanation,

definitional work, explanation, argumentation, claim-making, conflict resolution, interpretation of results, evaluation, and establishment of consensus (Cinquini & Norreklit 2015), which do not relate to the features the research described in this thesis.

Application of constructivism and mapping to research case Constructivism is applied in naturalist (biology, ecology, botany, zoology, medical) research requiring many participants value, the use of qualitative research method and aggregation of data from interview, observation, document study and image data analysis (H. Guo 2018). It does not consider objective artefacts, things or substances, as a context of interest, rather non-objective concepts such as concept generation, definitional work, explanation, claim-making, argumentation, conflict resolution, interpretation of results, evaluation, and establishment of consensus (J. Hwang, Park, & Hunter 2015). The research described in this thesis is expected to have substantially digressed if it is based on this research paradigm, which has no relationship with this research. In this paradigm and during the research design, different problematic issues arise including significance of experimental data and delimitation of phenomena. The researcher is confused in determining his status in the research either objectivity or subjectivity, doctrines and beliefs on the methodology, and ethical problem of the research results evaluation (Zehetmeier, Andreitz, Erlacher, & Rauch 2015). The research method includes action-research, conversation, discourse analysis, ethnography, clinical studies and group-based methodologies, reflexive interviewing, and visual and auditory elicitation techniques (Annansingh & Howell 2016). This research is suited in the field of construction engineering and has neither naturalistic aspect nor constructs, although the research has considered the influences of the environment on the system, which is an engineering term that is interested in the factors extrinsic to the system under consideration and has nothing to do with biological environment.

3.3.4 Pragmatism

The pragmatic stance is of the view that theory on reality is provisional and not absolute. In this paradigm, the experimental method is utilised as a means to pursue knowledge with the premise that the theory testing is provisionally verified (Scott 2016). The outcome of the inquiry is a function of a given time and within the internal environment of the researcher, and the researcher can assume the inferences made is limited evidence and subject to further investigation (Addis, Boyd, & Raiden 2016). The researcher seeks to explain reality through the likely causes and effects from limited evidence, whereby errors are corrected by further iterations (Voordijk & Adriaanse 2016). Shreds of evidence of varied kinds can guide decision-making as a result of social consequences rather than personal judgement (Ding, Yi, Tam, & Huang 2016). The use of practical case data and experimental method is unique for establishing concrete knowledge (Farjoun, Ansell, & Boin 2015).

Application of pragmatism and mapping to research case The epistemological stance of this research paradigm is associated with hands-on, do it as it is in practice, focus-based, action consequences, pluralist, and adopts qualitative and qualitative methods or variety of methods (ÇAĞLAR & Karababa 2016). It encompasses traditional academic model, whereby the formalised investigations are presented in the meetings or peer-reviewed journal (Emuze 2016). The method can be more informal method of data collection including observation, interviews, testing, experiments and documentation of practice shared among colleagues of the case under study (Visser 2019). The research is geared towards application in the practice field using organisation (CSC) case that transformed into a case study. In that case, informalities in data collection is acknowledged as well as selecting different methods of analysis. The research has a long-term objective of enhancing skills of practitioners and policy-makers since it has application in the real world and is the type of research any researcher who is interested in certain field of study is expected to pursue (Klein, Biesenthal, & Dehlin

2015). Therefore, pragmatism is the backbone of this research because all the main constructs and features of this research are embedded in the philosophical view.

3.3.5 Transformative

The focus of transformative research is on the contextual and historical factors as they affect sexism, emancipation, oppression, apartheid, gender inequality, child labour, racism, xenophobia, discrimination, supremacy, race and among other (Mertens 2014). Given the nature of the research problem, this research paradigm has no relational concepts with the research.

3.3.6 The paradigm of this Research: Application of postpositivism and pragmatism to research case

Comparing the the paradigms in relation to the research objectives and research question, a multi-paradigm of **postpositivism and pragmatism** (Creswell & Creswell 2017, Morgan 2007, Patton 1990, Rossman & Wilson 1985, Tashakkori & Teddlie 2010) is selected for this research. The following discussion corroborates the choice and assertions. It examines postpositivism first and, discusses pragmatism second and merged the two frameworks to form the paradigm for the entire research.

It is essential to develop a plan to execute an action, according to (Fellows & Liu 2015b) paradigm is a means of inquiry into discovery, which offers protection from the world compounding problems. An approach to questioning philosophical views requires a systematic framework to enhance the study of new concepts and ideas (Yvonne Feilzer 2010). The research paradigm provides an exploratory map to the research problem (R. J. Richards & Daston 2016), its application from the views of the world to solve a problem cannot be overemphasised. With this idea, the paradigm adopted forms a model and a guide to the entire research questions and supports the necessity for the

selected paradigm: postpositivism and pragmatisms.

Postpositivism is a philosophy with the view that either the inputs determine the output or the effects are because of causes (Bryman 2006, Creswell & Creswell 2017, Fellows & Liu 2015b, Pluye, Hong, Bush, & Vedel 2016). The variabilities in the construction project, discussed in earlier sections, affect planning and determine the outcome of the project, either positive and negative. Again, it is the view of the research that schedule is the outcome of planning. A good plan produces a good schedule and vice versa. The research tackles the deterministic nature of the project with an understanding of variability and influences. At any point in time, there is a cause of the resultant effects of the studied system. The research has identified the planning of construction projects as a system with inputs, environment and associated outputs.

The inputs interact with the environment, the system itself and standard outputs to yield the final output, specifically the project due date. These interactions result in causes and effects. In a study to provide the philosophy on qualitative methodology, (Behjati 2017) suggested that the practical view of the world is the external reality. This can consist of tangible and intangible data with sensing and communication based on developed system languages and attributes. In this research, a combination of physical and abstract data is utilised to present the real world in the construction project case. The planning system set up in this research employed inputs from the different phases under the system conditions to yield associated results in the output, which can be replicated in different experiments and simulations (Zhi, Malek, & Bahari 2016).

The analysis of the world is not to be constrained by an approach with specific facts and values, but a choice on different approaches (Gorski 2017). The research in relation to capturing different facets of the planning system mapped the real-world into a model with data from participants observation, conversations, measurements, monitoring and testing (Gillman 2016). The philosophical view is without the influence of what we think of the system under study (Winit-Watjana 2016) with the outcome either confirmed or

rejected (Walton & Phares 2018). The research has contested the need to bridge the gap between theory and practice by the utilisation of real case data from construction system that mapped the real-world into a model. A study of the real case requires the consideration of the discrete elements (Nouman, Taj, & Gul 2017) that are aggregated to form one complete system. It utilises intrinsic data (Fox & Alldred 2018) and includes verification of the accumulated data and facts to achieve unbiased results neutrally (Anderson 2017).

The research has attributed that the construction project is executed at different phases with homogeneous and heterogeneous data and that any analysis is expected to aggregate and triangulate the data to enhance a planning system based on external reality. The data is gathered, and the process for applying the data is based on scientific laws inclusive of heuristics, laws of conservation of mass and energy, differential equations, utility theory and optimisation. Postpositivism is of the concept that the process to carry out data application in the system is required to have a valid framework (Ravitch & Riggan 2016). The implementation and the analysis of each entity or components of the planning system are developed through a conceptual framework before the utilisation of the data. This conceptual framework depicts the network of the agents and entities in the construction project system.

The construction system has sophisticated attributes. Limiting the utilisation of the data on the conceptual framework is not adequate to generate results to explain the reality, even though it is the basis for characterising the entities relationship and testing hypothesis (Charnley et al. 2017). The methods and patterns are of importance to conduct system observations, measurements, generate results, unveil different realities, verify results and contribute to knowledge (Ravitch & Riggan 2016). Given postpositivism, the research applied multimethod, process patterns, variables feedbacks, observations, measurements, experiments, verification and validation of the results to demonstrate reality in the planning system.

One of the limitations of postpositivism as a multitrait methodology is the inability to capture real attributes (Gillman 2016), although it has the attributes for triangulation of different data supported by pragmatism. However, the inadequacy is supplemented with pragmatism methodology in this research. Pragmatism philosophy, in relation to its features of consequences of actions, problem-centred, practical, problem iterations, pluralistic, trial-and-error real-world, practice-centred (Bryman 2006, Creswell & Creswell 2017, Fellows & Liu 2015b, Pluye et al. 2016) has encouraged the application of a multi-hybrid method in this research. The complementary attributes of postpositivism-pragmatism rely on the proposition that this research:

- (a) evaluates the probability of cause and effects of variables;
- (b) contains experiment formulation analysis that relies on scientific theories, such as game theory, queuing theory, control theory, conservation of mass, automata theory;
- (c) involves several logical steps to move through problem formulation, solution formulation, solution verification and solution validation;
- (d) qualitative data complement the quantitative data;
- (e) entails multi-mode data analysis and integration;
- (f) real-world analysis is explored qualitatively and quantitatively;
- (g) utilises computer-aided programs and codes for analysis and;
- (h) validates results.

The benefit of the selected paradigm is that it offers flexibility to select a diverse range of data, method and analysis. The process of postpositivism-pragmatism is utilised and discussed in Section 3.4.

3.4 Research process

To keep the connection and to drive off the remaining part of the chapters with the research paradigm, a process flow diagram is developed and shown in Figure 3.2.

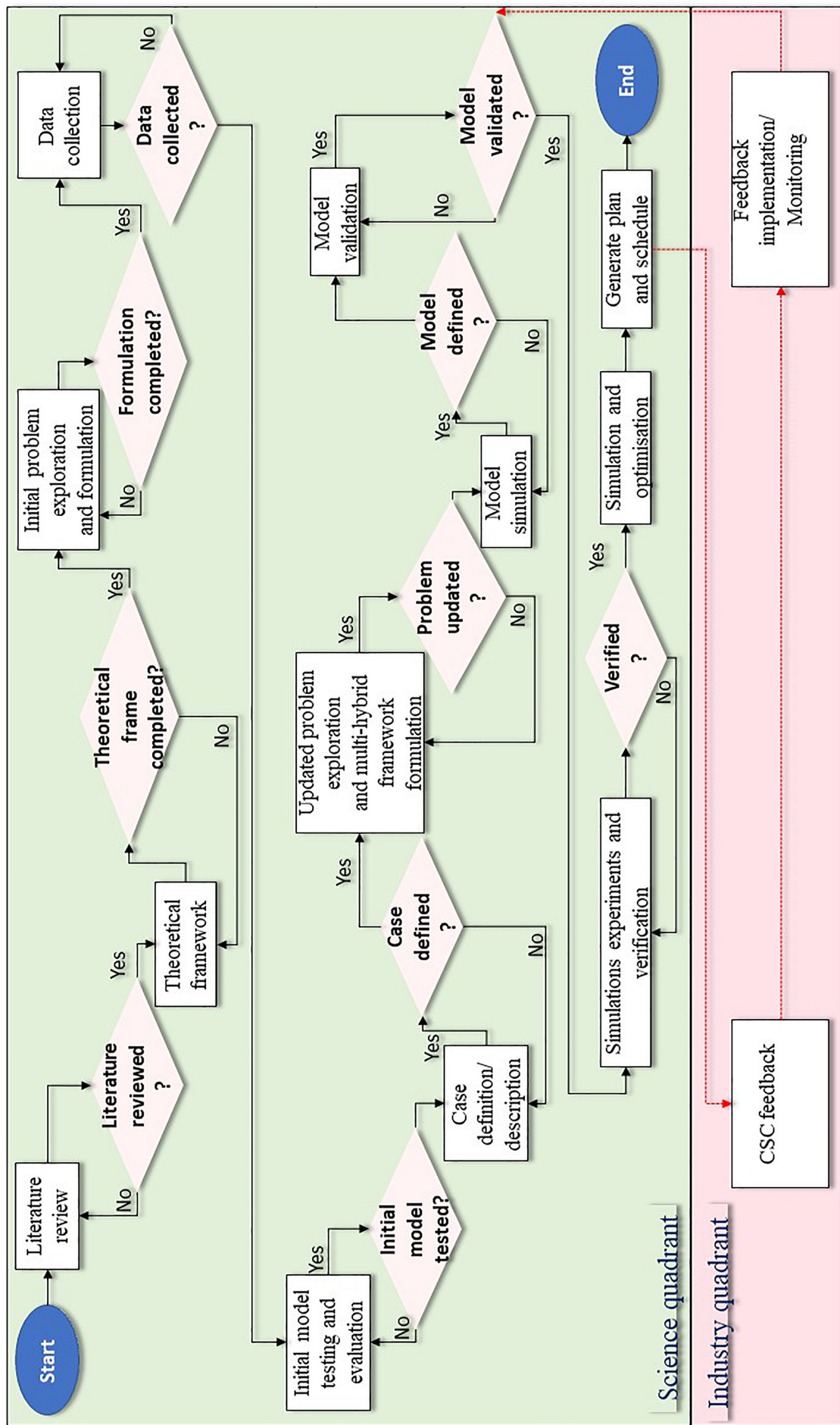


Figure 3.2. Research process

With respect to the postpositivism-pragmatism methodology for embracing real-world and pluralist method, the figure is divided into two quadrants: science quadrant of twelve logical steps and industry quadrant of two logical steps with a dotted red line. In the process flow diagram, decisions are made at each step either to continue with the successive step or to update and ascertain the accomplishment of the defined research objective and research question before moving to the next step. Each of the steps is completely implemented to achieve the research aim. However, each of the steps is explained in connection with its function for achieving the research objectives:

- (A.) *To understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading to time overrun;*
- (B.) *To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule* and;
- (C.) *To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.*

The detailed functions in relation to the research questions at the microscopic level are demonstrated in Table 3.3. Developing the research approach is a part. Nevertheless, the ethical consideration to make sure that the process to conduct the research in within the approve morals, of course, is another side of the research. The study was developed based on approved ethical considerations, and examined in Section 3.5.

Table 3.3

Research process relationship with research objectives

Research process	Research process function	Objectives
<i>Literature review</i>	Critical review of existing research	A
<i>Theoretical framework</i>	Research framework, data collection, research method and analysis techniques	A and B
<i>Initial formulation</i>	Framework adopted initial to evaluate and answer the research questions	A and B
<i>Data collection</i>	Input and values of the parameters and constructs of the entire reaction	A, B and C
<i>Initial model evaluation</i>	Applied to analyse the gathered data	A and B
<i>Case description</i>	In-depth case and data employed to answer the questions unanswered by the initial analysis	B and C
<i>In-depth multi-hybrid</i>	Framework adopted to enhance in-depth case analysis, measurements and testing	A and B
<i>Model simulation</i>	Analysis applied to achieve the research objectives	A, B and C
<i>Model validation</i>	Utilised to confirm that model behaviour is same with the real case	A, B and C
<i>Simulations verification</i>	Utilised to verify that model behaviour is same with the real case	A, B and C
<i>Simulation/optimisation</i>	Utilised to obtain best parameter amongst the model parameters	A, B and C
<i>Generate plan/schedule</i>	Utilised as the research output	A, B and C
<i>CSC feedback</i>	Utilised validate research and results	A, B and C
<i>Feedback implementation</i>	Utilised to implement feedbacks from the case study company	A, B and C

3.5 Research ethical approval

This section documents the concepts of morals and ethical consideration of the entire study. A confidentiality, anonymity, consent agreement duly signed between the CSC and the Researcher to protect confidential information and dissemination. The agreement, which is binding during and after the duration of the study, was under the Auckland University of Technology (AUT) Ethics policy. The ethics application was completed with the approval form, Appendix C: Form EA1 Application for Ethics Approval (AUTECH 2019a). It was approved by the committee (AUTECH 2019d), and ethics progress reported with (AUTECH 2019f). The research guarantees that no privileged and confidential information that might identify any of the study participants shall be disclosed (AUTECH 2019b), unless the participants consented permission to do so (AUTECH 2019c).

The data was anonymised which makes it impossible to determine the identity of individual responses (AUTECH 2019b, Petrova, Dewing, & Camilleri 2016). Project information was integrated, analysed and reported in any way in which the confidentiality of information is guaranteed (AUTECH 2019a, G. Williams & Pigeot 2017). No information collected was used for purposes other than the utilisation in the research (AUTECH 2019g, Mittelstadt & Floridi 2016). After the research study, the project information was shredded, small size of data was secured in a password-restricted folder in fulfilment of the approved ethics (AUTECH 2019a, 2019f, Bender, Cyr, Arbuckle, & Ferris 2017). Access to raw data was tightly restricted to only the research and supervisory team directly involved in the data analysis (AUTECH 2019e, Mostert, Bredenoord, Biesart, & van Delden 2016). The approval was received from the AUT's Ethics Committee (AUTECH), with approval number: 17/370 and a copy sent to CSC and was acknowledged before the researcher inductions and commencement of data collection. Also, the School of Engineering, Computer & Mathematical Sciences, Auckland University of Technology, approved the researcher

candidature to conduct the study.

In relation to the publications forming the output of the research, the researcher has not published any information or data explicitly provided in the report of the doctoral thesis (AUTEC 2019a, Kantanen & Manninen 2016). Irrespective of access to the researcher, the CSC line manager overseeing innovations was the only point of information transmission between the company and the researcher using company email and student university email. In the same vein, the dissemination of results to CSC is the duty of the innovation manager and not the researcher. However, the agreement to use the case of the CSC was not only to conduct research but with the intention that CSC could adopt the simulation and optimisation tool as a best practice approach to analysing, scheduling and planning for the execution of their complex projects.

The research concepts on morals and ethics are interposed into the research process to guide the remaining part of the research approach and theoretical framework. The next section, Section 3.6, examines the case study and its environment employed in this research.

3.6 Research case background

The research is aimed to provide a solution to a complex project environment. The researcher conceived the opportunity towards bridging the gap between theory and practice and of planning and scheduling. Since the academics and industry are two entities, collaboration is necessary to attain a holistic understanding of the real construction project problem and subsequent solution with case-study research (Marzouk & Enaba 2019). The demand from construction enterprises has been increasing for several decades, though, it is faced with challenges including disruptions in process and resources utilisation downtimes. A large number of efforts are required to ensure its accomplishments for specific goals.

Despite the human, material and equipment requirements regularly utilised to achieve the defined objectives, productivity, workflow and control strategy are of vital importance in the modern construction market (Meng 2019). The goal of the construction enterprise is majorly described by three attributes: 1) duration; 2) cost; and 3) quality. Embedded in the quality parameters are arguments relating to safety, specifications and shareholders' satisfaction (Al Nahyan, Hawas, & Raza 2019). There are a significant number of statistics showing the uncertainties, influences and disruptions prevalent in the construction sector. The disruptions occur either with one entity or a cascade to other entities, consequently leading to failure. The activities and resources schedules are developed with the traditional tools and theoretical methods, which are deterministic and insensitive to the event in real construction. The traditional tools are incapable of evaluating the planning and scheduling attributes and dynamics.

For a construction enterprise to stay on the business during the events and still operate at an acceptable time frame and profit margin, the scheduling and planning tools flexibility and tolerance to the disruptions is expected to be a requirement. The strategy and resilient scheduling of the construction resources in the dynamic and complex environment to sustain workflow and productivity and assure the set goals is a remarkable challenge. The complexity of construction activities springs up due to the interactions of different entities in the system characterised with different behaviours, individual and aggregate properties over time. The basis of the emphasis is supported by the new and central role construction scheduling plays in the operational, strategic and tactical activities and resources allocations. The initial baseline schedule is always developed with some or none in-built disruptions management, and it can deviate immediately in response to unexpected events.

The disruptions will generate the need for schedule revision and optimisation if the schedule is in the flexible mode, as well as real-time systems that proffer solutions in an instant and short-term mode. With the recent advances in different construction technologies and computer systems, real-case data collection and analysis for possible

improvements that foster planning in construction systems operations. The system at any stage is rooted in the goal, plan and policies of the different interacting entities in the system, which generate the same characteristics in coordinating the system entities.

There is a significant need to collect real data from the system of interests for making useful improvements in workflow scheduling, planning to support decision-making. Given those contexts, the researcher collaborated with one of the most active construction company, Case Study Company (CSC), in New Zealand to have an in-depth knowledge of the real-world requirements and to proffer solutions. The partnership with the company comprised site visits, collecting and studying real-time data from the construction project system, meeting, contract data, discussions and informal interviewing of the project management team, especially the construction managers and site supervisors, to obtain the real challenges and characteristics.

The issues and many interacting individuals and aggregate entities in the process are the motivating factors for the choice of a case study. Before presenting the problem statement, it is essential to highlight the researcher observations during the interactions with the CSC. The construction site is mainly a road improvement project, which includes business development for bidding and construction department for construction activities. The construction department has main construction activity execution sequence. The entire construction system is complex with interacting agents, hierarchical, dynamic, and constraints-driven. The real-time data collection is based on the observations and the developed database of the CSC.

The interview and communications with the construction team revealed that the main concern is on activity sequencing, productivity, influences and disruptions. In most cases, the disruptions on activity may escalate to other activities. The observation further generated a distinction that the behaviour of a construction system is very often difficult to analyse. In the construction manager's words, "we need the observation of the construction processes to facilitate evaluating our information to understand the

challenges”. The implication of the statement is likely to mean that the capability of analytical tools is not adequate to analyse the complex and dynamic construction systems, with the rationale of case selection, explained in Section 3.6.1.

The case study company uses Asta Powerproject, which is a total solution for project scheduling. The case study organisation is the main contracting company in New Zealand and uses the software tool for project delivery on-time across numerous projects. The CSC uses the tool because it is easier to use, generate accurate schedule, share plan with anyone with the software tool, collect and update progress easily, easy integration with other software (BIM modeling tools, Microsoft Project, Oracle Primavera P3 and P6 and SureTrak), better protection against litigation caused by delay, collaboration across programme plan and manages repeated tasks. The software architecture supports the planners in decision-making based on the input into the software that is based on the general tasks, resources assignments, and progress update. Similar to the Asta Powerproject, the case study company uses Primavera P6 to schedule tasks and resources, resource control, support for multi-tiered project hierarchies, tracking progress, data capture and customizable views.

With the software, the CSC company generates the key milestones, work area breakdown, critical path narrative, project planning key constraints and assumptions. The software also supports the CSC to develop the resources and productivities, program contingency, schedule risk and opportunity, and generate Gantt chart. The CSC utilises the output as the Level 3 Integrated Master Program for tracking progress and schedule update. The schedule developed is based on experience and historical data. Although the multi-million dollar project plan is based on the developed plan, which is not dynamic and efficient when one aspect of the project changes. The results of the changes indirectly cause overrun due to complexities. The optimisation carried on the plan is the schedule risk analysis, which is updated frequently. Simulation modeling and optimisation is not adopted in the planning and scheduling system of CSC; however, the demonstration of the research result has encouraged CSC to adopt the method to

one of the design cases in one their major contract in New Zealand, and the phase of the project. The use of the simulation and optimisation during the planned design phase of the contract is for decision-making. Relating the research to the CSC plan in terms of optimisation, the researcher utilised the Level 3 Master schedule to develop the discrete-event simulation of the project. The overview of the impact of data collected from CSC, means of data collection and the result obtained on the research are depicted in Table 3.4.

3.6.1 Research case rationale

However, to ensure that the research aim is consistent with every section of the thesis, the rationale is mentioned again in the case study section. The case study is created as part of the doctoral research project. The research project is the exploration and investigation of construction planning and scheduling in a real construction setting, specifically in the construction project. Among the concise focus of the study is the improvement of time and productivity in the presence of influences, uncertainties and complexities.

Within the coverage of the study, the researcher, accepts that given literature review and construction industry concerns, the case study can contribute to the body of research as well as the industry. The goal of the case study is to gain an understanding of construction project planning and scheduling to improve the process. The improvement goals are on reducing time overrun, planning predictability, reactivity and proactivity. More specifically, the case-study company aimed for a decision support system to enhance management decisions on scheduling and productivity.

In the subsequent sections of this chapter, the research design, research method, research analysis and research implementation are examined in two-folds. First, in the initial problem formulation of influencing factors on construction time management to answer research Question *Q5*.

Finally, in an in-depth research problem formulations with the multi-hybrid model to answer the remaining research questions. Each of the two divisions is demonstrated independently of the research elements to provide insights as well as how the initial problem formulation of influencing factors on construction time management has initiated an in-depth research problem formulation with the multi-hybrid model. Having examined the context of the case and from this point forward, the next section, Section 3.7 integrates different aspects of the research elements to demonstrate the strategy for the implementation of the initial problem formulation.

3.7 Initial problem formulation of influencing factors and construction project time management

The initial problem formulation is developed to provide insights and accomplish the objective *(B)*:

Objective *To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule* and; the research question *Q5* that examines:

What are the relationships between construction time management and influencing factors in construction projects necessary to gain insight about reducing time overrun in construction projects?

Within the initial problem formulation, the selected research design, research method and analysis are examined as well as the rationale for the selection of a research

approach. Time management in a construction project is a dominant feature in the construction management domain. It is a management strategy to enhance the performance of time in construction, though it is associated with influencing factors. The relationship of the construction time influencing-factors (CTF) with construction time management (CTM) is of crucial importance in defining the effectiveness of the whole construction project life cycle from the resulting impact (IM). Hence, this is mainly related to the resultant effects of CTF on CTM due to the relationship.

Moreover, to implement the problem formulation, the research explored the sources of CTF presents how it can be categorised, and develops a relationship framework between the CTF and CTM. The identification of the factors involved document analysis of CSC, secondary data and applying a comprehensive review of journal articles concerning construction phases. With the CTF-CTM relationship, secondary data was garnered to develop the CTF categorisation and relationship framework. The dynamic Bayesian network (DBN) model and simulation are applied, with the document analysis from CSC, to evaluate the model. In the entire section, CTF, CTM and IM terms are the acronyms for construction project time influencing factors, construction project time management and impact of CTF and CTM respectively. The research elements including research design, research method, research analysis and research implementation. A more detailed account of the research design of the initial problem formulation is given in the following Section 3.7.1.

3.7.1 Research design

The research design for the initial problem formulation of influencing factors and construction project time management discusses:

- (1) the initial problem modeling and simulation;
- (2) the CTF categorisation into main category and subcategory;

- (3) the category structure;
- (4) concepts of dynamic Bayesian network structure and;
- (5) the concepts and ideas of using DBN to conduct simulation modeling of CTM-CTF-IM relationship.

A case study is suited for the evaluation to show the dynamic causality of CTF and CTM relationship and seek the opinions of the CSC company project team. The case study is adequate for a detailed study on individual, organisation and project behaviour to gain insights and ideas on specific research question (Hancock & Algozzine 2016). This research considered CSC company as a single case organisation (entity) to gain insight into the CTM-CTF relationship. (Creswell & Creswell 2017, Yin 2017) discussed the advantages of the case study in the use of pluralist and triangulated data. (Ahmed, Opoku, & Aziz 2016, Fellows & Liu 2015b) have stated the utilisations of case study in construction management research. In those studies, a case study can be a means of understanding knowledge and generating proposals. It can present a mechanism for new development and ideas, as well as create a knowledge system for new or existing problem. Furthermore, a case study is applied to evaluate and develop statements and reports on the subject under study, which can generate propositions for further studies.

The internal objective is to provide valuable insight into CTF influence on CTM and how managers can apply the statement or reports from a relationship framework to improve time management performance at different project phases. There are many research studies (Agyei 2015, M.-Y. Cheng & Tran 2016, Chileshe, Rameezdeen, & Hosseini 2016, Conforto & Amaral 2016, Ghoddousi et al. 2017, Hou, Zhao, Wu, Moon, & Wang 2016, S. H. Lee et al. 2006, Pournader, Tabassi, & Baloh 2015, Senaratne & Ruwanpura 2016, Si, Marjanovic-Halburd, Nasiri, & Bell 2016) in construction management that have applied case study research design that supports its application in this research. Accordingly, this section of the study utilises descriptive case study. The selection of a case study to gain insight on CTM-CTF relationships and the associated impact is implemented using simulation modeling. The structure and

functions of the model are discussed in Section 3.7.1.1.

3.7.1.1 Initial problem modeling and simulation

Given the examination of simulation modeling in Section 2.7.3.2, while modeling is utilised for the evaluation and understanding of the case, simulation is employed to explore the dynamics of the case. The case presented in relation to the research question consists of the exploration of the relationship between CTM and CTF. Modeling and simulation is a design tool to interpret the relationship (Antunes & Gonzalez 2015, Brodersen et al. 2015, Zhou, Johansen, & Aston 2016). The evaluation of the knowledge to achieve the specific research objective is a function of simulation modeling of the concepts and knowledge of the relationship to support the research question posed in this study. Besides, the simulation model aids the utilisation of the case study data and the patterns of the generated results. In this part of the research, the model illustrates the static representation of the objects and variables in the case. The simulation adopts the model objects to solve the process network, which in the end served a purpose for prediction and decision-making. The main modeling and simulation platform to implement the initial problem formulation is a dynamic Bayesian network (DBN). To proceed in the simulation modeling, the following key points in Sections 3.7.1.2 to 3.7.1.4 are defined to illustrate the method in terms of data collection and analysis.

3.7.1.2 CTF categorisation

The creation of the categorisation with the data collection, in Section 3.7.2.2, comprises defining the main category based on stages of the construction project, defining the sub-category, and CTF coupling in Figure 3.3.

In the figure, the CTF are particularly differentiated into seven main categories: (1) design stage; (2) tender stage; (3) pre-construction stage; (4) procurement and subcontracting stage; (5) construction stage; (6) post-construction and as-built design

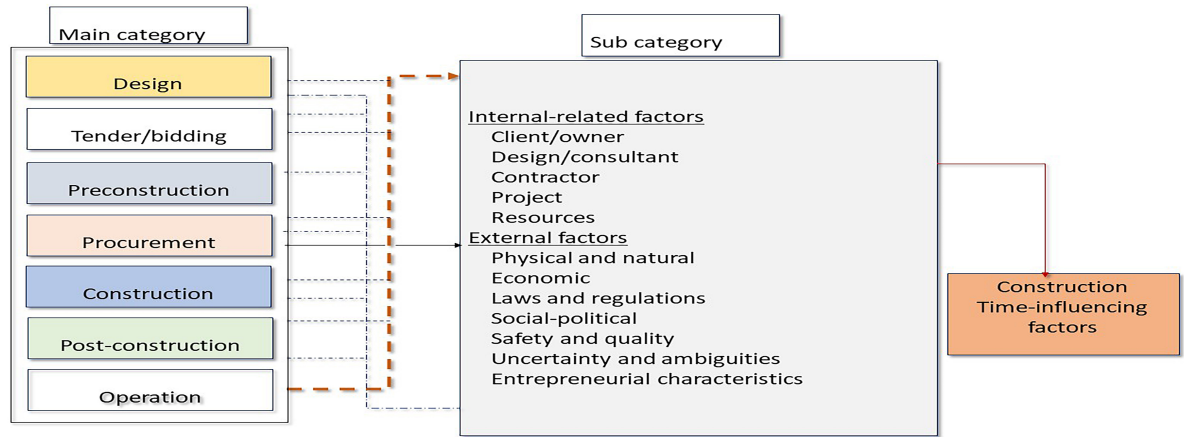


Figure 3.3. CTF categorisation

stage; and (7) operation. Similarly, the sub-category is subdivided into seven sub-categories: client, contractor, and subcontractor, supplier, design and consultant, construction project related, material and labour and equipment, and external. The sub-categories encompass the collected CTF. In Figure 3.3, while the sub-category consists of CTF, the main category likewise comprises the sub-category. The dotted lines highlight the possibilities of any of the CTF to affect any of the main categories that influence CTM.

The CTF categorisation facilitated the development of the CTF categorisation structure of the generated categories, illustrated in the subsequent section, Section 3.7.1.3.

3.7.1.3 CTF categorisation structure

The study selected the categories that are relevant to construction project stages. A variety of themes that generally facilitate the understanding of each category is provided in Table 3.5, which states each subcategory and its explanations.

In the table, the characteristics of various categories of factors, in terms of CTF, are presented to define their attributes. The CTF play a central role in determining either the success or failure of construction projects (Palikhe, Kim, & Kim 2019). There is a range of approaches applied to evaluate the CTF that effect on CTM. The approaches

Table 3.5

Category themes

Structure	Definition	Variable code
CTF factors	The influence factors	CTF
CTM strategy	The normal construction system assuming no disturbances	De_CTM, Te_CTM, PrC_CTM, PC_CTM, Co_CTM, PoC_CTM, OR_CTM
CTF-CTM observation	The outcome of CTF-CTM interactions	CTM_observ
Intervention strategy	The intervention strategy because of unsuccessful outcome of CTF-CTM interaction	CTM_interv
Additional CTF	An intervention, we suggested not free of associated factors	Add_CTF
Terminal impact	Final expected outcome of CTF-CTM interactions	IM

originate from mathematical and computation analysis, including statistics (Elinwa & Joshua 2001), fuzzy set theory (G. J. Sweis 2013b) and modeling (Asiedu, Frempong, Nani, & Holt 2016). In addition, the evaluation of CTF is dependent on the inputs from the construction management team. A significant part of the evaluations dealt with analysis to identify the magnitude of impact degree significances.

The resulting implication is that while some CTF can have huge impacts, others are likely to have less impact. The approaches believe that the solutions to poor CTM cannot be suggested unless the problem is fully investigated via a thorough understanding of CTF, and it can be based on different contexts (Enshassi, Kochendoerfer, & Al Ghouli 2016, J. K. Larsen, Shen, Lindhard, & Brunoe 2015). Amongst those contexts are location, industries, company sizes, respondents' demographic data, sample size, and sample location tend to be more popular. The CTF categorisation approach is presented with their latent attributes. The goal towards responding to the research question [Q5](#) is dependent on a modeling framework. In the instance of the research, the dynamic Bayesian network (DBN) is employed to accomplish the objective and is substantiated in Section 3.7.1.4.

3.7.1.4 Bayesian network and dynamic Bayesian network (DBN)

The CTF and CTM relationship can be implemented using modeling, statistics and analytical techniques. While the analytical including statistics methods do not consider the dynamic and complex nature of construction projects system, the modeling method can investigate the dynamic characteristics of the CTF-CTM system Borshchev (2013b). It is interesting to note that simplicity and ease of use of a particular method are important, even if the dynamic characteristics of the system is implemented. The real and complex systems are expected to be time-dependent, and their impacts on the environment are dynamic. A reasonable understanding of the interactions of different system variables with their surroundings is meaningful when they are observed over time Rafiq, Chryssanthopoulos, and Sathananthan (2015). The variables are either deterministic or probabilistic that specifies the relationship Dean and Kanazawa (1989). While the relationship of deterministic variables requires exact parameters, the relationship of probabilistic variables depends on conditional probability and uncertain variables (Leu & Chang 2015).

Bayesian network (BN) is a graphical model to determine the distribution probabilities based on conditional dependencies (Weber, Medina-Oliva, Simon, & Iung 2012). BN is based on algorithms that consider the non-linearity of the interacting variables through risk assessments and conditional probabilities of the finite set of random variables (Nielsen & Sørensen 2018). However, the usefulness of BN is in the range of equilibrium conditions and does not represent the dynamic and uncertain conditions (Codetta-Raiteri, Bobbio, Montani, & Portinale 2012) that characterise the construction domain. As an extension of the BN, DBN models influences in stochastic domain considering systems changes over time (Daly, Shen, & Aitken 2011) and a temporal extension of the BN (Han, Zhang, Homayouni, & Karmaus 2017). The distinction of dynamic in DBN with dynamical systems is that the parameter or the graphical network does not change with time; somewhat, modeling of dynamic system

(Hruschka Jr & Ebecken 2007).

The focus on applying DBN in this research is to use temporal reasoning to create and enhance time-series type of decision support systems, which are not available in previous studies. Given the concepts highlighted above and BN capabilities, BN extended to DBN can be utilised to model the time-based relationships between CTF and CTM. It is not the intention of the research to discuss the theory of BN and DBN; but, a simple principle for applying DBN to explore CTF relationships with CTM. The understanding of CTM-CTF analysis with DBN is centred on the theory of conditional dependence, temporal reasoning, CTF-CTM inference in DBN, and the unrolling of DBN (Daly et al. 2011). With the examined concepts of DBN, the next Section 3.7.1.5 investigated how the DBN is applied to depict the relationship of CTM-CTF-IM.

3.7.1.5 CTM-CTF-IM dynamic Bayesian network structure

Dynamic Bayesian network (DBN) is defined based on the quantitative part: network structure; and the qualitative part: network parameter (Zou & Conzen 2004). In the BN network structure, there is a link between the parent node and the child node. In the illustration of BN principles, CTF, CTM and IM are the representation of a collection of variables at different nodes, which is at $t = 0$ of the dynamic system represented in DBN. The variables can be physically represented in a multi-dimensional array, Figure 3.4, depicts some of the combinations and interactions.

The multi-dimensional array provides input and process-output structure for defining relationship applied for decision-making (Kagioglou et al. 2001). A coherent system for visualising the internal and external relationship between one variable to enhance evaluations and analysis of the impacts of the relationships is presented by a multi-dimensional array (Wong 2009). Three main symbols, CTF, CTM and IM, are selected to develop the model for clarity of comprehension. The insights of each label: CTM strategies at each stage, CTF influencing the CTM and CTM-CTF interaction

variables, respectively, the output variable of the system is IM: observable variable of the Bayesian network.

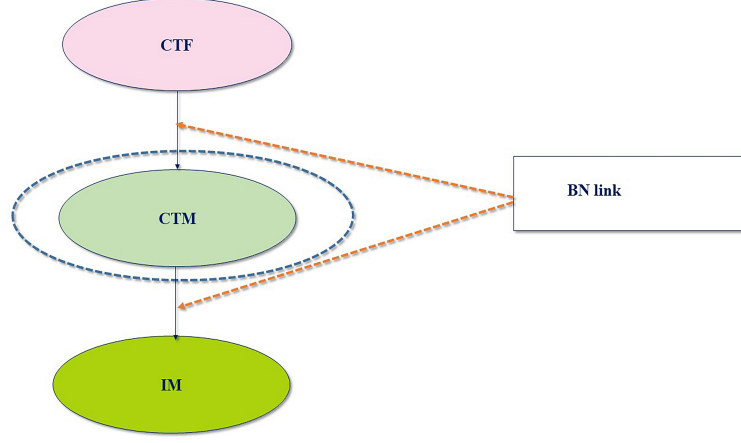


Figure 3.5. Bayesian network of CTF-CTM-IM

The BN extension to DBN, is developed by connecting the BN over time steps, hence, $CTF, CTM_t, CTM_{observt}$ and IM . It implies that as soon as the observation arrives, t is increased to $t = 1$ since it is in the stochastic domain. The result is a collection of $CTF - CTM - IM$ nodes represented in Figure 3.6, with arcs connecting a pair of the random variables. While CTM is the observation of CTF node, IM in its turn is the observation of CTM-CTF node interactions. The parent node is observed through the child node, each node having an inherent probability distribution, depicted in Equation 3.1.

$$(CTF - CTM - IM)_t = (CTF, CTM_t, IM) \quad (3.1)$$

The parent node CTF influences the child node CTM. The parent node CTM influences the child node IM because of the influence of the grandparent node CTF with a resultant joint probability distribution. The CTM nodes and the IM nodes are transformed from BN to DBN by adding temporal nodes (time-based node), as shown in Figure 3.7. In this case, the DBN structure is defined by temporal nodes, temporal arc, temporal delay symbolised with 1, and normal links. The temporal delay is the influence of the CTF nodes on the resulting observations, which means that the current value at time slice t

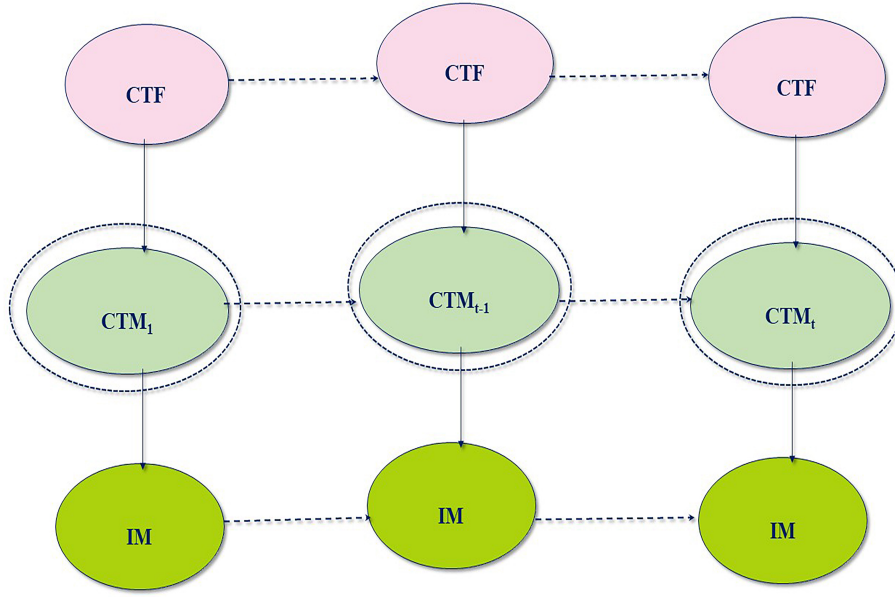


Figure 3.6. DBN of CTF-CTM-IM

of the terminal observations is influenced by the past value at time slice $t - 1$. Unlike the BN that links only the parent and child node, the DBN temporal link connects two temporal nodes and to itself with a time delay denoted in the square depicted in Figure 3.7, which will form the basis of DBN modeling in this study.

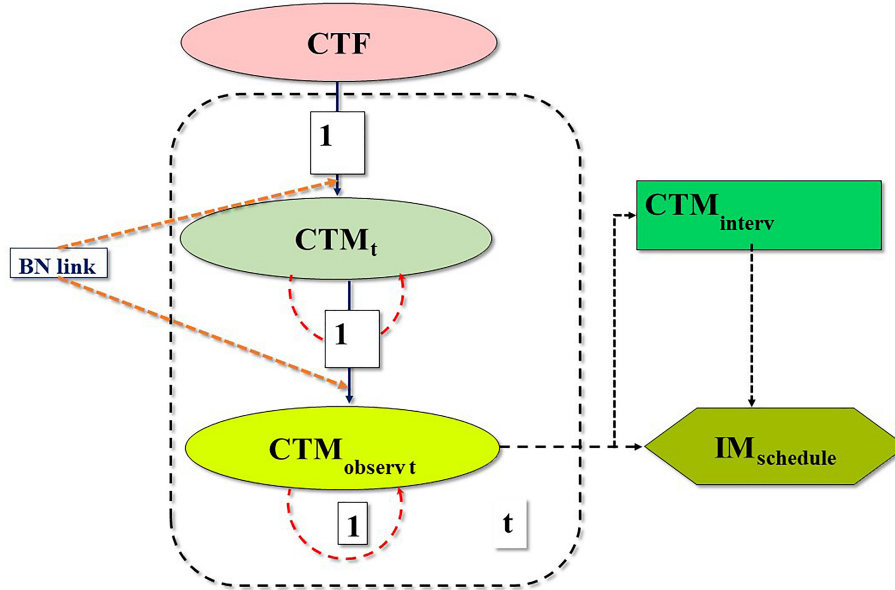


Figure 3.7. CTF-CTM-IM DBN structure

By applying probability reasoning to enhance decision-making, accordingly, the study

devised three sets of parameters based on the variables defined in 3.5, more specifically CTF , $CTM_{observation}$ and IM ;

Initial parameters:

The CTM as planned is at initial state distribution S_1 at $t = 1$ and transformed to another state S_D at $t = T$ due to the interaction between CTF and CTM.

$$\mathbf{Pr}(CTM | CTF) \text{ and } \mathbf{Pr}(S_1 | Pa(S_T), CTF, CTM) \quad (3.2)$$

The probabilities are the probability distributions of CTM given CTF and the probability distribution of the initial time step implemented in the temporal plate that captures the dynamics of the state transformation.

Temporal parameters:

The transitions of the CTF, CTM, and IM variables in time steps, which is a two-slice temporal BN is formulated as follows;

$$\mathbf{Pr}(S_T | Pa(S_T), CTM) \quad (3.3)$$

Contemporary parameters:

The probability distribution for CTF assumed to be constant for a specific factor, given by;

$$\mathbf{Pr}(CTF) \quad (3.4)$$

Terminal parameters:

$$\mathbf{Pr}(IM | (S_T), CTF, CTM) \quad (3.5)$$

The nodes of first slice do not have parameters, but the nodes in the second slice have conditional probability table, which are time variant. The joint probability distribution is generated by unrolling the time steps temporal BN. Then the impact of the probability distribution of one variable over the other variable is evaluated by the

joint probability distributions, represented in Equation 3.6.

$$\begin{aligned} \mathbf{Pr}(CTF, CTM, S_{1:T}, IM) = & \mathbf{Pr}(CTF) \cdot \mathbf{Pr}(CTM | CTF) \prod_{i=1}^N \mathbf{Pr}(S_1^i | Pa(S_1^i), CTF^i, \\ & CTM^i) \prod_{t=2}^T \prod_{i=1}^N \mathbf{Pr}(S_t^i | Pa(S_t^i), CTF^i) \prod_{i=1}^N \mathbf{Pr}(IM_i | (S_T^i), \\ & CTF^i) \end{aligned} \quad (3.6)$$

The analysis of the model is dependent on the input data. The input required to evaluate the DBN structure in relation to the conditional probability is dependent on the conditional probability table (CPT) (Bakshan, Srour, Chehab, El-Fadel, & Karaziwan 2017, Rigosi et al. 2015, W.-S. Wu, Yang, Chang, Château, & Chang 2015, X. Wu et al. 2015), which tabulated in Table 3.13. Therefore, unit analysis, data collection, sample inclusion criteria, and data reliability and validity are discussed in the following section. Having considered the CTM-CTF-IM relationship concepts, it is vital now to consider the primary sources of data required to analyse and implement the developed CTM-CTF-IM relationship concepts with DBN, examined in Section 3.7.2.

3.7.2 Research method

Presenting the simulation modeling structure is one method; but, the data required initiate the simulation, evaluation and analysis is the objective function of this section. The data collection and methods are discussed in three themes: 1) unit of analysis; 2) data collection and inclusion criteria and; 3) data reliability and validity. The ideas are developed to enhance the implementation of the model analysis for this initial simulation modeling formulation. The primary source of data is the CSC document analysis and secondary data from the works of literature using a systematic review.

3.7.2.1 Unit of analysis

In formulating the research method, it is fundamental to establish the unit of analysis by the unit attributes under research investigations. As well as the identification and interactions of the system components in the system under considerations (Bell, Bryman, & Harley 2018, Bengtsson 2016, Bogers et al. 2017, Creswell & Creswell 2017, Fellows & Liu 2015b, Yin 2017). Construction planning and scheduling spread across construction project phases (CP). It begins from the design phase, tender phase, procurement phase, construction phase, post-construction phase and operation phase centred on stakeholders' time objectives (SO) Influenced by construction time management factors (CTF). The research selected Seven (7) CP, One (1) SO and n number of CTF to illustrate with sufficient details on the construction system identified from the road improvement project utilised for investigations and evaluations. The reason for the items selected to illustrate the unit analysis is to capture the essential themes in relation with the research Question [Q5](#) asking for the decision support system to explore the relationships between construction time management and influencing factors?

The components of the unit analysis are developed to capture sufficient details of the main constructs: CTM and CTF, that formed the research question. Furthermore, it assists in the creation of the relevant variables standing out to offer an answer to the research question. The selection of the unit of analysis resulted in an embedded case of 1 context, 1 case item and 7 CP phases plus the n number of CTF units of analysis, shown in Figure 3.8.

In the figure, the case variable is an instance of the context and the units of analysis are the instances of the case variable, which generate the embedded case study (Phua 2013, Yin 2017). The next element of the research method is the data collection instruments and data collection.

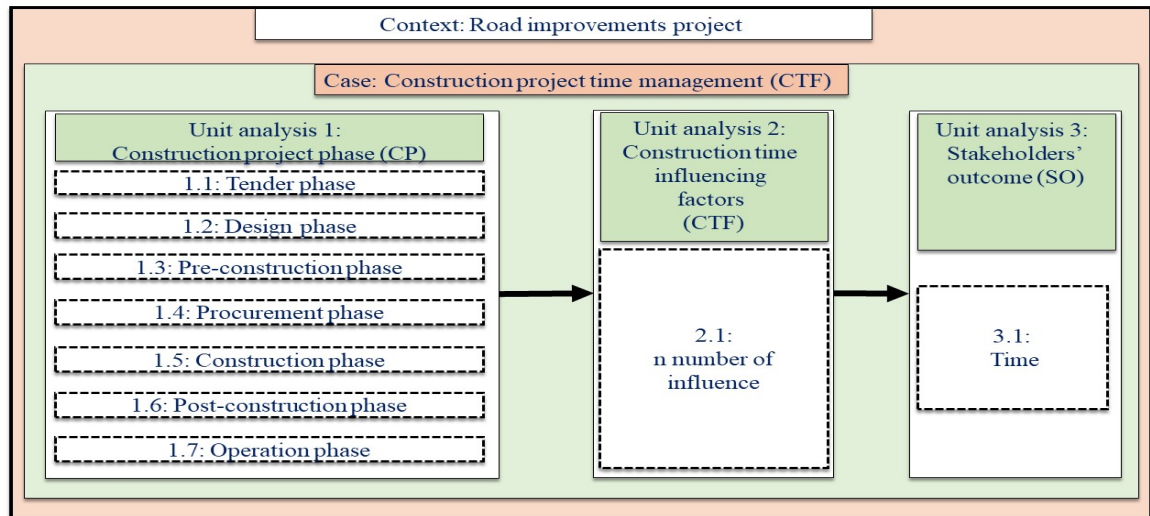


Figure 3.8. Embedded case study unit of analysis

3.7.2.2 Data collection instruments and data collection

The case study analysis offers the opportunity for different data collection methods (Matthews et al. 2015, Rule & John 2015, Yin 2017). Before the development of the simulation modeling for CTM-CTF-IM relationship, the study applied two methods of data collection. These are the data collected from the literature review that formed the secondary qualitative data, and the data collected from the case study company. Whereas the secondary data was utilised to formulate the simulation modeling, the data from CSC, in terms of project phases implementation, formed the qualitative and quantitative data into the simulation modeling and validation.

3.7.2.2.1 CTF on systematic review

In the first instance, a literature review was conducted on previous studies that have documented CTF on CTM. The utilisation of secondary data relevant to the research question offers quality information, save cost as well as enhancing longitudinal and cross-functional analysis (Bell et al. 2018, Johnston 2017, Mok, Shen, & Yang 2015, Takey & de Carvalho 2015). The systematic review considered peer-reviewed journal,

which facilitated data collection characterised by the attributes (Ali & Watson 2016, Darko & Chan 2017, Nicholas et al. 2015) presented in those secondary data references. The research approach engaged the application of a systematic review method to determine and elucidate the CTF. The steps to expedite an in-depth exploration of CTF are laid out along these lines:

- (i) The formation and generation of search words and key parameters;
- (ii) Inclusion criteria and the selected papers timeline;
- (iii) Decision on the type of database and database search relevant to the study intention and;
- (iv) The articles' results selection criteria and content analysis.

To begin with the database search, the following keywords were utilised, and depicted in Table 3.6.

Table 3.6

Keyword for database search

Keyword		
1	"Time management"	4 "Time impact factors"
2	"Time management factors"	5 "Time influencing factors"
3	"Time and schedule overrun"	6 "Time performance factors"
		7 "Delay factors"
		8 "Success factors"
		9 "Failure factors"

The choice of the keywords is based on the contexts identified of CTF analysis in the literature. In the outlined steps, the concepts (i) to (iv) are illustrated in Figure 3.9, and it shows the components and process applied in each idea.

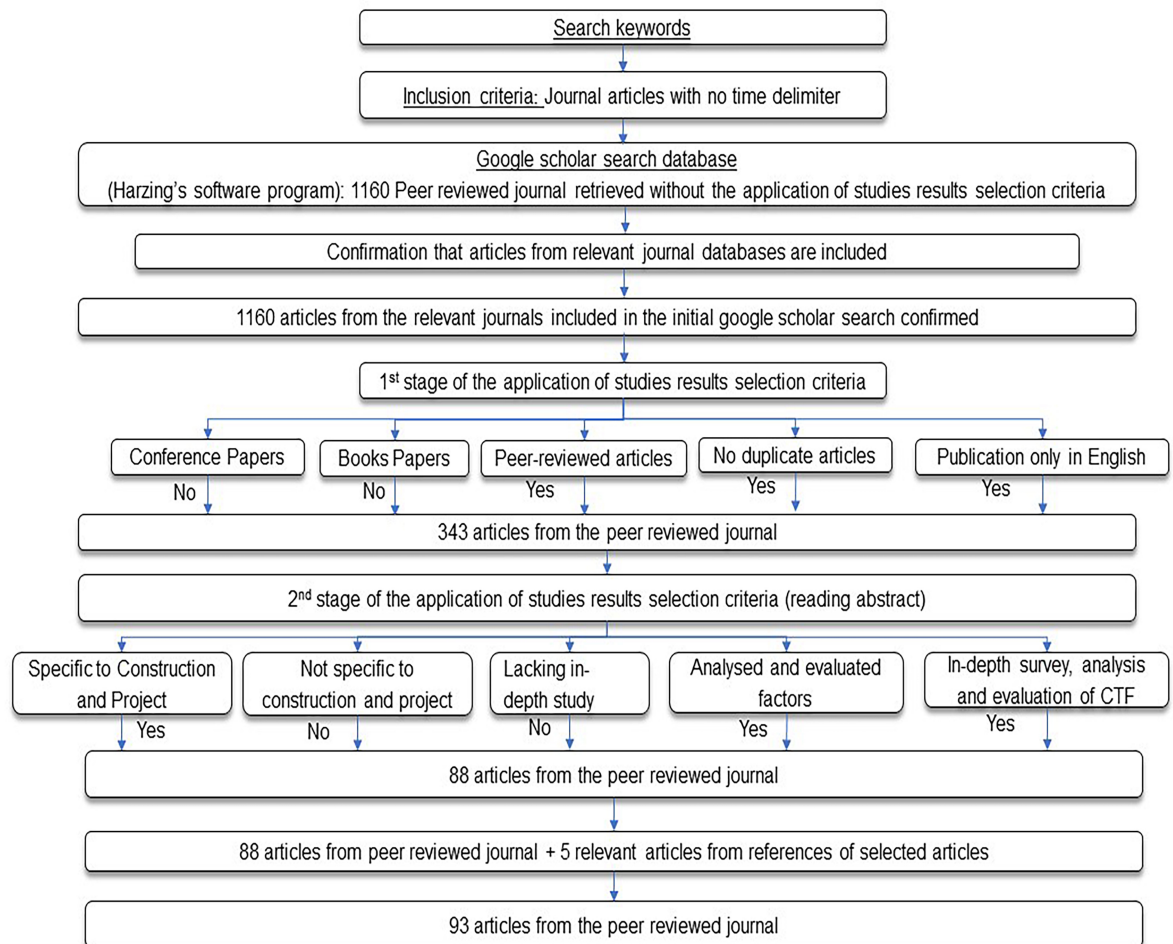


Figure 3.9. Process for articles selection

The formation of these keywords is to accomplish the research objectives. Since it is the objective of this study to gather and present construction phase categorisation of the CTF, the publications time delimiter was not set to any specific period. The approach to the time delimiter is to ensure that the categorisation encompasses an extensive range of the CTF with comprehensive data attributes. The CTF in the different studies identified are based on several contexts: location, type of project, demography, industries, different economic development stages, company sizes, respondents' demographic data, analysis sample size, and sample location. Because of this, setting a search start date or end date will cause inherent bias.

Similarly, in the process of identifying and reviewing the articles, the study did not encounter a single paper that has developed the CTF-CTM evaluation using DBN. The developed keywords promoted the approach to conduct a database search with a google-scholar engine using Harzing's Publish or Perish software program (Harzing 2014). The software is an effective means for publication/journal search and citation analysis (Scruggs, McDermott, & Qiao 2018). A database search using this software interacts with many of the journal, publications, books, reports and universities databases to present article samples using input keywords or strings. It searches articles from a diverse range of databases. The keywords were combined with construction projects and project management to identify the article samples with the initial result of 1160 articles. In the same vein coupled with the research objective, the study carried out an additional database search on a range of targeted and specific publications and journals in construction and project management research using the same keywords "+ construction and project management in the first search.

The result of the search enhanced the confirmation of the initial search results or sample articles. Since Harzing's Publish and Perish can interact with the journals, the separate search validates that we have retrieved the articles from the relevant journals based on the keywords. It is the priority of this study to take preference for papers that are published based on in-depth analysis and review. Subsequently, from the 1160

articles, some papers were excluded that did not satisfy the study preferences. Interest was focussed on peer-reviewed articles due to their quality, and duplicate articles were removed.

Articles included those that were not published in the English language because of the unavailability of an immediate system that can effectively translate the languages of these articles to English. However, this challenge is not expected to develop a bias in the CTF categorisation creation based on the contexts. Three hundred forty-three articles are selected after applying the exclusion criteria. An initial review of the abstracts presented the need for further analysis; subsequently, the researcher read the abstracts of the 343 articles. The exclusion criteria for further analysis entails the need to include those journals with in-depth scientific research and scope essential to time management, particularly related to construction and project management.

Time is involved in human activities and other academic disciplines. It is not the objective of the research to discuss general time management and its influencing factors, but time management in the construction industry. The results of the content analysis and the application of the selection criteria included 88 relevant papers. Additionally, five articles were obtained based on the review of references to the articles. Ninety-three (93) papers were selected that forms the basis of the current research on CTF-CTM relationship. The CTF identified from the included articles, presented in Tables 3.7, 3.9 and 3.11 , are employed to develop the CTF categorisation.

Given the CTF systematic review and the research literature review, the development of CTM and CTF relationship framework and testing using DBN is implemented to enhance the relationship network and visualisation. By drawing on the previous studies, theory to practice are related by collecting data from the CSC process documents. Accordingly, the discussion on the data collected from the CSC is depicted in the next discussed item, initial data collection from CSC.

Table 3.7

Identified CTF

CTF	Te	De	PrC	Con	PrC	PoC	Opr	Author
Unaware of stakeholders needs	++	++	++	++	++	++	++	(Fageha & Aibinu 2016)
Low technology innovation	++	++	++	++	++	++	++	(Tawalare, Laishram, et al. 2018)
Lack of team empowerment	++	++	++	++	++	++	++	(Tawalare et al. 2018)
Poor mechanism of alliancing	++	++	++	++	++	++	++	(Lahdenpera et al. 2017)
No insight of CTF features	++	++	++	++	++	++	++	(Gacasan, Wiggins, & Searle 2016)
Inadequate information	++	++	++	++	++	++	++	(Hassanain, Aljuhani, Sanni-Anibire, & Abdallah 2018)
Lack of relational database	++	++	++	++	++	++	++	(Z.-A. Ismail 2017)
Lack of improved work flow	0	0	++	++	0	0	0	(Olivieri, Seppänen, & Denis Granja 2018)
Many strategies	0	0	++	++	0	0	0	(F. Y. Ling 2018)
Lack of technical strategies	0	0	++	++	0	0	0	(Vilventhan & Kalidindi 2018)
Lack of advance payments	0	0	++	++	0	0	0	(O. I. Aje, Olatunji, & Olalusi 2017)
Abundance contractor flexibility	0	0	++	++	0	0	0	(F. Y. Ling & Khoo 2016)
Cascaded subcontractor delay	0	0	++	++	0	0	0	(Gurmu, Aibinu, Toong Khuan, et al. 2016)
Inefficient working hours	0	0	++	++	0	0	0	(Gurmu et al. 2016)
Traffic control planning	0	0	++	++	0	0	0	(Gurmu et al. 2016)
Project start-up planning	0	0	++	++	0	0	0	(Gurmu et al. 2016)
Lack of transparency	0	0	++	++	0	0	0	(Ibem, Onyemaechi, Ayo-Vaughan, et al. 2018)
Adverse weather	0	0	++	++	0	0	0	(Ballesteros-Pérez et al. 2012)
Delay inpayments	0	++	++	++	++	++	++	(J. I. Lee, Lee, & Park 2018, A. Rostami & Oduoza 2017)

++:available; 00 unavailable;Te Tender; De Design; PrC Procurement; Pre construction;PoC Post construction; Opr Operation

Table 3.9

Identified CTF

CTF	Te	De	PreC	Con	PrC	PoC	Op	Author
Inadequate schedule assessment	0	0	++	++	0	0	0	(M. A. Bragadin & Kähkönen 2016)
Geotechnical factors	0	0	++	++	0	0	0	(Amadi & Higham 2018)
Project complexity	++	++	++	++	++	++	++	(Nguyen & Hadikusumo 2018)
Resources inadequacy	0	++	++	++	++	0	0	(Karimi et al. 2017, Nguyen & Hadikusumo 2017)
Site Management	0	0	++	++	0	0	0	(Akomah & Jackson 2016)
Weather	0	0	++	++	0	0	0	(Jung, Park, Lee, & Kim 2016)
Variation	++	++	++	++	++	0	0	(Suleiman & Luvara 2016)
Construction noise	0	0	++	++	0	0	0	(Kwon, Song, Lee, Kim, & Park 2018)
Relationship conflict	0	0	++	++	0	0	0	(Vaux & Kirk 2018)
As referenced here	++	++	++	++	++	++	0	(T.-K. Wang, Ford, Chong, & Zhang 2018)
Process factors	0	0	++	++	0	0	0	(Lindhard & Larsen 2016)
As referenced here	++	++	++	++	++	++	0	(Agyekum-Mensah & Knight 2017)
As referenced here	++	++	++	++	++	++	0	(Caldas & Gupta 2017)
As referenced here	++	++	++	++	++	++	0	(Ansah & Sorooshian 2018)
As referenced here	++	++	++	++	++	++	0	(R. Sweis, Moarefi, Hoseini-Amiri, & Moarefi 2018)
As referenced here	++	++	++	++	++	++	0	(Adebisi, Ojo, & Alao 2018)
As referenced here	++	++	++	++	++	++	0	(Prasad, Vasugi, Venkatesan, & Bhat 2018)
Coordination challenges	0	0	++	++	0	0	0	(El-Sabek & McCabe 2018)
Out of sequence work	0	0	++	++	0	0	0	(Abotaleb & El-adaway 2018)

++=available; 00 unavailable; Te Tender; De Design; PrC Procurement; Pre construction; PoC Post construction; Opr Operation

Table 3.11

Identified CTF

CTF	Te	De	PreC	Con	ProC	PoC	Opr	Author
Project delivery misplaced priorities	0	0	++	++	0	0	0	(Razmdoost & Mills 2016)
Material logistics and crew constraints	0	0	++	++	0	0	0	(J. Liu & Lu 2018)
Lack of real-time inspection	0	0	++	++	0	0	0	(Yao et al. 2017)
Poor logistics system	0	0	++	++	0	0	0	(Niu et al. 2016)
Waste	0	0	++	++	0	0	0	(Bhatla, Pradhan, & Choi 2016)
Bid preparation uncertainty	0	0	++	++	0	0	0	(Duzkale & Lucko 2016)
Safety issues	0	0	++	++	0	0	0	(Umer, Li, Szeto, & Wong 2018)
Poor procedures	0	0	++	++	0	0	0	(Gacasan et al. 2016)Okafor2016
Poor procurement process	++	++	++	++	++	++	++	(Kwofie, Afram, & Botchway 2016)
Weak planning institutions	0	0	++	++	0	0	0	(Babatunde, Adeniyi, & Awodele 2017)
Political interference	0	0	++	++	0	0	0	(Babatunde et al. 2017)
Finanacial distress	0	0	++	++	0	0	0	(Edwards, Owusu-Manu, Baiden, Badu, & Love 2017)
Interface problem	0	++	++	++	0	0	0	(Senaratne & Ruwanpura 2016, Shen et al. 2016)
Inefficient coordination strategy	0	++	0	0	0	0	0	(Hassanain et al. 2018)
Inadequate schedule assessment	0	++	0	0	0	0	0	(M. A. Bragadin & Kähkönen 2016)
Poor front-end planning	++	++	0	0	0	0	0	(Sindhu et al. 2018)
Design error and rework	0	++	++	++	0	0	0	(Ham, Moon, Kim, & Kim 2018)
Country risk	++	++	++	++	++	++	++	(De Marco, Mangano, & Narbaev 2017)
Lack of transparency	++	++	++	++	++	0	0	(Ibem et al. 2018)

++ :available; 00 unavailable;Te Tender; De Design; PrC Procurement; Pre construction; PoC Post construction; Opr Operation

3.7.2.2.2 Initial Data collected from CSC

The initial analysis of the simulation modeling is examined using the dynamic Bayesian network. While the platform for the CTM-CTF-IM analysis is GeNIe academic and secondary data from literature is applied to formulate the model, the data collected from CSC are utilised to operationalise the simulation modeling. The item in this section presented the collected data and data inclusion criteria. The GeNIe is amongst the software tool applied for modeling and learning with BN, DBN, and influence diagrams (BayesFusion, LLC 2019). The central modeling topology in GeNIe involves nodes and links as a network and are implemented using the conditional probability table (CPT).

At the beginning of the model formulation, there was a formal discussion and consultation with four field experts, involved in different functional aspects of the road improvement project including business development, tendering and construction. The discussion was to seek their opinion on the nature of the interaction between CTM and CTF. The selection of the population sample was the limited availability that the circumstances could allow for the case: the road improvement project. The study gathered CSC projects documents, including baseline schedules and process documents, and the relevant parameters and values extracted to develop the CPT. After the initial feedback and data collection, the central state variables of the CTM-CTF simulation modeling was developed supported by the literature survey and CTF categorisation.

The type of data collected, within the context of solving the simulation model that proffered an answer to the research question **Q5** was mainly to obtain the CPT of the different phases, depicted in Table 3.13.

Table 3.13

Conditional probability table.

	$p(TE)$	$p(DE)$	$p(PrC)$	$p(ProC)p(Co)$	$p(PoC)$	$p(OR)$
Efficient	0.85	0.65	0.89	0.68	0.5	0.98
Inefficient	0.2	0.4	0.05	0.3	0.49	0.01
MayBeEfficient	0.1	0.3	0.15	0.01	0.01	0.01

The table is based on the state variables defined in Table 3.14.

Table 3.14

Main variables states

Main variables	Discrete state 1	Discrete state 2	discrete State 3
CTF	Present	Absent	
CTM	Efficient	Inefficient	MayBeEfficient
IM	Value	Value	Value
CTM Intervention	Intervene	DoNotIntervene	
CTM.Observation	Affected	Not affected	MayBeAffected

In Table 3.13, while the state variables are *Efficient*, *Inefficient* and *MayBeEfficient* on the column headers show the construction project phases, the values inside the table are the conditional probability values. The CPT is utilised for the main definitions of each state of the variables. The CTM changes from the initial state to a defined state when CTF influences it, and the number of CPT grows exponentially with the number of the parent nodes. The collected CPT parameters are varied in sensitivity analysis experiments to determine the joint probability distribution. The CTF variable has two main states, either it is present, or it is absent having a probability of 1 or 0, and there is no intermediate state. Similarly, Table 3.14 depicts the main variables and their likely states based on the conditional probabilities. Besides, the intervention can be in only two states, and the impact has a probability value that is either successful or unsuccessful.

The entire data collection is a combination of primary and secondary data informed by the pluralist paradigm and case study design adopted in this research. The method of data collection, therefore, offered the capability for reliability and validity of the data and capacity for comparative study because of the required theoretical and practical data (Bell et al. 2018, Sandrk Nukic & Huemann 2016, T. A. Williams & Shepherd 2017). The next item is the discussion of the reliability and validity of the gathered data.

3.7.2.2.3 Data reliability and validity

The gathered data is required to have the attributes of consistency of measures and an assurance that the collected data has the aptitude for portraying the intended measurement (Bell et al. 2018, Creswell & Creswell 2017, Dikko 2016, Henseler, Hubona, & Ray 2016, Moeyaert, Maggin, & Verkuilen 2016, Yin 2017). The process to extract the relevant data was based on document analysis and discussion of the extracted data with the CSC team to ensure consistencies in the extracted data. The data represented the business documents utilised by CSC over time, in relation to different phases of the project. Consequently, the data derived from the document content analysis was presented for discussion with CSC team to ensure the evidence of reality in the CSC process.

Even though secondary data has a problem of variation over a specific timeframe and ecological fallacy (Bell et al. 2018, Creswell & Creswell 2017, Plescia & De Sio 2018, Yin 2017), the gathered data is a good representation of the case within the duration of the research project. The analysis method for the collected data consists of simulation in a dynamic setting, and the conditions of parameter variation are of primary interest to the research. Simulation modeling conducts different variations of data over time to evaluate the outcomes (Zahran 2016). The structure and functions of CTM-CTF-IM relationship using DBN are explained in the next section, Section 3.7.3.

3.7.3 Research analysis

This section investigates the network architecture pivotal to the implementation of the DBN simulation modeling in the GeNIe platform. The network structure construction is initiated through the definition of structural interaction between the variables. The initial strategy tends to mitigate the impact of the factors, the observation of the impact and subsequently applied decision support to reduce the impact on construction

objectives. However, the study suggested that the intervention strategy can generate more factors that affect the resulting objective. The schematic structure of how the variables and nodes are connected, which presents the network is shown in Figure 3.10.

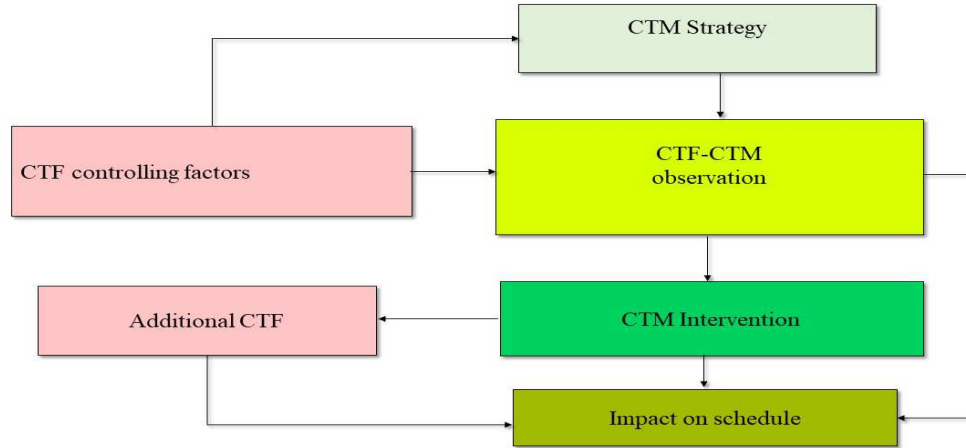


Figure 3.10. The Implementation network structure

The description of the network components is consistent with Table 3.14. The categorisation of CTM-CTF-IM interactions facilitate the creation of the network structure. The researcher chose the categorisation to enhance the development of the network structure utilised to develop the DBN. In Figure 3.10, six structural categories are suggested, and arrows applied to link the variables and generate the DBN.

The concept of CTF-CTM-IM categorisation discussed in the previous sections elucidates that CTF are linked to CTM strategy due to their direct influence during different project phases. The consequence of the influence generates a CTF-CTM interaction observation, which results in either a favourable outcome or the need for a dynamic intervention strategy. In the time domain, the interaction strategy results to further CTF-CTM-IM observation with the suggestion that the intervention strategy can subsequently yield additional CTF that affect the outcome. The dotted line is implemented to establish that intervention strategy is only effective when CTF is present and with existing inefficient CTM. Table 3.14 and Figure 3.10 are combined

to develop the DBN network implemented in GeNIe - a modelling tool for dynamic Bayesian network and influence diagram. The DBN assisted the observation of the CTF-CTM-IM nodes and predicted the probability distributions over time of the CTF influence on CTM. Concerning the implementation network structure in Figure 3.11.

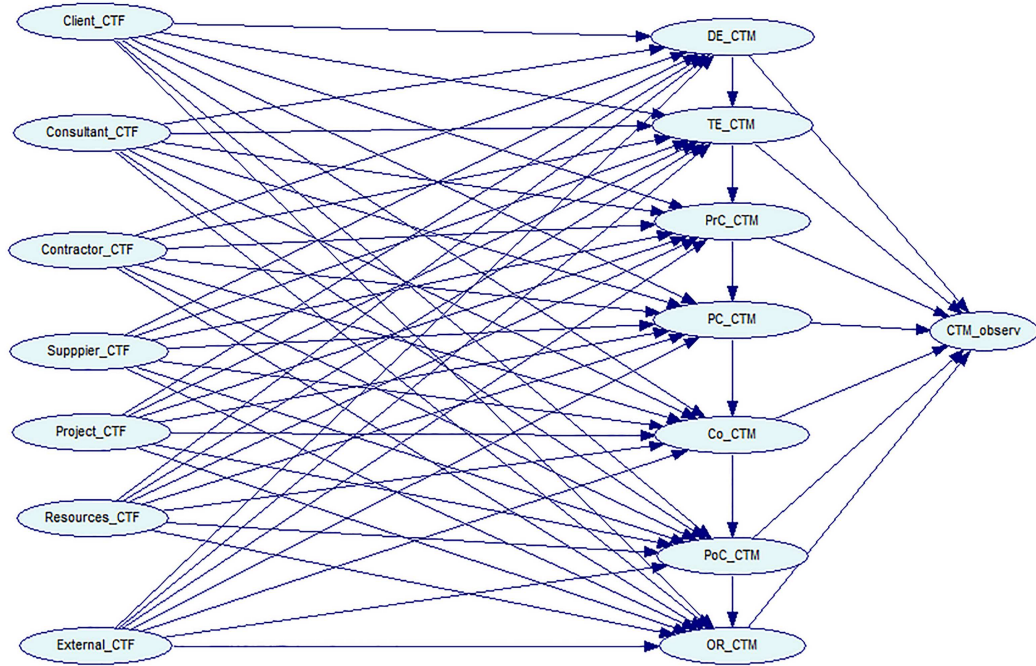


Figure 3.11. Model structure in GeNIe.

The figure shows the network topology of the interaction of CTM with CTF to generate the outcome, the *CTM_observ*. The CTF represents the factors generated from client, design, contractor, project, resources and external factors. The CTM represents the management efforts at different phases of the project. The DBN nodes are divided as depicted in Table 3.15.

The CTF hidden nodes or the CTM nodes are the values that generate the observations of influence on CTM variables. The CTF hidden state is inferred subject to the observations of CTM in the current time. Then the observations are stored in the temporal nodes and subsequently predict future observations resulting in the predicted impacts in the terminal nodes. The network structure is depicted in Figure 3.11 as implemented in the analysis software, GeNIe. One network structure identical to the

Table 3.15

DBN variable and nodes

Variables	Anchor	Temporal	Terminal	Number of Variable
CTF	++	0	0	7
CTM	0	++	0	49
IM_schedule	0	0	++	8
CTM_interv	0	++	0	7
CTM_observ	0	++	0	7

++:available; 00 unavailable

phases is employed to reduce the network structural complexity, which encloses each component nodes. The intervention strategy nodes are the decision-making node when the CTM strategy nodes are inefficient to mitigate the influences due to the CTF nodes. The IM nodes have values or parameters employed to measure the impact or outcomes and connected to the components of the temporal plate when the network is unrolled, in Figure 3.12.

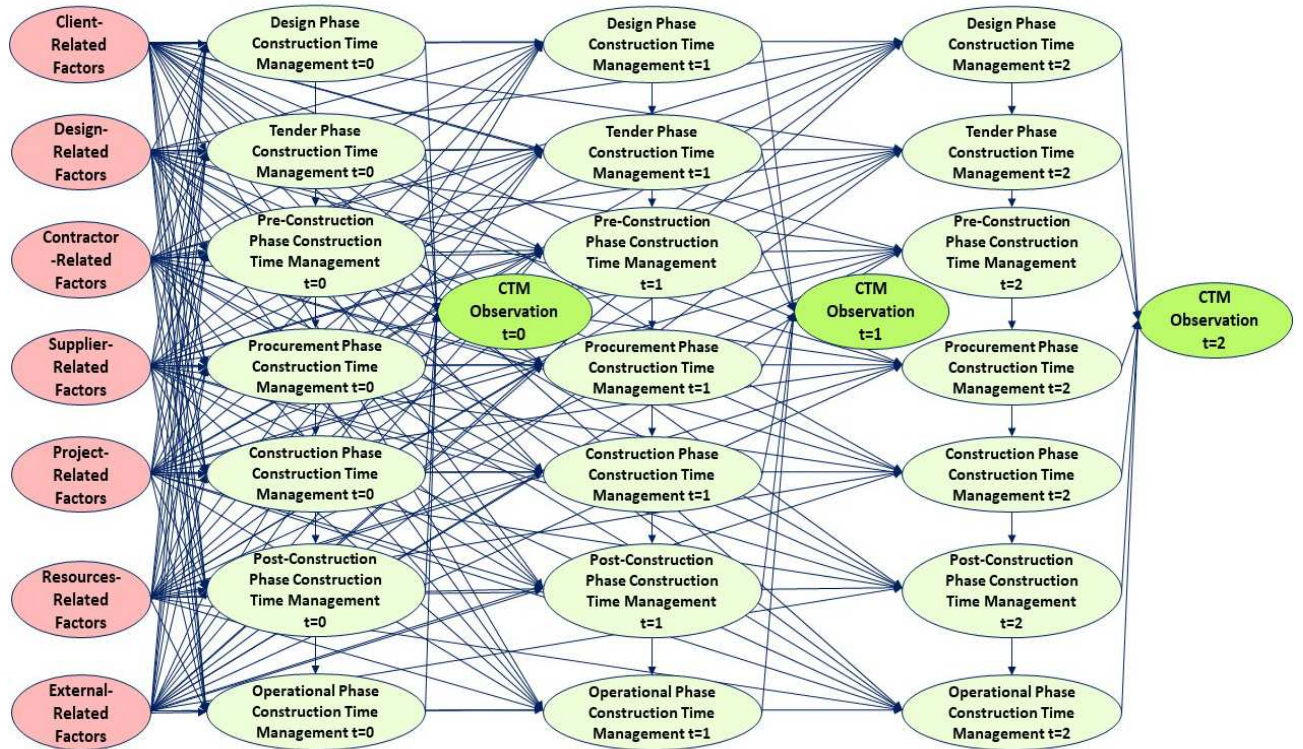


Figure 3.12. The CTF-CTM-DBN unrolled

The impacts are measured in terms of $IM_{schedule}$, and can be related to cost IM_{cost} ,

$IM_{quality}$, IM_{scope} , $IM_{function}$, IM_{safety} and IM_{profit} . The impacts are terminal nodes which are not represented in the time stamp, but future occurrence parameters due to the interaction of CTF and CTM. Each node is assigned states, and the combination of the state probabilities enumerates the expected values. The variables are assigned states to discretise the continuous variables into three states to enhance building the multi-dimensional conditional probability tables.

To generate the parameters and states values using the Figure 3.11, the CTF_n ($n = 1, 2, 3, \dots, 7$) is the parent node of CTM k ($k = 1, 2, \dots, 7$). The temporal nodes, repeated at 3-time steps, inside the temporal plate, become the aggregated parents of the IM observation node and subsequently the parent node of the impact (IM) nodes. The terminal CTF observation and impacts are not repeated in every time slice and are only for initial conditions and final conditions, respectively. In the temporal plate, the $t = 1$ time steps are the time when CTF influence begins to affect CTM strategy until the time when it is captured by the observation nodes as well as the intervention strategy. The $CTF - CTM - IM$ analysis depends on the developed dynamic network structure and the condition that the probability of the state of CTM strategy nodes is dependent on the state of CTF nodes.

Likewise, the probability of the state of the terminal variables (IM) is dependent on the state of CTM strategy and intervention strategy. In the DBN, time series data are utilised to identify and estimate the likelihood distributions of parameter across CTM nodes states $P((CTM)_t | (CTM)_{(t-1)})$, and the observations nodes states $P((CTM_{observ})_t | (CTM)_t)$ that reinvigorate the application of intervention strategy. The definition of the arcs in the temporal plate is quantified using a set of parameters conditional probability tables (CPT) of the variables' states, shown in Table 3.16.

The source of CPT data is from a survey of construction professionals utilised to define the parameters of the variable states and explore the relationships between CTF-CTM-IM nodes. Having discussed the building of CTM-CTF-IM simulation modeling, the following Section 3.7.4 explain the implementation of the simulation

Table 3.16

Conditional prior and posterior probability

Parameter name	Model parameter	Prior and posterior probability
Contemporal parameters	CTF	$p(CTF)$
Initial parameters	InitialCTM strategy	$p(CTM_1)$
Temporal parameters	CTM strategy	$(p(CTM_t Pa(CTM_1)), CTF)$
Temporal parameters	CTF_Observation	$(p(CTM_{observ} Pa(CTM_t)))$
Terminal parameters	Impact (IM)	$(p(IM_{schedule}), Pa(CTM_{observe}))$

modeling DBN.

3.7.4 Research implementation: CTM-CTF-IM DBN simulation modeling implementation

This section provides an explanation of the simulation in GeNIe. A framework (Kagioglou et al. 2001, Mbachu 2008, Yashiro 2014) is proposed to portray the relationship on how construction time management strategies can result to either effective or ineffective CTM performance, and as displayed in Figure 3.12.

The idea of the framework is to address the need for the construction industry, particularly related to time management. The primary objective of the framework is to develop the answer to the research question, Question [Q5](#). The framework was developed into three main variables of CTM, CTF and IM. The relationship can either result in the enhancement of CTM for timely completion of projects or adversely affect the CTM leading to overruns and failures in the project criteria. The significant implication of this is that a successful CTM is expected to yield positive outcomes in the performance outcomes.

The figure consists of nodes and links. The nodes are the CTF nodes: time influencing factors represented with vertical red circles at the beginning; CTM: time management at each project phase displayed with vertical light-green circles and; IM: outcome of CTM-CTF interactions illustrated with vertical green circles. The nodes are related to

Tables 3.15 and 3.16 and Figure 3.11. The lines are the links showing the relationships. Inside each node, the general states are defined with Table 3.14. Concerning DBN that investigates conditional probability distributions of the variables, the values of the states defined in Table 3.14 are the values in the conditional probability table (CPT) in Table 3.13.

Ineffective CTM accorded by CTF yields negative performance results. There is a tendency that CTF influenced CTM to yield an expected result. This is likely to be true if the effectiveness of the construction management team accepts the impact as an opportunity to create enhanced strategies to achieve success in the criteria. This research explored those possibilities using the dynamic Bayesian network, CTF categorisation, CTM relationships and conditional probability table. The intervention and impact nodes are not implemented in the dynamic structure, instead in the Bayesian network after unrolling the CTF-CTM network.

Section 3.7 has explained the methodology for the initial problem formulation that depicts CTM-CTF-IM relationship. The section investigated the relationship and answers the research question [Q5](#). The essence through the answer of the question generates decision-support system, ascertained in [Chapter 4](#), to guide construction time management.

The research identifies sources of CTF from previous studies, presents how it can be categorised to improve on the CTM performance, and developed a relationship framework between the CTF and CTM. A large number of existing CTF were identified Tables 3.7, 3.9 and 3.11 by applying a systematic review of journal articles and are categorised using construction project cycle. In addition, real data from CSC was gathered from the company project documents. The CTF categorisation is presented together with CTF-CTM-IM relationship framework using a dynamic Bayesian network (DBN). The relationship of the CTF-CTM-IM variables was examined with DBN. The outcome or the results and analysis of the initial problem formulation is surveyed in

Chapter 4.

Section 3.6 stated that the remaining elements of the research is in twofold: (1) in the initial problem formulation of influencing factors on construction time management to answer research Question **Q5** and; (2) in an in-depth research problem formulations with the multi-hybrid model to answer the remaining research questions. With respect to the two divisions and having completed the research design of the first part, the next part is Section 3.8, and is developed because of the following reasons:

- (1) the section 3.7 did not answer the entire research questions;
- (2) it draws attention for further investigation to achieve the research goals;
- (3) while it contributed to the insight of CTM-CTF-IM, it did not consider the interesting components of the system and the associated interactions in terms of the agents and entities in the system.

Regarding the itemised reasons, the next section is presented to provide an in-depth analysis geared towards accomplishing the other stated aims.

3.8 Process-based Multi-hybrid Method

The revelation by the literature review in Chapter 2, specifically Section 2.7.3.2, simulation modeling and optimisation are recognised as essential components to planning and scheduling problems, in an uncertain environment. In relation to the itemised reasons in the final paragraph of Section 3.7.4, an in-depth case study methodology is explored to provide insight on multi-method analysis and evaluation in hierarchical planning to enhance decision-making.

In that section, an insight on CTM-CTF-IM relationship in a construction system was elucidated by a dynamic Bayesian network (DBN), though it was not comprehensive to evaluate the multi-component systems of the construction project. Therefore, an exploration for further research design, research method, research analysis and research

analysis implementation of multi-hybrid methods forms this point going forward of this section and its subsections. The insight derived through the different research stages confirms that the different project conditions responsible for planning and scheduling problems are generated due to the different project conditions (Davari & Demeulemeester 2018). The solution to the issues requires a system capable of mimicking different project parameters and different conditions that map the real-world situation into a model (Mostashari 2011, Nasirzadeh et al. 2018a). In system simulation field, there are four primary systems associated with simulation modeling, namely system dynamics, discrete event simulation, discrete rate simulation and multi-agent systems (Banks 1998, Borshchev 2013b, Borshchev & Filippov 2004, Sumari, Ibrahim, Zakaria, & Ab Hamid 2013). The choice of a modeling framework in our research case is a function of the real-world situation mapping into the paradigm presented in the reference pattern.

Furthermore, the capabilities of the different simulation methods to enhance the capturing of different aspects of the research goals is a point to consider. Section 3.7 considered an initial idea of the research that investigated CTM-CTF-IM relationship exploration, analysis and implementation for different project phases. In this section, the following activities are selected as the dynamic and complex system for in-depth study:

- (1) Tender phase of the entire project;
- (2) Construction system part of the whole road improvement project and;
- (3) The project influences.

The construction is an open system consisting of different production entities (areas), each of which contains activity (production) lines, activity locations, processing times, and other associated conditions and influences. It is subject to complex constraints, such as technological constraints, operational sequence constraints, logical constraints

and resources capacity constraints. Those itemised parts not only provided the adequate case for satisfying the objectives but are selected with the research timeline towards achieving the objectives:

- (B) *To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule* partly answered and;
- (C) *To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.*

In addition to the objectives is a set of the remaining questions (Q6 to Q14) developed to achieve the objectives stated in Table 3.17, in particular:

Table 3.17

Research questions

	Research Questions
Question Q6	What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?
Question Q7	What mechanism can best integrate multi-decision support for planning and scheduling of construction projects?
Question Q8	To what extent can the model assure the flexibility to accept multiple inputs?
Question Q9	What are barriers that may be associated with the model integration, and how are they addressed?
Question Q10	How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?
Question Q11	How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?
Question Q12	What is the technique to present the model solution for application by the construction project team to improve the planning decision?
Question Q13	To what extent can the integrated planning solution aid the capability of construction project management?
Question Q14	14. How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?

Further data are gathered from the case study company (CSC) through observations, observations clarifications and discussions, informal interviews and process documents. Data analysis involved reviewing, categorising, synthesising, and interpreting the information attained from the CSC. The analysis produced themes both within

the academics' as well as across the company concerns. The idea of the research elements of this part of the study is to affirm the case study strength for providing opportunities for theoretical and practical synergy to approach planning and scheduling challenges in complex systems for the road improvement project. Accordingly, with the developed structure, and as stated in the last paragraph of Section 3.6 of the research methodology, the research elements of this section begin from research design to research implementation including research method, research analysis and implementation.

To begin the discussions and investigations in the sections that form this central section, the main section heading namely process-based multi-hybrid Method, is defined to clarify the reasons for its selection. The name is of twofold: 1) process-based and; 2) multi-hybrid. The multi-hybrid has been clarified sufficiently in previous sections and will be clarified further in the next sections because it is the central theme of the entire research.

3.8.1 Multi-hybrid method research design

The second research design of the entire research methodology comprised the design to integrate different components of the research case study, which is insufficient in the initial research design. A further in-depth investigation of integrating those components is the goal of this section including:

- (a) the examination of the BPMN part of the research that named the second part of the research methodology as process-based;
- (b) the description of the research case study concepts and ideas;
- (c) the description of the construction condition;
- (d) the presentation of the model and duration patterns, which are the references for mapping the real case into the model with duration pattern generated from CSC planning data;
- (e) the level of abstractions for guiding the selection and matching of the contract phases into the model;

- (f) the explanation of the selected platform for the multi-hybrid implementation and analysis;
- (g) the design of the simulation models, i.e. System Dynamics (SD), Discrete Event Simulation (DES), Discrete Rate Simulation (DRS), and Multi-Agent System (MAS) and;
- (h) hybrid structures, such as the combination patterns, which are the main component pivotal to the name of this section of the methodology.

To begin with, the process-based part that formed the name of this section of the methodology is discussed by its concepts and application to the research. In this research, process-based is as a result of the idea of business process modeling network (BPMN).

3.8.1.1 Business process modeling network (BPMN)

The construction system of the research case has different components. BPMN is an approach for capturing the different components and entities of the system, shown in Figure 3.13.

It is represented as a graphical model of the entire contract phases that enhanced the model development and hierarchical structure (Cimino et al. 2017, Conforto & Amaral 2016, Geiger, Harrer, Lenhard, & Wirtz 2018, Kalenkova, van der Aalst, Lomazova, & Rubin 2017, Lübke & van Lessen 2016, White 2005) for utilisation in the hybrid modeling and simulation. It is utilised to model the collaborations of different entities in the system (Chinosi & Trombetta 2012, Object Management Group 2019). The aspects of this research consist of phases, entities, components, business processes, interactions amongst the entities and modeling building, and as a result, they are suitable for application in the research. It is not the aim of the research to describe the theory of BPMN, but the interest is on setting up the framework, processes and logical interactions of the hybrid models (ABS-DES-DRS-SD) and their components, as depicted in Figure 3.14 as a sample.

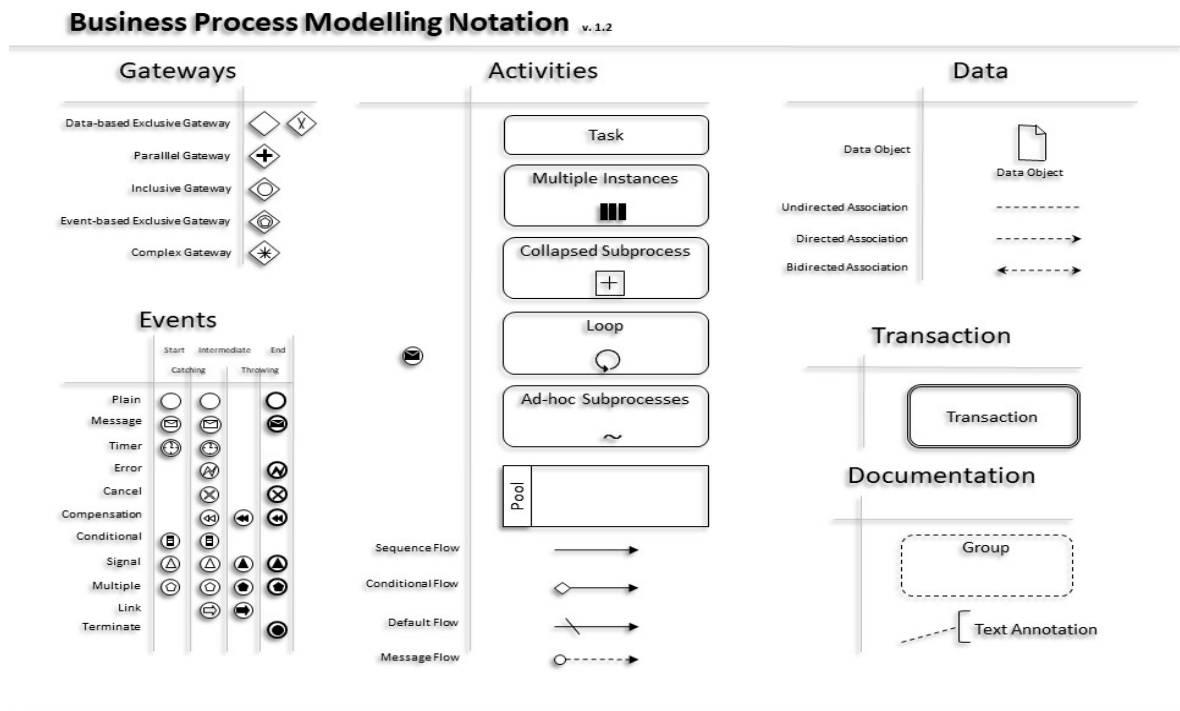


Figure 3.13. BPMN notations

3.8.2 Case problem description

The case project is a road improvement project in one of the Motorway in New Zealand spanning for 8.5 km with a budget of Hundreds of million dollars and three years duration, to improve safety and capacity. It spanned across two road interchanges on a major motorway. The road improvements comprise:

- (a) 8.5 km road work including widening of the southbound carriageway;
- (b) Widening of the northbound carriageway;
- (c) Construction of new bridges and widening of the existing bridges;
- (d) Upgrading of an interchange along the axis of the road improvements networks;
- (e) Upgrading of median shoulders and construction of concrete median barrier;
- (f) Construction of pathway;
- (g) Improvement of road lighting;

3.8.3 Construction condition description

The activities of the construction construction are different in terms of jobs required and the processing times at different construction points or machines. Although the activities of the road improvements are repetitive at various sections, they are executed at the same sequence. Each job may have varying processing times (0.5hr, 1hr, 2hrs, 3hrs, and other times.) at each activity point. The job completion at each section has a duration assigned to it. Of course, the construction completion has overall goals on the due date. When there is any insufficiency in the capacity along with the activity execution, the affected activity will be in the queue or waiting. Where the time of waiting exceeds the buffer quantity, the permissible specific duration is likely to be affected. This can be estimated as they occur, and the delayed activity increases the number of activities in future activity lists.

Some of the construction activities are distributed within site locations. The construction activities intend to increase safety and revenue for both client and contractor. The activities are sometimes disrupted and needed to be restored. Even, knowledge of the impact of disruption can be obtained earlier to enhance decision on the type of required support systems. Inability to respond to disruptions - influences - generates disruptions itself. The delay in response increases the probability of the disruptions leading to reduced productivity.

The resources system needed to respond to the disruptions consists of resources at different locations or central locations. The activities at the beginning stage have defined amount of resources capacity. The resources capacity needs to be monitored including the capacity flexibility on achieving the project as planned. A combined effect of the management influence at the tender phase, activities, resources usage and activities influences are required to determine the uncertain time durations to enhance decision supports. The research elements applied to investigate the research goals are assessed in the next section, Section 3.8.4.

3.8.4 Model and durations reference pattern

Reviewing the planned baseline schedule and system complexity, reference patterns depicted in Figure 3.15. and Figure 3.16,

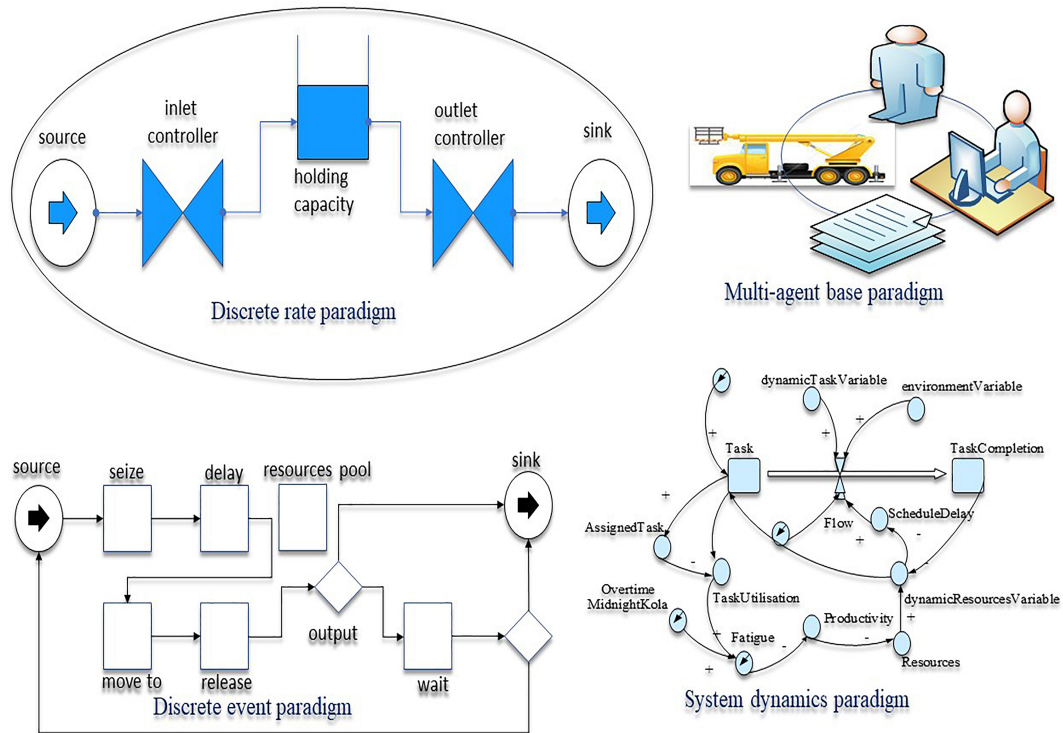


Figure 3.15. Model reference pattern

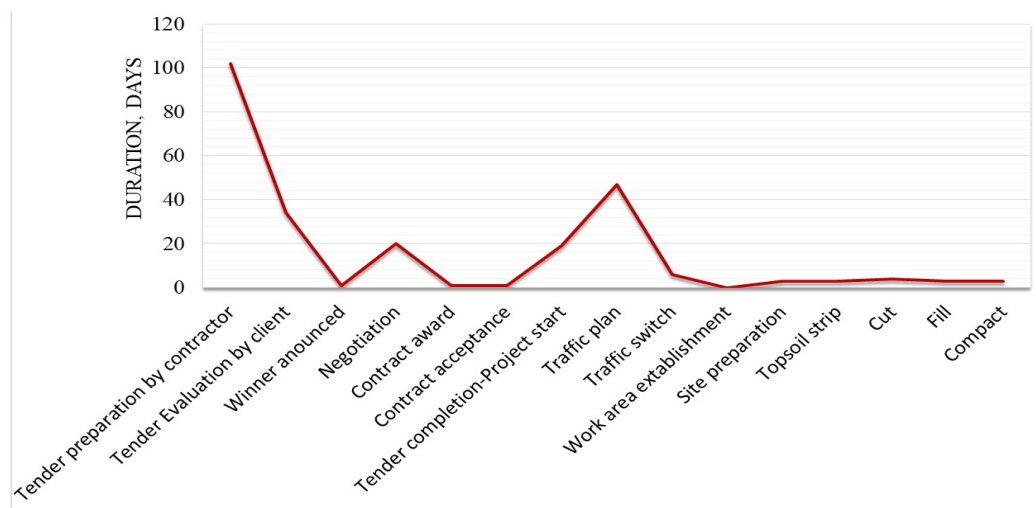


Figure 3.16. Case schedule reference pattern collected from CSC document

They are created for the tender phase and construction construction durations as well as the influences causing disruptions. The model reference pattern in Figure 3.15 is developed in the research to show the ABS-DES-DRS-SD model configuration, which guides the multi-hybrid concepts. The primary project outcome from the time, quality and cost objectives mostly investigated in this research is time. In the same vein, Figure 3.16 depicts the time reference pattern extracted from the case study company time programming. The reference patterns are developed to generate similar patterns as possible explanations to achieve and validation the research goals. The following themes are described and assessed to present the framework that determines the research design, including:

- (a) the level of abstraction namely: the nature of variables (business, economic, social) since the project environment is heterogenous and complex in nature;
- (b) platform for model development, building and verification
- (c) overview of simulation models, i.e. System Dynamics (SD), Discrete Event Simulation (DES), Discrete Rate Simulation (DRS), and Agent-based System (ABS);
- (d) hybrid structures, such as the combination patterns; and
- (e) knowledge communication and collaboration among models, e.g. 'where', 'when', 'which' and 'how'.

3.8.5 Level of abstraction

The significance of implementing dynamic changes and schedule 'what-if' scenarios motivated the proposition for simulation modeling and optimisation in this research. The choice of a simulation modeling system is dependent on the level of details designed for the model. The complexity of construction projects is caused by operational, strategic and tactical variables (Borshchev 2013b, Herroelen & Leus 2005, S. H. Lee et al. 2006). The construction plan and schedule are among the tools used for planning and controlling construction projects, and of course, it shares the same attributes.

The need to identify the level of abstraction in project planning and control is twofold:

the changing openness of the project environment, dependencies, and feedback loops in project systems which can be high or low. At each level of abstraction, a range of the variable is generated which determines the planning and control structure of the construction projects. Figure 3.17 presents the level of details or abstractions in planning and scheduling construction projects.

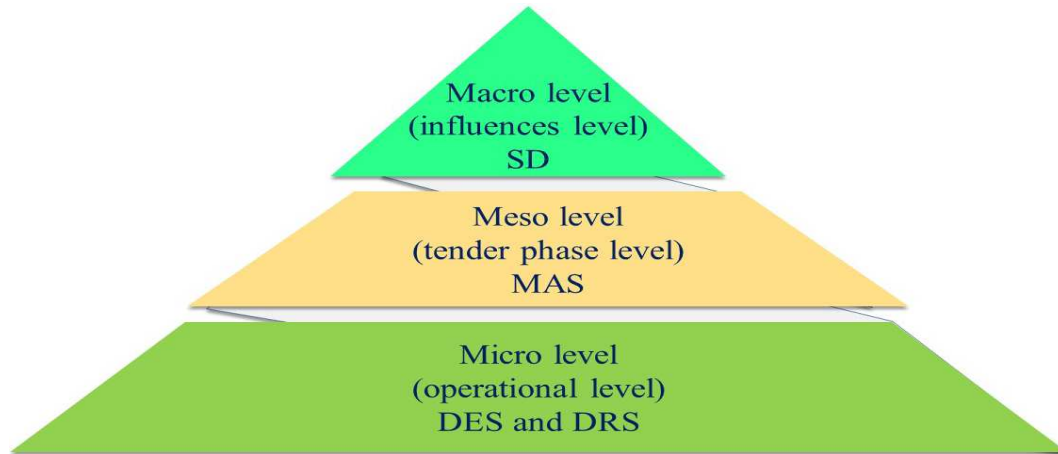


Figure 3.17. Duration reference pattern

(Borshchev 2013b, Herroelen & Leus 2005, S. H. Lee et al. 2006)

At the top of the figure, low level of details or high level of abstraction, represents accumulation, flow, causal feedback loops, influences and factors that result in the project business and strategic decisions. It is the macro level that requires the least number of details. The complexity of this level determines the level of endogenous variabilities and dependencies of the variables. The intermediate of the diagram, meso level, shows a medium level of details or intermediate level of abstraction that consists of tactical (interlinked strategic, social and operational) variables.

The micro level is a high level of details or a low level of abstraction and requires a high level of operational details. The level abstractions instructed the aspects of the hierarchical planning (Pezzulo, Rigoli, & Friston 2018) suitable for modeling each of the project phases: tender phase, construction phase and the associated influences considered in this research. The next Section discusses different model designs to facilitate the answers to the relevant research questions. Sections 3.8.6 to 3.8.9 illustrate

the design of the agent-based model, discrete-event model, discrete-rate model, and system dynamics model that formed the core of the research. The design of those sections are pivotal for providing answers to the outstanding research questions (*Q6 to Q13*) and the second research objectives.

3.8.6 Agent-based model (ABS)

The tender phase is modeled as an open space where the client, bidding company and the accompanying business and project management agents can see and talk to one another. The stakeholders' in the tender phase are considered as agents. Within one agent are other agents with formal and informal communication through message passing and message receiving in line with client and bidding company business processes. The message passing of bid proposal request from the client to bidding company initiates communication between the business units, bid department, alliance companies and project management team to work together for the evaluation and appreciation of the proposal for bid submission decision.

The research has utilised the case study process to develop the communication and discussion towards submitting the bid at the specified due date. When a message that requires action is passed, a particular duration is utilised to complete the action and send back the response. The message sending, the message receiving, action taking, and message response is represented in Figure 3.18, which is a communication diagram.

In the figure, for instance, the client sent tender or request for proposal to CSC: the bidding company. The bidding company received the proposal and sent it to the business unit manager and his team as well as the bid manager to explore the opportunities either go or no-go decision to bid. Assuming there are opportunities in the tender, the bid manager assembled his team to prepare the bid. Similarly, the CSC sent a confirmation of tender acknowledgement and interest to tender.

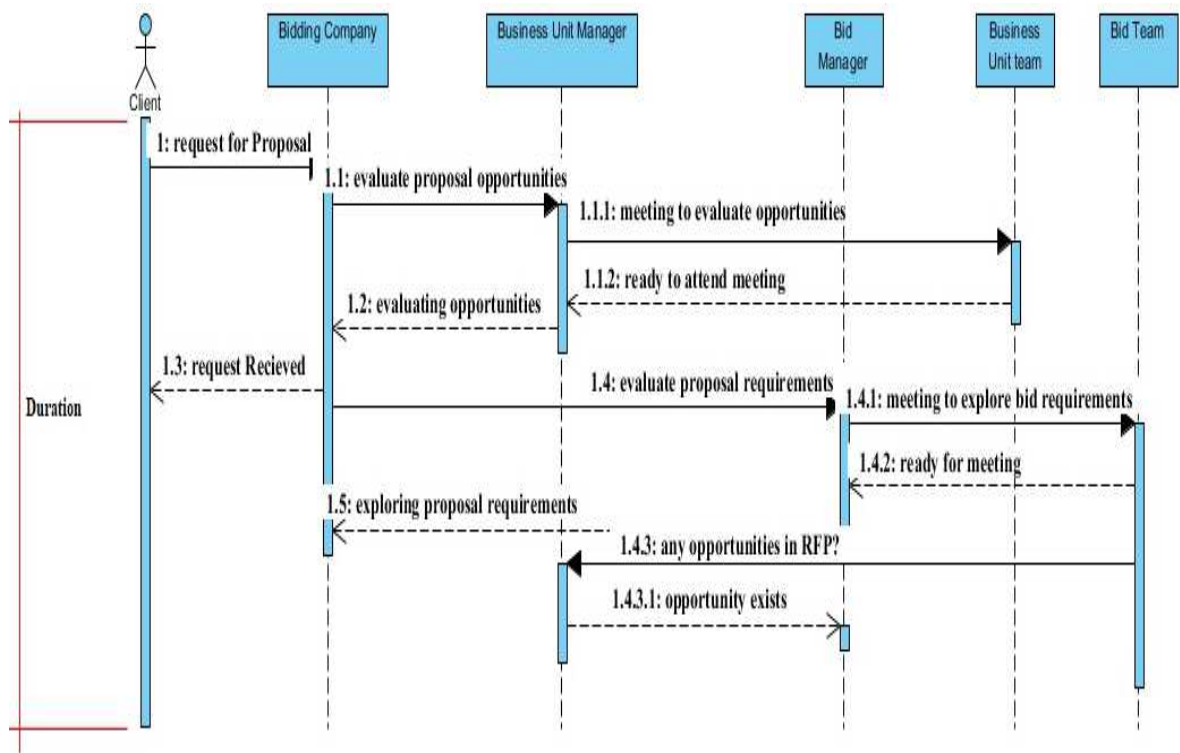


Figure 3.18. Agent based paradigm framework

A defined number of activities are required to accomplish bid requirement and submit a competitive tender. In the process, different departments make decisions and collaborations to gather the bidding requirement. The decision-making and collaborations involved time and influences from different teams working efficiently to complete the bidding package. It is central to evaluate what if conditions on the bid submission date if a particular decision-making influence affects the time in units: day and week. Consequently, the agent-based modeling (ABS) is utilised to capture the entities and components in the form of input, output and interactions in the tender phase of the contract. In this regard, the components are model as agents: sending messages, receiving messages and making time and message decisions. The representation is embedded in the business process modelling (BPMN) and extensively depicted in logical process order of the CSC similar to BPMN Figures 3.29a to 3.29e in Section 3.8.10, which are not included in this research report in line with the approved ethics agreement. The next section examines the foremost component of construction

modeling and simulation, the discrete-event simulation in Section 3.8.7.

3.8.7 Discrete-event model (DES)

The mapping of construction operation for schedule generation will be based on discrete-activity simulation algorithm that shows the flow of entity, tasks, and resources. The algorithm relies on the theory that resources are scarce and entities queue and compete for the resources (Hamzeh, Saab, Tommelein, & Ballard 2015, Larsson, Lu, Krantz, & Olofsson 2015, M. Lu 2003, Mostafa & Chileshe 2018). Discrete-event simulation is one of primary process modeling for construction operations and decision-making support (Alzraiee et al. 2015, H. Kim, Bang, Jeong, Ham, & Kim 2018, D. Li & Lu 2019, Louis & Dunston 2016, Mawlana, Vahdatikhaki, Doriani, & Hammad 2015, Pradhananga & Teizer 2015, Shawki, Kilani, & Gomaa 2015). Mapping the DES system to an approximation of a real world of the construction construction process, the DES system is defined as presented in Figure 3.19 with inputs, environments, resources, output and system boundaries.

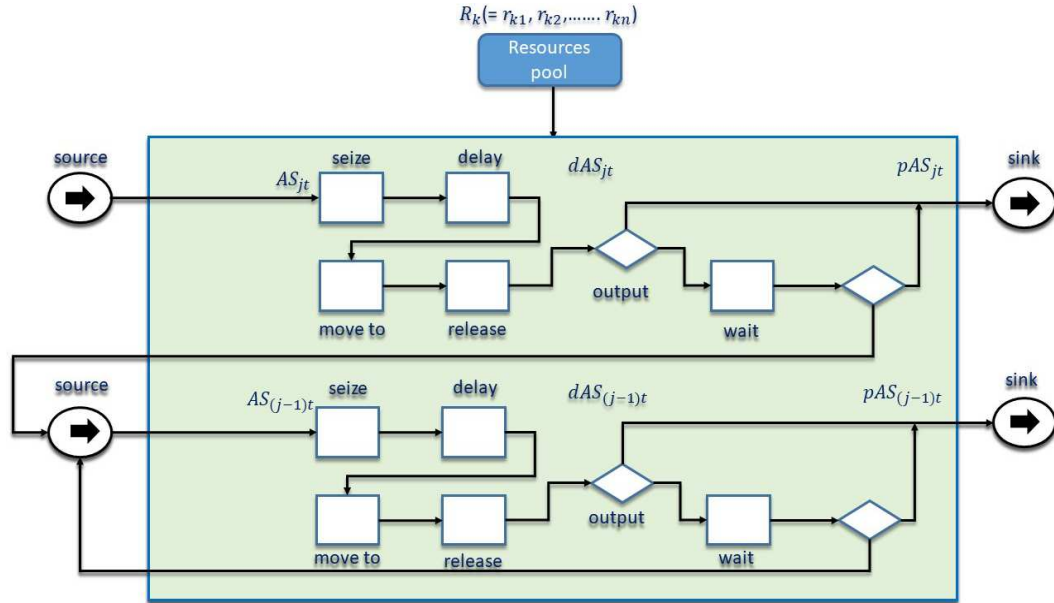


Figure 3.19. DES event system

In the development of the model, entities from the source block are injected into the

process flowcharts with several operations as blocks that require human, material and equipment resources (static, moving and portable) and exit at the sink. Because of queue theory, the due dates and release dates are stochastically simulated to arrive at the outputs. Let the construction system be represented as: $ES_{construction}$, an assumption is that the construction system remains constant between successive activities because each subsystem or process has a uniform execution. The completion of the construction activities stated in the problem description comprises subsystem or work clusters including: $S_{cleargrub}$, $S_{soilstrip}$, S_{cut} , $S_{undercut}$, S_{fill} , $S_{compact}$. The subsystems represent the states of the construction system, and completion of each activity involves the activities execution from the initial state to final state within each subsystem activities, and a jump from one state to another state successively. Within the subsystem, for instance clear grub, each activity $AS_{cleargrub,j}$, for $j = 1, 2, \dots, n$ occurs at a certain time $AS_{cleargrub,jt}$ with a processing time $pAS_{cleargrub,jt}$. The time between the arrival of $AS_{cleargrub,j}$ and $AS_{cleargrub,j-1}$ is A_{jt} . However each activity has a possibility of delay $dAS_{cleargrub,jt}$. Each activity has a particular completion time or duration, $cAS_{cleargrub,j}$, illustrated in Figure 3.20,

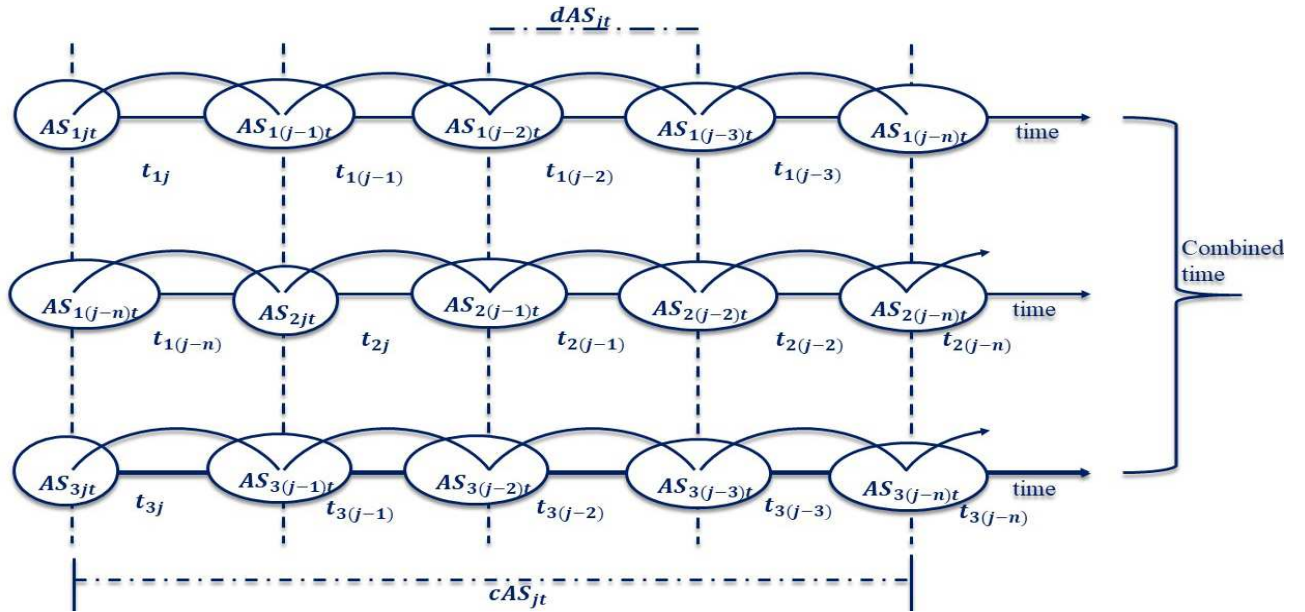


Figure 3.20. Activity queue logic

The equation structure depicted in Figure 3.21.

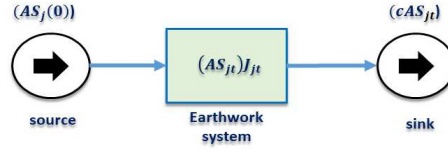


Figure 3.21. Formulated equation structure of the system

and is set out for each subsystem in Equation 3.7:

$$cAS_{jt} = AS_{jt} + pAS_{jt} + dAS_{jt} \quad (3.7)$$

Given Figures 3.19 and 3.21 as well as setting $AS_{cleargrub,j0} = 0$, the system and subsystem process can be represented in Equation 3.8:

$$AS_j(0) + \sum_{j=1}^{\infty} (AS_{jt})J_{jt} = cAS_{jt} \quad (3.8)$$

Irrespective of the positive and successive activities, construction system completion can be executed in a combination of series and parallel links because construction activities are repetitive, as shown in Figure 3.22. For instance, while a truck is loaded with excavated materials and drives off, the excavator continues the excavation process. However, one activity finishes before another begins. What is implemented is the possibilities of adding more equipment to complete a job on time, still the same activity process. The sequential representation of activities transformation concerning time, t , for completing the activities are formulated in Equation 3.9, which is dependent on Figure 3.21.

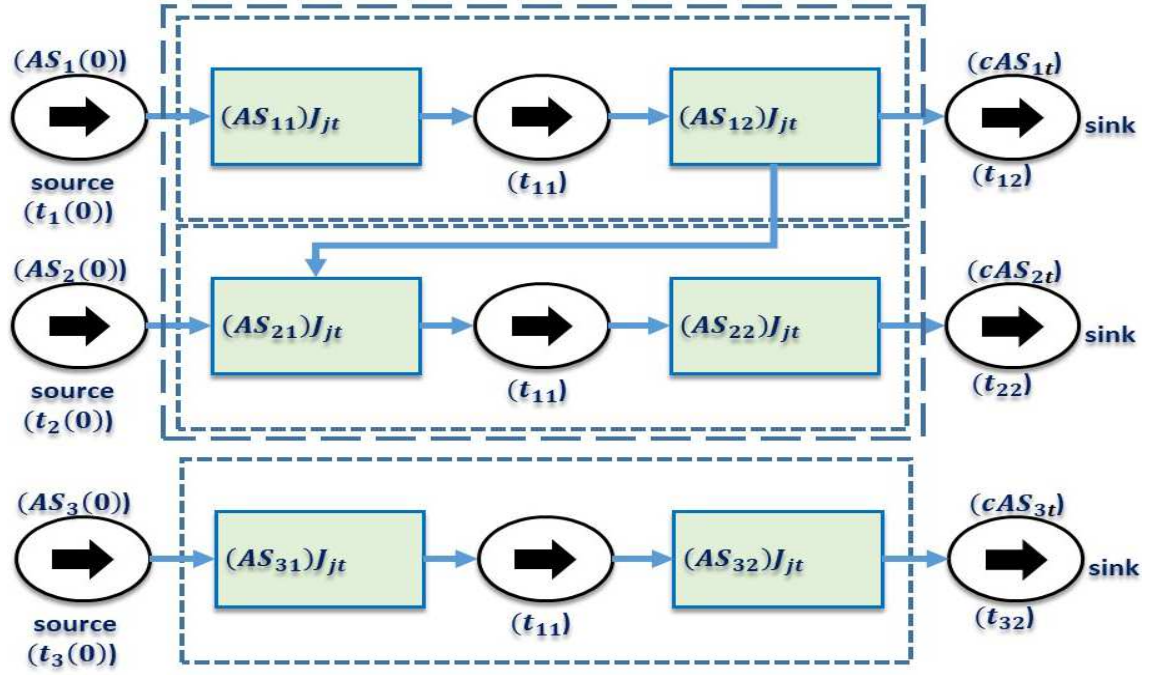


Figure 3.22. Formulated equation of the system

$$\begin{aligned}
 AS_1(0) + (t_{11}) + t_{12} &= cAS_{1t} \\
 AS_2(0) + (t_{21}) + t_{22} &= cAS_{2t} \\
 AS_3(0) + (t_{31}) + t_{32} &= cAS_{3t} \\
 &\vdots \\
 AS_j(0) + (t_{j1}) + t_{j2} &= cAS_{jt}
 \end{aligned} \tag{3.9}$$

In general, the discrete-event simulation (DES) embodies the modeling and simulation of the activities sequence in the construction operations. On the other hand, notwithstanding the proficiency of DES to model construction operations, there are aspects of the construction process operations that consist of material flow in and out of the construction system, requiring control as well. The side of the construction process section: the bulk flow of excavated and bulk filling materials that are not modeled by DES because of the assumption of no system change is the main focus of the next section, Section 3.8.8: the discrete-rate simulation (DRS).

3.8.8 Discrete-rate model (DRS)

In DES for the construction system, the assumption is that there is no change in the system. In the part of the system activities, there is the bulk flow of excavated materials, loading of trucks with excavated materials, filling the excavated locations with bulk filling materials. Those parts of system activities are modeled with the discrete-rate simulation (DRS). Discrete-rate simulation is employed to model the logical operations of the linear continuous bulk flow of excavated and filling material in the construction operations (Damiron & Krah1 2014, Shan, Luo, Wu, Li, & Shen 2015).

The activities in DRS comprise the flow of distinct and homogeneous bulk materials. In the model, there are intervals from the start of the flow of bulk materials and the end of the flow of the bulk materials of defined capacity (Shan et al. 2015). The bulk flow of materials is implemented during excavation, soil stripping, and loading trucks with the excavated materials and filling. For example, in the filling of materials, time is spent for the filling and the volume of the filling changes from time equals zero to the time of completion of the activities. Therefore, there is a change in the filling locations process between time intervals. In consideration of the construction part of the road improvements, shown in Figure 3.23, the areas with green sections depicts locations of the construction activities.

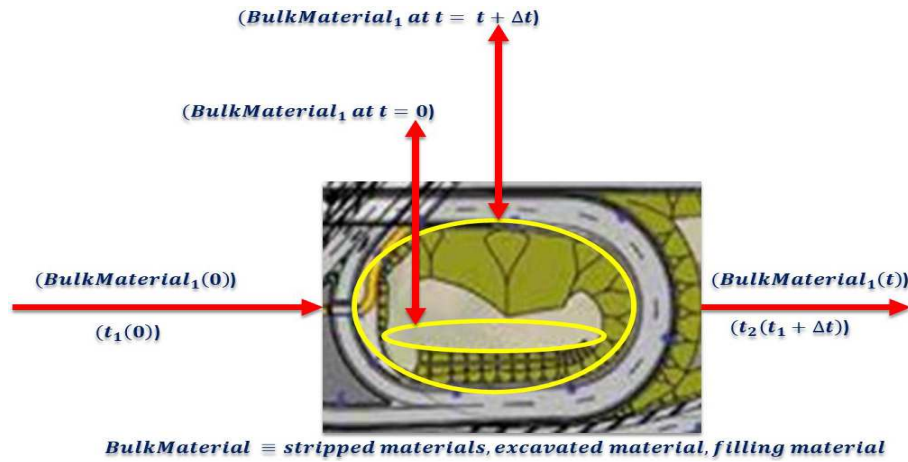


Figure 3.23. Formulated equation of the system using ramp area

The assumption here is the system is static even when there is a change in the physical system volume from one point to another. This is within the cutting or filling volume and defined spatial coordinates of the construction activity. The DRS will be integrated into the DES process in the simulation, and the presentation of the DRS model idea is formulated because of the following discussions. A section of the area (the ramp area) is selected as a control volume that requires either soil stripping, excavation, or filling in the spatial space. There is a linear change in the volume within the y and x spatial coordinates, and the change in system volume changes along with time. The time is the interval utilised in either excavation, stripping or filling process, shown in Figure 3.24.

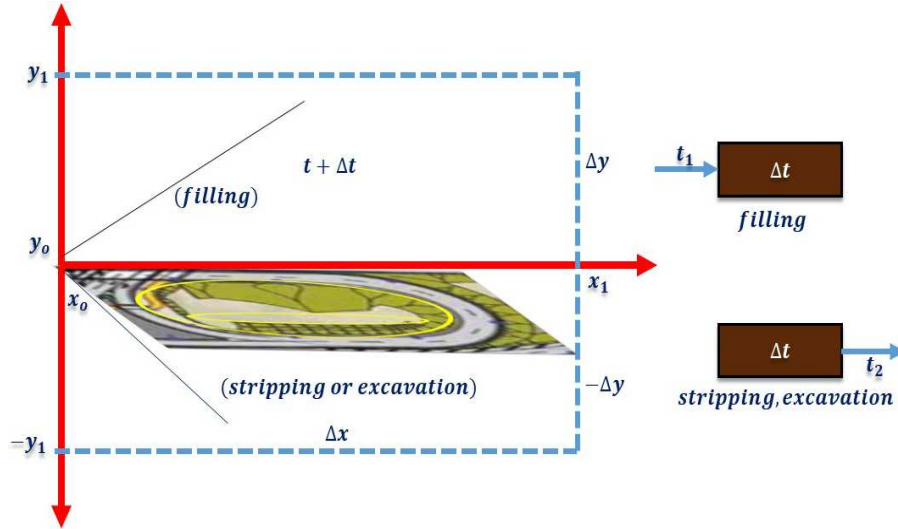


Figure 3.24. System volume variations

Since in discrete rate equation we are dealing with the flow, then with law conservation of mass can be formulated with Figures 3.24 and 3.25 and Equation 3.10.

$$\begin{aligned}
 & \text{Filling : } volume_{out} = 0 \\
 & \text{Stripping/Excavation : } volume_{in} = 0 \\
 & t = \Delta t
 \end{aligned} \tag{3.10}$$



Figure 3.25. Formulated volume conservation equation of the system

Having defined the tender phase and construction phase aspects of the construction project contract, the discussion on the modeling of the influences on those phases is the main point of Section 3.8.9.

3.8.9 System dynamics model

The system dynamic equation proceeds from the law of mass and energy conservation (Azar 2012, Borshchev & Filippov 2004, Han et al. 2013, Shepherd 2014, Sterman 1992, 2000). The law forms the support for the elemental mathematics adapted to formulate the model (Borshchev 2013b, Han et al. 2013, Richardson 2013, Sterman 2000). The prototype predicts the influence on the construction system and resultantly effects on the schedule. There is a range of influences on the construction and bidding phase system; however, the researcher considered a couple of the influences, namely precipitation, access egress and management influences. In the model formulations, the assumption is that there is no variation for spatial coordinates, and the parameter in consideration has no derivative to time as well as being deterministic (Abotaleb & El-adaway 2018, Alvanchi et al. 2011b, Han et al. 2013, Sterman 2000).

In that regard, the model is represented by nonlinear algebraic equations (Alvanchi et al. 2011b, Borshchev 2013b, Han et al. 2013). In the precipitation influence model, system dynamics and agent-based approaches are integrated. The groundwater level through rainfall affects the excavation and compaction processes.

The rainfall is a function of when it is either raining or not raining, each maintaining a

specific number of flow with a distribution between 0 and 1. The raining process in an influence agent is in turn modeled with system dynamics where the rate of excavation and compaction is controlled by the water accumulation and evaporation behaviour. The SD integrates the interface between the raining or not raining agents and the dynamics of the flow on the excavation and compaction activities.

The SD model depicts the rain flow rate causing the accumulation of water that reduces the productivity of construction equipment on the condition that if evaporation of water from the soil is high, productivity can improve irrespective of rain flow. The effects on construction processes are investigated using system dynamics, and the attributes of either raining or not raining are investigated using agent-based, depicted in Figure 3.26.

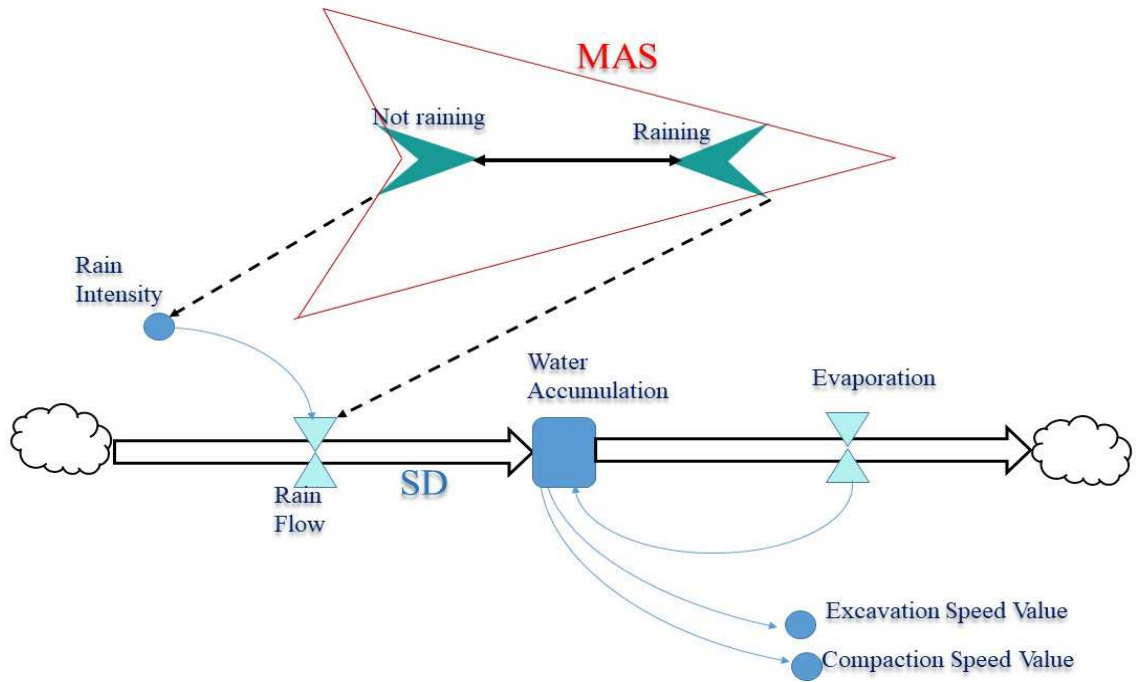


Figure 3.26. Precipitation influence model

Mathematically, the model is a combination of algebraic Equations (3.11) to (3.14), and rain intensity described as a triangular distribution:

$$\frac{d(\text{water Accumulation})}{dt} = f(\text{rain flow}, \text{evaporation}) \quad (3.11)$$

$$f(Rainflow) = itsRaining * rainIntensity/60 \quad (3.12)$$

$$f(evaporation) = waterAccumulation \quad (3.13)$$

$$\begin{aligned} f(excavation\ speed\ value, compaction\ speed\ value) = \\ main.precipitationInfExperiment ? (waterAccumulation < 50 ? 1 \\ ?(waterAccumulation > 1000 ? main.precipitationEffect \\ ?((main.precipitationEffect - 1) * waterAccumulation / \\ 950) + (1 - 50 * (main.precipitationEffect - 1)/950)))? 1 \\ send("CompanyInterest", this); \end{aligned} \quad (3.14)$$

The design of the individual model has been discussed so far, and despite those discussions, the models are yet to illustrate how they have answered the remaining posed questions in this research. Moving on to consider the answers to those questions, the central theme of the combined models is examined in Section 3.8.10 to present the integration framework of the multi-hybrid models.

3.8.10 ABS-DES-DRS-SD integration framework

The interaction of different model approach depends on the paradigm communication channel and association interfaces. The communication structure of the integrated model and multi-method framework is shown in Figure 3.27.

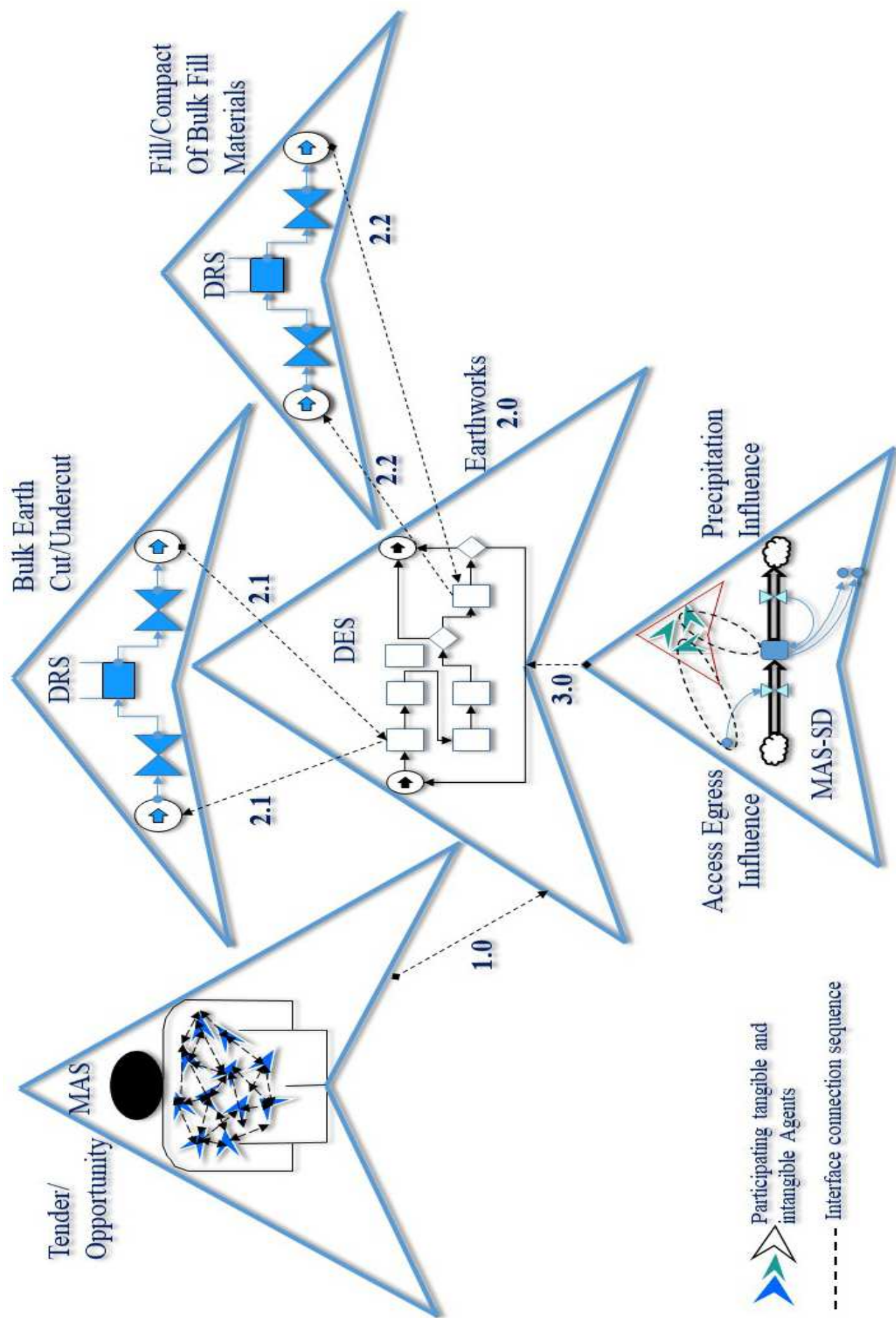


Figure 3.27. Multi-method paradigm framework

The figure illustrates the components and the framework of the multi-hybrid method of agent-based simulation (ABS), discrete-event simulation (DES), discrete-rate simulation (DRS), and system dynamics (SD). In Figure 3.27, the shapes of the four-sided representation are the agents. In this regard, the tender opportunity is an agent and inside it is other autonomous sub-agents including client, CSC, business unit manager and team, bid manager and team and alliances, construction manager and team, and project manager and team. Inside the sub-agents are sub-sub-agents, for instance, bid management team collaborating and interacting with the bid manager. One direction arrow line, (1.0), connects the DES from ABS.

The directional interactions demonstrated that the construction operations commence after the tendering/bidding and contract award. In addition, it depicts that the outcomes and deliverables of the tendering/bidding phase are the inputs to the construction phase. At the centre of the entire framework is the discrete-event model (DES), (2.0); accordingly, it is the heart of the multi-hybrid aggregation. The DES is an agent, accomplishing the process and activity-based operations of the construction part of the construction project contract. Inside the DES agent is the process-centric structure of the constructions activities. Given the discussion orchestrating the application of DRS as discussed in Section 3.8.8, some activities of the construction operations, for example, bulk excavation and filling, are executed within DES using discrete-rate simulation (DRS), which is an agent. The arrow line, (2.1 and 2.2), connecting the DES and DRS are in both directions.

At this stage of the framework, the main phases: tender and construction phases consider in this research are completely illustrated. The next element of the framework is the influences affecting the construction, illustrated using the system dynamics model (SD). The influences are the agents affecting construction activities. Inside the SD is another ABS in interaction with SD in precipitation influences. The arrow line, (3.0), connecting the DES and SD is in one direction. Correspondingly, the influences are as discussed in Section 3.8.2. The multi-method tree illustrating the simple communication

of the model's communications and collaboration with Figure 3.27, is shown in Figure 3.28.

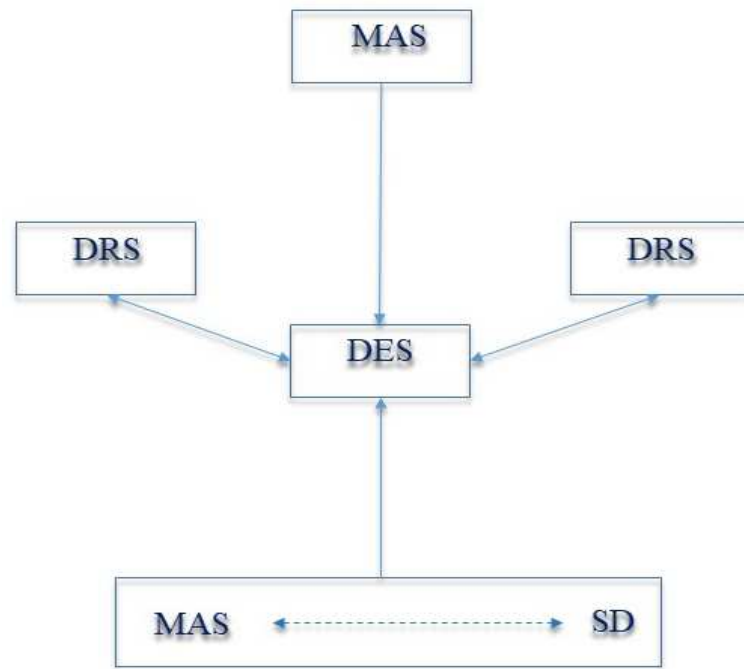


Figure 3.28. Multi-method Tree

In relations to the interactions and collaborations, many channels are likely to exist; however, the research will apply two-way communication protocol in DES and DRS; one-way communication protocol in ABS and DES; one-way communication protocol in SD and ABS; and one-way communication protocol in MAS-SD and DES. Business process modelling network (BPMN) is utilised to integrate the models and agents communications, collaborations and contract executions, which enhanced framework development. The construction section of the road improvements processes is developed in DES and DRS models and can be represented in Section 3.8.2.

In the construction process, the BPMN is divided into sections in Figures 3.29a to 3.29e.

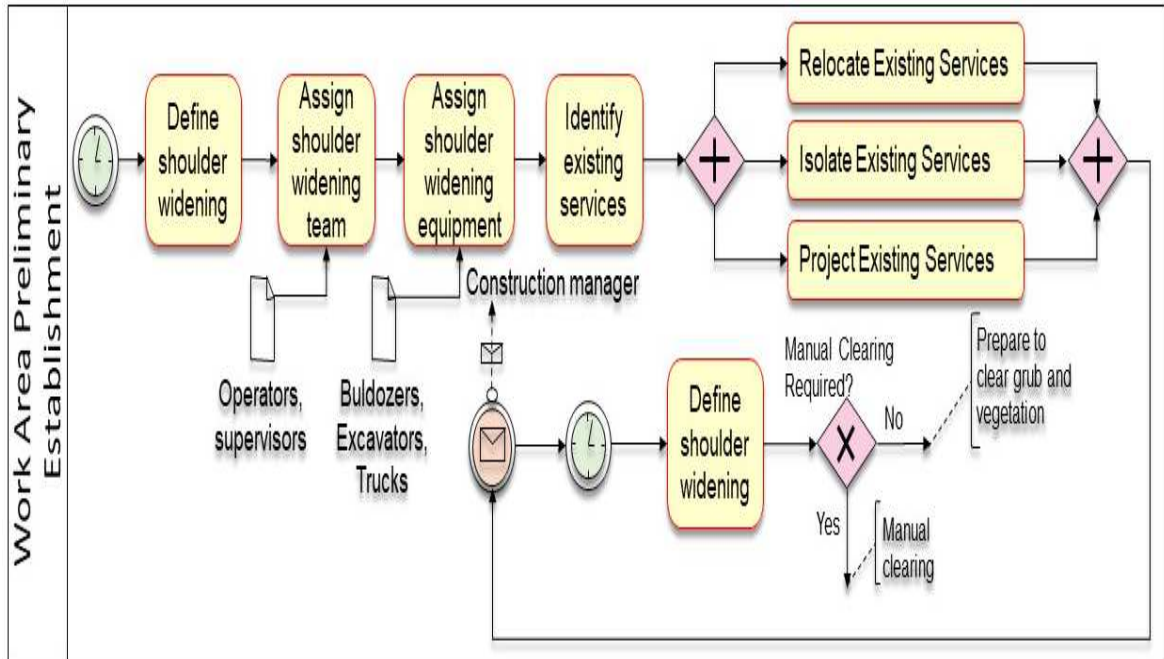


Figure 3.29a. Construction work area establishment

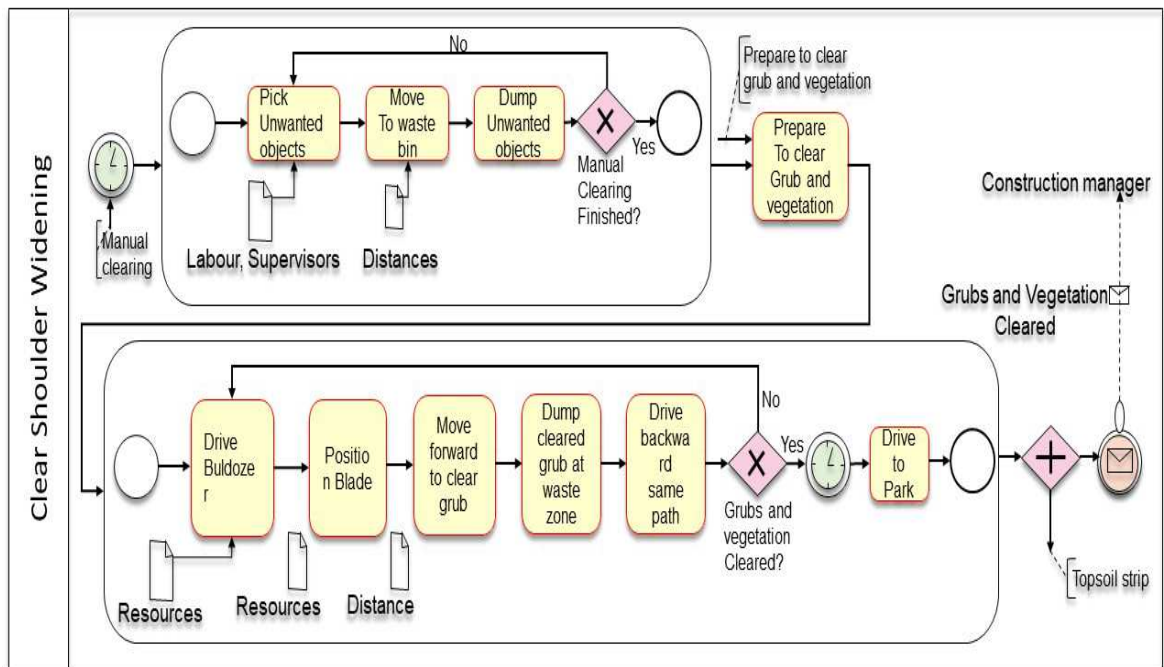


Figure 3.29b. Clear Shoulder Widening

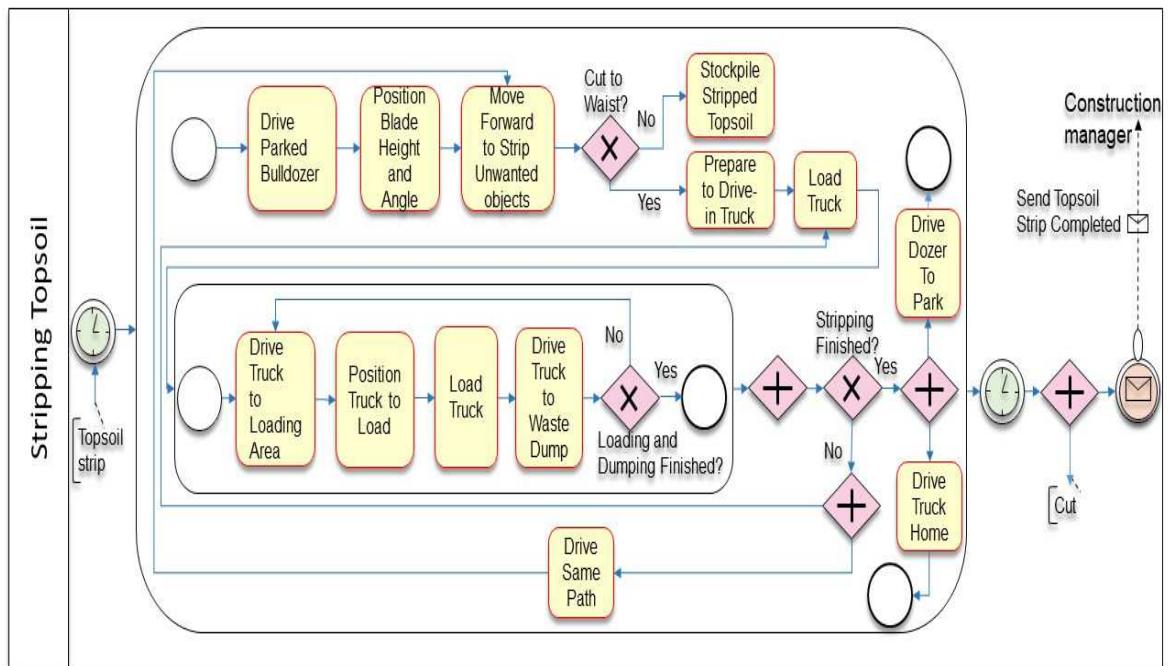


Figure 3.29c. Stripping Topsoil

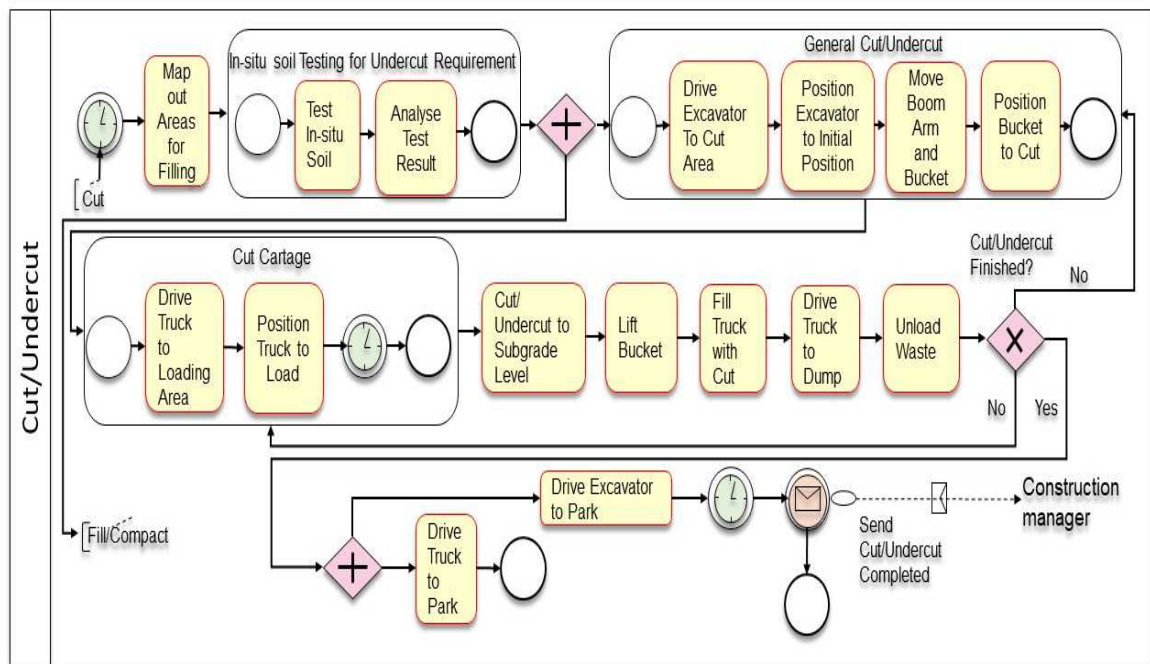


Figure 3.29d. Cut and Undercut

Those construction processes are developed by utilising the concepts and ideas presented in the BPMN descriptions. The first integration is at the excavation stage and filling stage. For instance, in the DRS and DES combination framework, DES is the dominant model in the combination given its utilisation to model a large part of the construction events. DRS is utilised to model the bulk flow of materials. The framework is selected to the level of abstractions presented in Figure 3.17. DES is used as the core simulation because it is the sufficiently established approach of construction simulations (H. Liu et al. 2015) based on its process-centric capability. However, before proceeding to the next section, the research questions that are answered by the process-based multi-hybrid method are examined.

In a joint association of different types of known simulation paradigm, this research has developed a new concept of hybrid models centred on the system behaviour and attributes of each activity in the road improvements. This is most notably the tender phase and construction phase and some of the associated influences. Each model captured individual constituents of the construction project systems. In that case, the ABS embraces the tender phase with its components modeled as agents, sub-agents and sub-sub-agents. In the same idea, the DES included the construction operations in terms of constant discrete activities. DRS models the linear constituents of discrete activities, which the DES is deficient in proficiency. Taking into account the literature analysis of this research, the ABS, DES and DRS are not recommended modeling tools for variabilities, changes and influences. SD is a modeling method for evaluating the influences and construction system dynamics. Interestingly, the different methods offered the revelations of the answers to the posed research question *Q6*, asking:

What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?

In addition is the research question *Q8*, asking:

8. To what extent can the model assure the flexibility to accept multiple

inputs?

The *Q8* enhanced the answer to research question *Q7*, asking:

What mechanism can best integrate multi-decision support for planning and scheduling of construction projects?

This is based on the supporting goal of the research to test the functionality of the combined models, by applying real-world construction section of the improvement project and its contract tendering/bidding phase, which included some of the influences during those phases of the project. As a result, a multi-hybrid model framework is developed, which is the core of the remaining in-depth analysis and solutions to the entire research problems.

Before proceeding to the analyses of the multi-hybrid research method, it is vital to present the modeling platform to strengthen the application and implementation of the multi-hybrid models' framework. Consequently, Section 3.8.11 puts forward the platform.

3.8.11 Platform for model development, building and verification

A multi-hybrid framework, pivotal to the answers to the raised research questions, is developed, but another major challenge different from the integration of the models is the platform to derive the potential benefits of the hybrids of models. The developed framework and models are utilised to construct a simulation environment for system verification. **AnyLogic©** (The AnyLogic Company 2018) is the simulation platform for modeling the multi-paradigm. The implementation of AnyLogic software proffers solutions for the problem of multi-method modeling. The choice for the AnyLogic is

based on the levels of abstractions and the theory of hybrid model system, namely ABS, DES, DRS, SD, simulation and optimisation which are the underlying principles, theory and analysis of the research.

The analysis includes utilising the framework in the Anylogic software, simulation and experiments to validate the model, and analysis on the influence of good and bad management on tender phase. Furthermore, it comprises access egress influence on the system, groundwater influence analysis, sensitivity analysis ("what if") on construction equipment and system optimisation ("what best"). The ideas in the framework and model formulations are dependent on the analysis tool, the AnyLogic software invented by the AnyLogic Company. The choice of the selected platform is dependent on the research design of this phase of methodology that combined agent-based simulation, discrete-event simulation, discrete- rate simulation and system dynamics.

Another challenge is how to implement the framework in AnyLogic, and in that case, there is a part answer to the research question *Q9*, asking:

9. What are barriers that may be associated with the model integration, and how are they addressed?

Given the demonstrated models designs, the next Section 3.8.12 discusses the research method uniquely developed as part of the research elements of this part of the methodology.

3.8.12 Multi-hybrid models research method

Another challenge to the analysis and implementation of the multi-hybrid model is the gathering of multi-input data into a framework to enhance modeling and simulation. The research framework, so far, has shown the aptness to employ multi-input data because the construction project system is a multi-component system. Similar to the initial research formulation and data collection, while the unit analysis and data collected for the multi-hybrid investigation are discussed, the data collection

instruments, inclusion criteria and data reliability and validity approach are consistent with Section 3.7.2. The data are gathered to enhance the implementation of the model analysis for the hybrid model simulation, verification, validation and optimisation.

3.8.12.1 Multi-hybrid model unit of analysis

The construction project system for generating plan and schedule spreads across construction project phases (CP), and this part of research evaluated the tender phase and construction phase centred on time, cost and quality of stakeholders' objectives (SO) influenced by the stated factors (CTF). The research selected 2 CP, 1 SO and 3 CTF to enhance sufficient details on the dynamics of the construction system. The selections resulted in an embedded case study of 1 context, 1 case and six units of analysis, shown in Figure 3.30, with the units of analysis interrelated and overlapping one another.

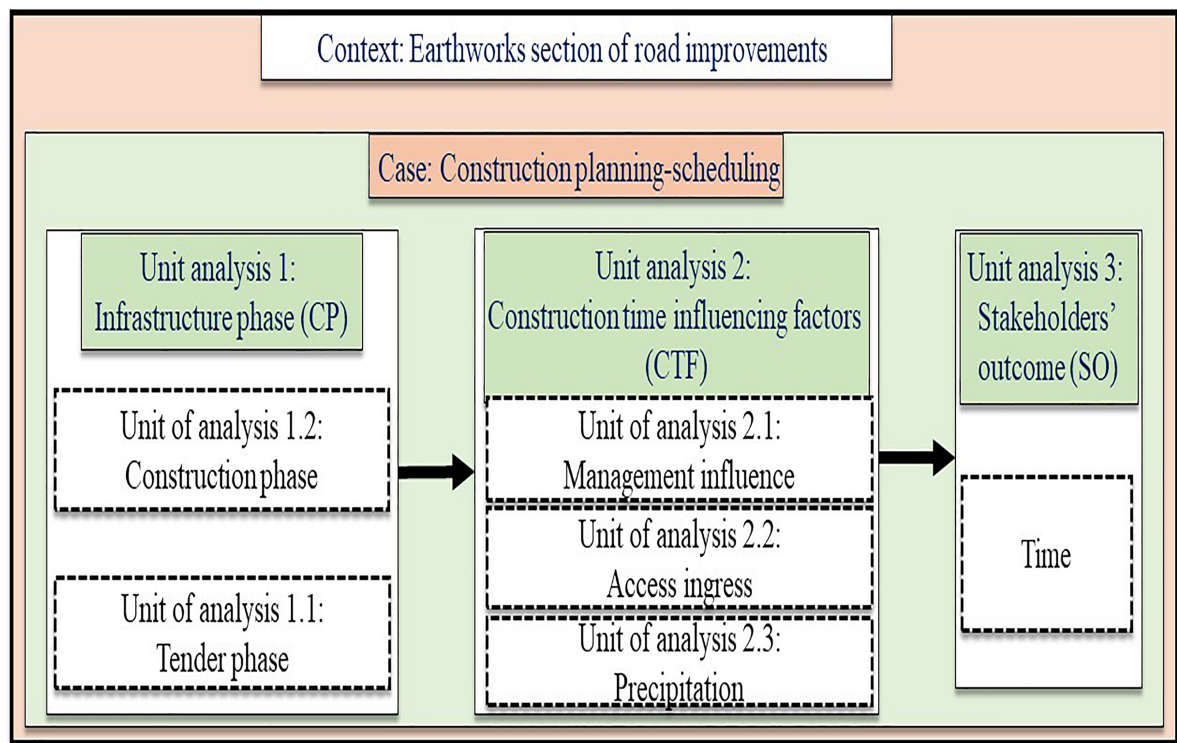


Figure 3.30. Embedded case study unit of analysis

In the figure, the case is an instance of the context, and the units of analysis are the instances of the case, which generate the embedded case study (Yin 2017). Each context is to be applied in one location. In this research, 33 different work locations (work clusters) are identified, which means that the research case study is multiple-case-in-one-case.

3.8.12.2 Method of data collection

There are different methods for data collection selected because of the units of analysis applied in the case study. The embedded case study was conducted per the agreement between the AUT and the CSC. In the collaboration framework, the research project guaranteed confidentiality of project information used in the development of the study. Accordingly, the researcher was formally introduced at the project office of the CSC and subsequently enrolled in HSE inductions and training.

The researcher had access to the construction site, project team, databases and documents. Informal interviews were conducted to obtain a good understanding of the tender phase, construction processes and related influences. The interviews, project reports, data from company databases, organisational process documents and observations are triangulated and formed the primary sources of data utilised in the simulation modelling and optimisation. The method of data collection was in congruence with the explanatory nature of the case study. Due to the number of units of analysis, the diversity within the one case study was accomplished by the selection of project team members in different roles and experience of the road improvement project at CSC.

3.8.12.3 Data collection

The data collection for the case study spanned between November 2017 and August 2018. The data sources are mainly from the informal interview, observations, company

and project documents as well as discussions. During the commencement of the case study, the scope tended to be comprehensive. Initially, the research aimed to develop a simulation model to evaluate and investigate multi-objective project planning and scheduling, including cost and quality. The goal was not achieved; instead, the researcher and the supervisors agreed to focus on a specific objective. The available data at the launching of the case study, and the research timeline, together with the levels of abstractions required determined the extent of the research. Some of the data extracted for building the model is shown in appendix 1. The data consists of area chainages, x-coordinates and y-coordinates of the chainages, chainages depths distributions, and chainages volumes distributions.

The groundwater table was calculated based on the wet weather calendar data from CSC. The data collected is prepared for groundwater modeling is tabulated in Appendix 1.

The precipitation agent in the model has a statechart that defines the duration of rain and dry weather. The wet calendar is not utilised directly, instead a data analysis. The calculation of distribution for the duration that the rain persist is in Equations (3.15a) to (3.15h).

$$Rainfallperiod = \sum_{t=1}^{4002} t = 12.5days \quad (3.15a)$$

$$Amountofrainfall = \sum_{n=1}^{4002} n = 11891.87mm \quad (3.15b)$$

$$Averagerainfallperyear = \frac{amountofrainfall}{rainfallperiod} = 951.1mmperyear \quad (3.15c)$$

Number of times with rain, the average number of times with rain, maximum number of times with rain, and a minimum number of times with rain:

$$Numberoftimeswithrainfall = COUNTIF(A4 : A40002, "> 0") \quad (3.15d)$$

$$Totalperiodofrainfall = SUMIF(A4 : A40002, " > 0", B4 : B40002) \quad (3.15e)$$

$$AveragerainTime(min) = \frac{SUMIF(A4 : A40002, " > 0", B4 : B40002)}{COUNTIF(A4 : A40002, " > 0")} = 20.1 \quad (3.15f)$$

$$Averageraintime(min) = 202 \quad (3.15g)$$

$$Averageraintime(min) = 0.1 \quad (3.15h)$$

Therefore, rain lasts for *triangular*(0.1, 202, 20.1) minutes.

The dry weather lasted for *triangular*(0.1, 34561, 515) minutes, using Equations (3.16) to (3.20). The equations illustrate the number of times with no rain, average number of times with no rain, maximum number of times with no rain, and minimum number of times with no rain:

$$Numberoftimeswithnorainfall = COUNTIF(A4 : A40002, " = 0") \quad (3.16)$$

$$Totalperiodofnorainfall = SUMIF(A4 : A40002, " = 0", B4 : B40002) \quad (3.17)$$

$$Averagenoraintime(min) = \frac{SUMIF(A4 : A40002, " = 0", B4 : B40002)}{COUNTIF(A4 : A40002, " = 0")} = 515.5 \quad (3.18)$$

$$Maximumnoraintime(min) = 34561 \quad (3.19)$$

$$Averagenoraintime(min) = 0.1 \quad (3.20)$$

The probability of rain and no raining, determined by Equation Eqs. (3.21a) and (3.21b) was used in the model to define if it is raining or not at the beginning of the model.

The outcome data is used in the initiallyRaining parameter for precipitation agent.

$$Rainprobability = \frac{AveragerainTime(min)}{AveragerainTime(min) + Averagenoraintime(min)} = 0.038 \quad (3.21a)$$

$$Rainprobability = \frac{AveragenorainTime(min)}{AveragerainTime(min) + Averagenoraintime(min)} = 0.96 \quad (3.21b)$$

The intensity of the rain in mm/min was calculated using *triangular*(0.0178, 20.1, 0.05), which shows the maximum, minimum and average values of rain intensity in mm/min taken from the data.

Similarly, in the system dynamics model on the precipitation agent of the model, the evaporation is calculated as *waterAccumulation* < 0.005?0 : 0.004097398, which is evaporation in mm/min calculated from the Evaporation file is tabulated in appendix 1. It is assumed here that when water accumulation is below an arbitrary threshold of 0.005, there is no more evaporation. The water accumulation was derived from the evaporation data in Equation Eqs. (3.22) to (3.24).

$$Totalamountinmm = \sum_{i=1}^{20091} i = 39696.9mm \quad (3.22)$$

$$Numberofminutes = COUNTIF(A4 : A6730) = 9688320minutes \quad (3.23)$$

$$Evaporationminimum = \frac{Totalamountinmm}{Numberofminutes} = 0.004097 \quad (3.24)$$

3.8.12.4 Observations

As a part of data collection, the researcher was properly trained and given health, safety and environment (HSE) induction: a certification to visit construction sites. During the site visits, direct observations were recorded, illustrated in Appendix 1.

The recordings were made with notes together with informal discussions with site staff. Informal interviews were made with the project teams, whenever convenient, to have an in-depth understanding of the construction sequences and influences. To attain an accomplishing observation, before each observation, the researcher contacted the project engineer to be aware of the construction operation planned for execution.

The feedback aided the researcher to plan parameters needed to be observed by creating an observation guide and checklist. Among the items in the checklists are the list of the features, events and activities to be observed, prepared how to maintain the non-obstructive relationship with the team, ensured the accomplishment of the agreed ethical conduct and planned not to be based on the observations. While the observations were ongoing, the researcher related the observations with the discussions and interviews with the project team (Bell et al. 2018). Each observation lasted for 240 minutes to have comprehensive observations.

3.8.12.5 Informal interviews and discussions

The interview section was informal interviews (Bell et al. 2018, Creswell & Creswell 2017), which followed the process of accessible introduction, more specific questions in the middle, and ending with open questions. Four semi-structured interviews were conducted with the project teams for the road improvements projects and the innovation manager, however not recorded or transcribed, instead the researcher took notes enhanced by continuous discussions with the team. The instrument utilised in the interview that lasted one hour with notes taken are:

- i. introduction;
- ii. personal, group, and company background;
- iii. general experiences of introducing on construction planning and scheduling;
- iv. the specific question on project tender and construction phases; and
- v. the ending.

3.8.12.6 Documents

In addition to the conducted interviews and construction operations observations, there are other documents collected from CSC keeping in mind the confidentiality and competitive aspects of the construction market. The documents are CSC organisation process documents during bidding and opportunity analysis phase, road improvement photos, master project plan and updated schedules. The chainage documents, trucks cartage movements, construction documents, email documents and the project descriptions documents were also collected to enhance the researcher insight on the components and facets of the project.

Consequently, there was a large amount of data; however, a thorough document analysis and data extraction facilitated the gathering of relevant data. The overall data collected supported the answer to the question *Q8*, asking:

To what extent can the model assure the flexibility to accept multiple inputs?

The implementation of the developed framework in AnyLogic was a challenge. The section 3.8.13 main point and the idea is the illustrations of the framework analysis and implementation in AnyLogic platform.

3.8.13 Multi-hybrid method research analysis and implementation

In the Sections 3.8.7 to 3.8.9, the researcher presented the theoretical foundations of the hybrid models. The principles are applied to elaborate on the development of the

framework in Section 3.8.10. The framework presented the integrated models enhanced the technical descriptions of the construction project system, which is complex and dynamic. How to analyse and implement the integration to solve the complex system of the construction is a challenge. It was a problem because different non-uniform components are linked together to produce solution to the planning and scheduling problem. The goal of this section is to demonstrate how the framework is enclosed in AnyLogic to address the challenges and test the integrated models.

Besides the available platforms, the research involves different objects with different characteristics that are not easily implemented by drag and drop of objects. A definition and programming of the objects collaboration to form a unified system are implemented by the researcher for effective integration. Regardless of the drag and drop interface of AnyLogic objects, a programming interface for Java script language is implemented in combination with the developed Anylogic objects. In this chapter, the researcher focused on the step-by-step procedure of the implementation of the hybrid model in AnyLogic software, which is dependent on Figure 3.27 and the connection sequence.

3.8.13.1 ABS implementation for tender phase

The agent logic is a set of asynchronous collaboration among the agents namely sending a message, receiving a message, taking actions on the message, sending a reply, and in some cases, no reply is required (Abar, Theodoropoulos, Lemarinier, & O'Hare 2017, D'Agostino & Modgil 2018, Lomuscio, Qu, & Raimondi 2017). The implementation of the ABS in the tender phase in relation to agents' hierarchy and communications are based on CSC process document analysis.

The hierarchy and the communications are shown in BPMN sections of the agents. The statechart describes the event-based behaviours of the objects in terms of actions and reactions. While the behaviour within each object is the object action (state), the reaction exiting a state is the reaction (transition). In this research, only message and

timeout transitions in AnyLogic are utilised since the objective of the research is on planning (a collaboration by communication) and scheduling (timing). Each object or the instance of objects becomes the statechart (state and transitions), and it is shown in Figure 3.31.

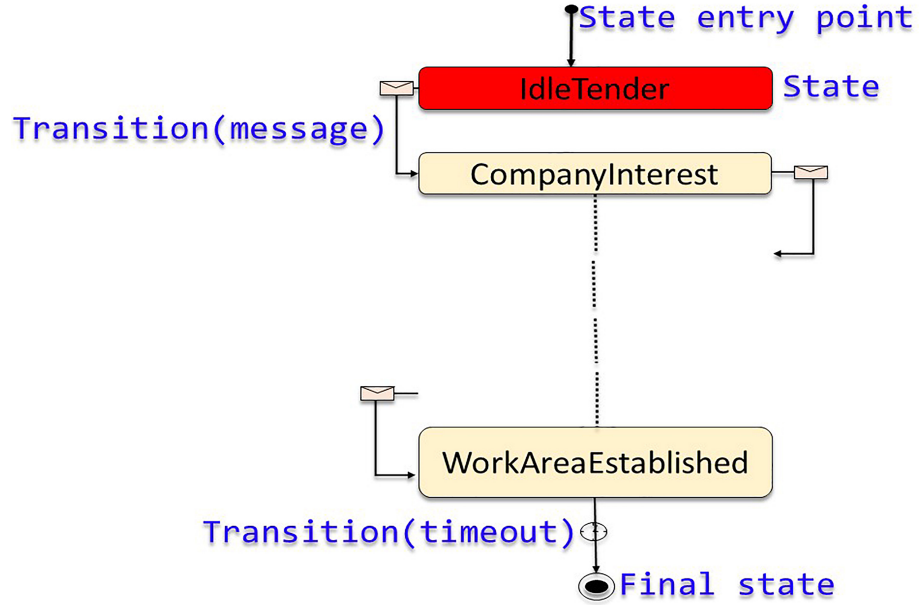


Figure 3.31. State diagram representation

The objects statecharts are employed to accomplish tasks during the bidding phase. The objects are instructed to actualise the tasks by sending messages to it, and the bidding object will be unable to implement the tasks if it does not understand the tasks it receives. In that manner, for the tender object and statechart to understand and achieve the tasks, it requires a set or sequence of instructions to follow in order to produce matching results to the instructions. In Anylogic, the instructions are implemented by using functions (methods). Moreover, in the sent instructions, an agent argument can be sent in the message sent to the object, as shown in Equation 3.25.

$$< objectname > . < instructions > (< arguments >); \quad (3.25)$$

The agent communication method, as previously shown in Figure 3.18, and agents are the objects sending and receiving the messages. The research defined the agents using

the hierarchy presented in Figure 3.32.

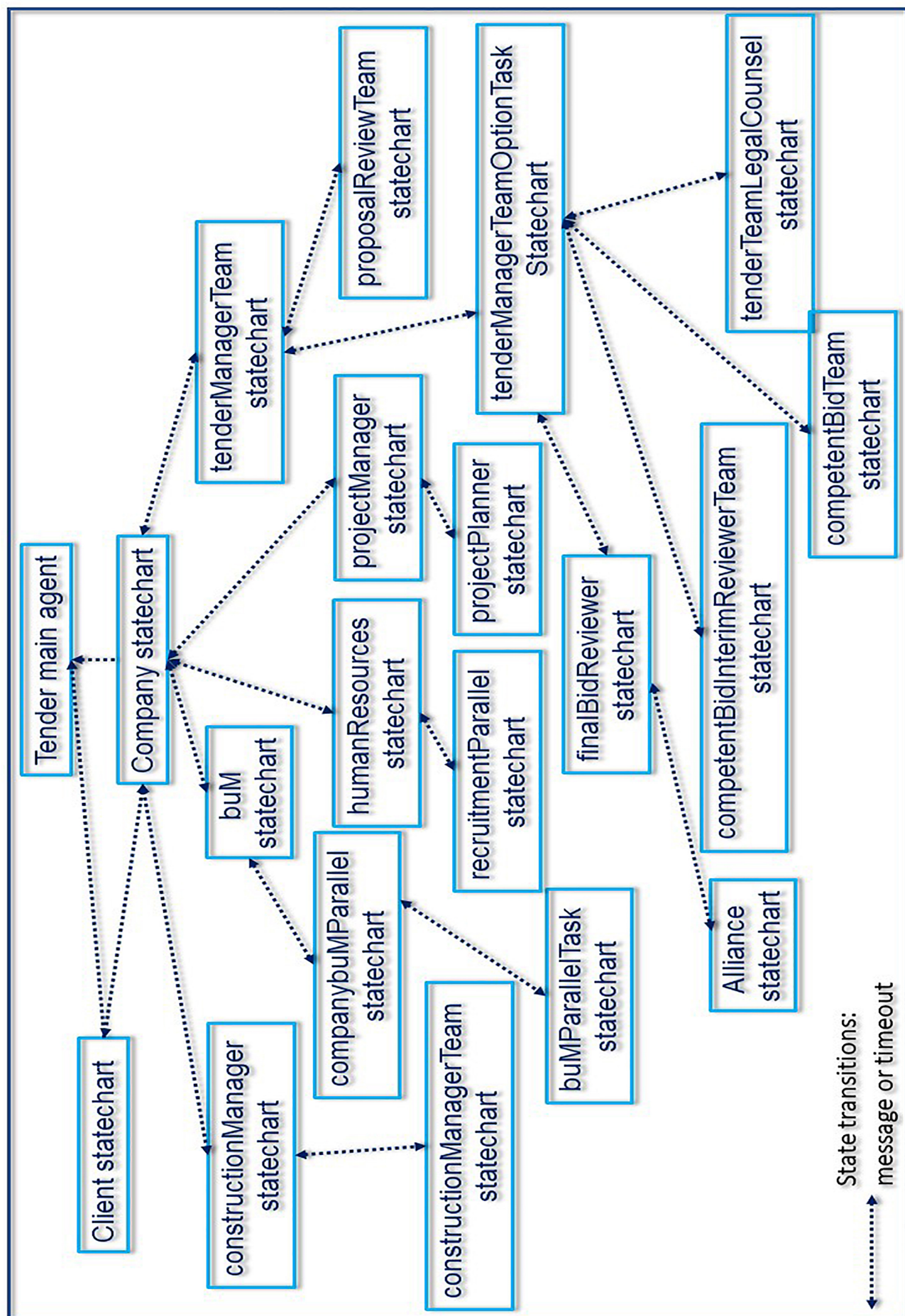


Figure 3.32. Tender agent hierarchy

The figure shows the active objects and their instances, whereby tender is the instance of the construction system, company and clients are the instances of tender, and the objects of the company for tender implementation are the instances of the bidding company. Since the bidding agents have some characteristic values that make them distinct to one another concerning performing different or similar tasks, they have a memory for storing a specific type of data for executing their action to either produce a reaction or no reaction. The characteristics can change or remain constant throughout the simulation execution. Whereas the constant characteristics are represented as a parameter, the characteristics that change during execution is a variable. The state, transition, method and argument for agent's collaboration and communication are implemented in the agents' unique statechart. Except for the construction operations BPMN in Figures Figs. 3.29a to 3.29e and tender statechart in Figure 3.33, the BPMN communications of other agents are presented with Figure 3.32.

3.8.13.2 Tender statechart

The tender agent is the entity that receives and documents the output at any time during the request for proposal, request for bid, proposal acceptance, preparation of the proposal, tender submission and contract award. The use of a tender agent is the documentation of tender deliverables as soon as they are completed either a notification from the client or the bidding company – the case study company (CSC). It neither sends any messages nor takes actions on the received messages; instead, it is created to track the progress of the bidding phase.

The collaboration with other agents in the tender phase is the documentation state. In the tender statechart, each state only receives information - the message arrival - and will not exit until the final phase of the statechart since the states do not produce any reaction. The beginning of the statechart is an entry point (initial), and the exit point is a final state. The tender statechart receives communication on a particular message, as depicted in Table 3.18.

Table 3.18

Tender Statechart Component

Statechart	Transition/trigger
1 CompanyInterest	On a particular message
2 ClientInterestAcceptance	On a particular message
3 clarifiedScope	On a particular message
4 ApprovedSiteInformationVisit	On a particular message
5 clientAcceptedProposal	On a particular message
6 SubmittedBid	On a particular message
7 NotifiedContract	On a particular message
8 ContractAward	On a particular message
9 AwardAcceptance	On a particular message
10 TenderCompleted	On a particular message
11 ProjectIndicators	On a particular message
12 PostAwardSchedule	On a particular message
13 OtherApprovedPlans	On a particular message
14 ProjectStart	On a particular message
15 TrafficPlan	On a particular message
16 TrafficSwitch	On a particular message
17 workAreaEstablished	On a particular message

In Table 3.19, the particular message for different statecharts is illustrated with the sent message function. The sent message function is the method employed to send the message in Javascript that is well comprehended by the sender and receiver. Again, for the tender statechart, messages are sent from either the client or directly from CSC throughout the entire tendering/bidding phase and construction.

The BPMN contains the pool, and the tender contract with message flows sent to it from other statecharts. In Anylogic, the message flows are the states rich history without any action. The events in the tender agent life are receiving documentation messages triggered from outside by other agents working assiduously to prepare bid documents before due dates and ensure contract award. As soon as the agent receives a document, it awaits the next document without timeout transitions. It receives a matching instruction relating to the tasks using the function (method) call developed with Java scripts.

Table 3.19

Tender statechart "on particular messages" recieved from client and CSC

On particular Message	Sent message function script
1 "Company Interest"	if (varCompanyInterest) send("Company Interest",this);
2 "Interest Accepted"	if (varInterestAccepted) send("Interest Accepted",this);
3 "Answered TQ and RFI"	if (varAnsweredTQandRFI) send("Answered TQ and RFI",this);
4 "Site Information and Site Visit"	if (varSiteInfoAndVisitApproval) send("Site Information and Site Visit Approval",this);
5 "Proposal Accepted"	if (varProposalAccepted) send("Proposal Accepted",this);
6 "Company Bid"	if (varCompanyBid) send("Company Bid",this);
7 "Bid Win Notification and Negotiation"	if (varBidWinNotificationAndNegotiationMeeting) send("Bid Win Notification and Negotiation Meeting",this);
8 "Contract Award"	if (varContractAward) send("Contract Award",this);
9 "Award Acceptance"	if (varAwardAcceptance) send("Award Acceptance",this);
10 "End of Tendering"	if (varEndTenderTasks) send("End of Tendering",this);
11 "Project Vision Performance"	if (varProjectVisionPerformanceIndicators) send("Project Vision Performance Indicators",this);
12 "Schedule Approved"	if (varScheduleApproved) send("Schedule Approved",this);
13 "Client Plans Approval"	if (varClientPlansApproval) send("Client Plans Approval",this);
14 "Start Project Activity"	if (varStartProjectActivity) send("Start Project Activity",this);
15 "Approved Traffic Plan"	if (varApprovedTrafficPlan) send("Approved Traffic Plan",this);
16 "Project Traffic Switched"	if (varProjectTrafficSwitched) send("Project Traffic Switched",this);
17 "Project Work Area Established"	if (varProjectWorkAreaEstablished) send("Project Work Area Established",this);

The tender statechart does not send any message, instead receives only messages. The table is developed from the BPMN, and it is utilised to design the statechart logic. The representation of the message received is depicted in the tender statechart BPMN, Figure 3.33.

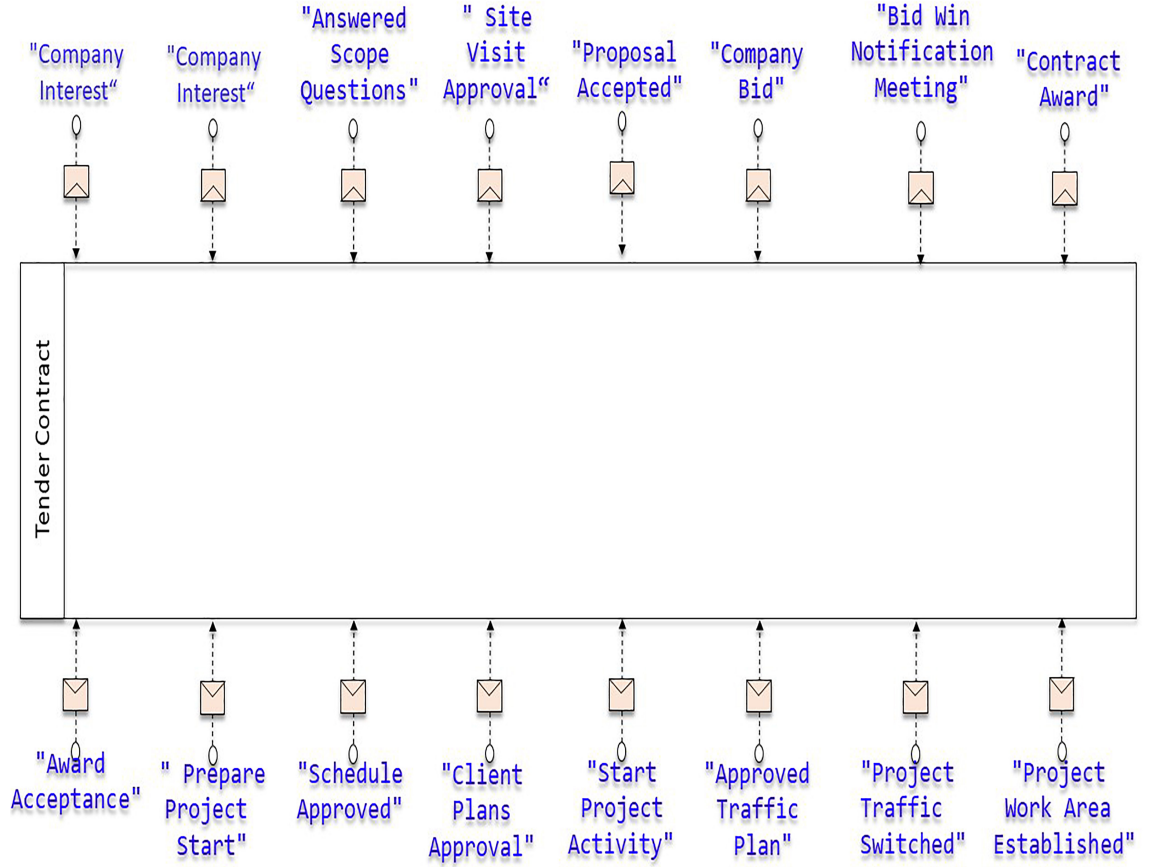


Figure 3.33. Tender statechart BPMN

As an illustration, in one of the agent's messages sent to the tender agent statechart, which is similar to the messages sent by other agents, the researcher defined a method as set out in Equation 3.26 to send a message from the company to the tender object.

$$\text{sendCompanyRequest()}; \quad (3.26)$$

The method is utilised to send instructions to the tender statechart to either execute an action or do nothing. In this case, the message argument is the documentation of a

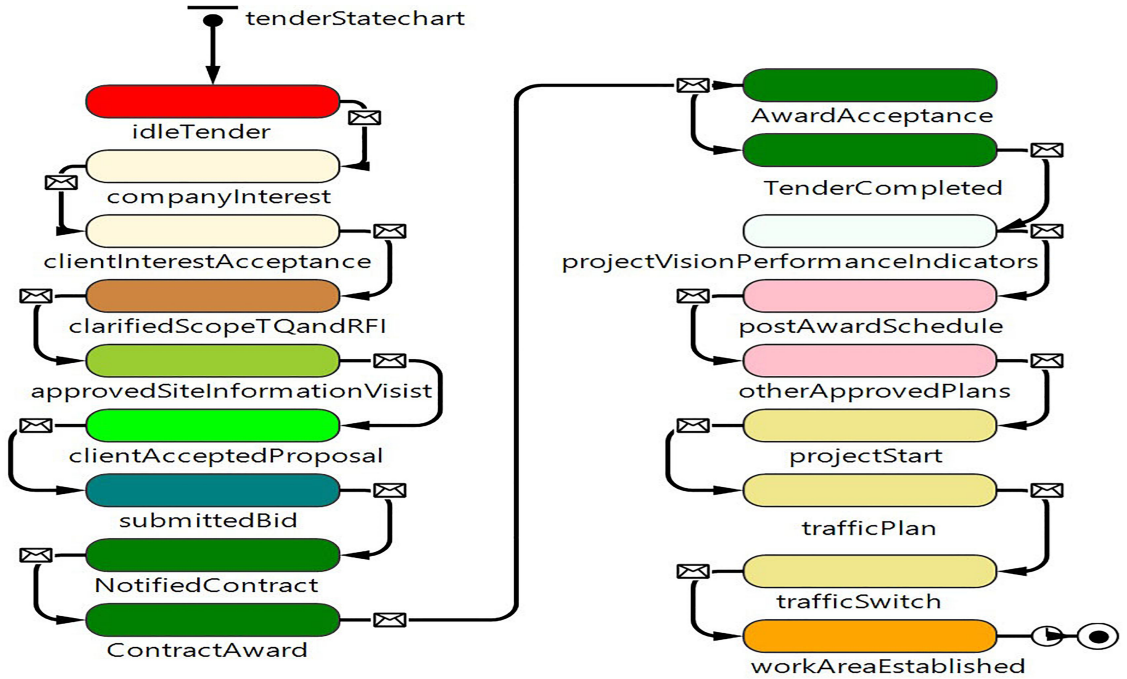
string argument; a constant parameter laid out in Equation 3.27 employing the overall method depicted in Equation 3.28. The defined method sends the message to the tender statechart with a String argument "Company Interest".

$$\text{"CompanyInterest"} \quad (3.27)$$

$$\begin{aligned} & \text{if}(\text{varCompanyInterest}) \\ & \quad \text{send}(\text{"CompanyInterest"}, \text{this}); \end{aligned} \quad (3.28)$$

The method in Equation 3.28 is the means utilised to send bidding deliverables to the tender statechart. The other agents can be in different states that do not coincide with the state of the tender statechart. For this reason, the "if" statement ascertains the state before sending or receiving the message. Each message in Table 3.18 represents the statecharts, and it is implemented in Anylogic in the form of a sequence from 1 to 17 with a total of seventeen messages transitions shown in Figure 3.34.

Figure 3.34. Tender Statechart



While the tender agent is selected as the improved road agent throughout the bidding

and construction phase, the client agent is the agent responsible for creating opportunity and contract to achieve the tender agent product, discussed in the succeeding Section 3.8.13.3.

3.8.13.3 Client statechart

The client agent is the requestor of request for proposal (RFP). Unlike the tender statecharts, while requesting the proposal, the client agent expedites actions on query, clarifications, approval actions and reactions messages sent to it by the bidding company as well as decides on the contract award. The interest is on the bidding company (CSC) towards tender preparation and contract award. The tender or the proposal requested by the client has due dates for submission; hence, the tender go, or no-go decisions and preparation are monitored promptly.

In the client statechart, messages are received and delivered as well as reactions to messages leading to both timeout transitions and message transitions. The execution of actions on the messages requires time and planning. The collaboration between the client and CSC is developed with the BPMN, and the messages delivered and received with the instructions shown in Figures 3.35a to 3.35d consistent with the BPMN.

State	Action	Reaction	Transition(Timeout or Message)
1 idleClient	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	
2 prospectAdvert	<i>main.createNewGanttObject(self.name());</i>	<i>companyStatechart.fireEvent("Request (timeWaitProspectResponse : Proposal or Tender");</i>	<i>DAY)</i>
		<i>main.setTimeSpentInTask(self.name());</i>	
3 waitInterestResponse	<i>sendCompanyInterest();</i> <i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Company Interest"
4 receiveBonafideInterest	<i>main.createNewGanttObject(self.name());</i>	<i>var InterestAccepted=true;</i> <i>sendInterestAccepted();</i> <i>main.setTimeSpentInTask(self.name());</i>	<i>(timeWaitToReceiveInterest : DAY)</i>
5 waitInterestScopeClarification	<i>sendScopeClarificationQuestions();</i> <i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Scope Clarification Questions"
6 receiveCompanyScopeClarification	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	<i>(timeToReceiveCompanyScopeClarification : DAY)</i>
7 scheduleScopeClarificationMeeting	<i>main.createNewGanttObject(self.name());</i>	<i>var ScopeClarificationMeeting=true;</i> <i>sendScopeClarificationMeeting();</i> <i>main.setTimeSpentInTask(self.name());</i>	<i>(timeToScheduleScopeClarificationMeeting : DAY)</i>
8 waitScopeClarificationMeeting	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	<i>(timeToWaitScopeClarificationMeeting : DAY)</i>
9 clarifyScope	<i>main.createNewGanttObject(self.name());</i>	<i>var AnsweredTQandRFI=true;</i> <i>sendAnsweredTQandRFI();</i> <i>main.setTimeSpentInTask(self.name());</i>	<i>(timeToClarifyScope : DAY)</i>
10 waitTQandRFIResponse	<i>sendTQandRFIAnswered();</i> <i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	"TQ and RFI Answered" "TQ and RFI not Answered"

Figure 3.35a. Company Agent Communication

State	Action	Reaction	Transition(Timeout or Message)
11 receiveCompanyTQandRFIAcceptance	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i> ;	<i>(timeToReceiveCompanyTQandRFIAcceptance : DAY)</i>
12 waitCompanySiteInformationVisitRequest	<i>sendSiteInfoAndSiteVisit();</i> <i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i> ;	<i>"Site Information and Site Visit"</i>
13 receiveCompanySiteInformationVisitRequest	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i> ;	<i>(timeToReceiveCompanySiteInformationVisitRequest : DAY)</i>
14 approveSiteInformationVisit	<i>main.createNewGanttObject(self.name());</i>	<i>var SiteInfoAndVisitApproval=true;</i> <i>send("Site Information and Site Visit Approval",this);</i> <i>main.setTimeSpentInTask(self.name());</i> ;	<i>(timeToApproveSiteInformationVisit : DAY)</i>
15 waitFormalProposalAcceptance	<i>sendSiteInfoAndVisitApproval();</i> <i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i> ;	<i>"Site Information and Site Visit Approval"</i>
16 receiveFormalProposalAcceptance	<i>sendCompanyFormalAcceptance();</i> <i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i> ;	<i>"Company Formal Acceptance"</i>
17 sendProposalAcceptanceConfirmation	<i>main.createNewGanttObject(self.name());</i>	<i>var AcceptedCompanyProposalAcceptance=true;</i> <i>sendAcceptedCompanyProposalAcceptance();</i> <i>main.setTimeSpentInTask(self.name());</i> ;	<i>(timeToSendProposalAcceptanceConfirmation : DAY)</i>

Figure 3.35b. Company Agent Communication

State	Action	Reaction	Transition(Timeout or Message)
18 waitCompanyProposal	<i>clientAcceptsCompanyProposal();</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Company Proposal"
	<i>main.createNewGanttObject(self.name());</i>		
19 receiveCompanyProposal	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	(timeToReceiveCompanyProposal : DAY)
20 sendProposalAcceptance	<i>main.createNewGanttObject(self.name());</i>	<i>sendProposalAccepted();</i>	(timeToSendProposalAcceptance : DAY)
		<i>main.setTimeSpentInTask(self.name());</i>	
21 waitCompanyCompletedBid	<i>sendCompanyBid();</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Company Bid"
	<i>main.createNewGanttObject(self.name());</i>		
22 receiveCompanyCompletedBid	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	(timeToReceiveCompanyCompletedBid : DAY)
23 evaluateBid	<i>main.createNewGanttObject(self.name());</i>	<i>var BidWinNotificationAndNegotiationMeeting=true;</i>	(timeToevaluateBid : DAY)
		<i>sendBidWinNotificationAndNegotiationMeeting();</i>	
		<i>main.setTimeSpentInTask(self.name());</i>	
24 waitingForContractNegotiation Meeting	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	(timeToWaitingForContractNegotiationMeeting : DAY)
25 negotiateContractToFinalise	<i>main.createNewGanttObject(self.name());</i>	<i>var ContractNegotiationMeetingEnd=true;</i>	(timeToNegotiateContractToFinalise : DAY)
		<i>sendContractNegotiationMeetingEnd();</i>	
26 completeContractAward	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	(timeToCompleteContractAward : DAY)

Figure 3.35c. Company Agent Communication

State	Action	Reaction	Transition(Timeout or Message)
27 awardContract	<i>main.createNewGanttObject(self.name());</i>	<i>var Contract.Award=true;</i>	<i>(timeToAwardContract : DAY)</i>
		<i>sendContractAward();</i>	
		<i>main.setTimeSpentInTask(self.name());</i>	
28 waitForContractAcceptance	<i>sendAwardAcceptance();</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Award Acceptance"
	<i>main.createNewGanttObject(self.name());</i>		
29 acknowledgeAcceptance	<i>main.createNewGanttObject(self.name());</i>	<i>var AwardCompleted=true;</i>	<i>(timeToAcknowledgeAcceptance : DAY)</i>
		<i>sendAwardCompleted();</i>	
		<i>main.setTimeSpentInTask(self.name());</i>	
30 waitForCompanyPlan	<i>sendProjectPlan();</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Project Plan"
	<i>main.createNewGanttObject(self.name());</i>		
31 approveProjectPlan	<i>main.createNewGanttObject(self.name());</i>	<i>var ApprovedProjectPlan=true;</i>	<i>(timeToApproveProjectPlan : DAY)</i>
		<i>sendApproveProjectPlan();</i>	
		<i>main.setTimeSpentInTask(self.name());</i>	
32 waitActivityStart1	<i>sendApproveTrafficPlan();</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Approve Traffic Plan"
	<i>main.createNewGanttObject(self.name());</i>		
33 reviewTrafficPlan	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	<i>(timeToReviewTrafficPlan : DAY)</i>
34 approveTrafficPlan	<i>main.createNewGanttObject(self.name());</i>	<i>var ApprovedTrafficPlan=true;</i>	<i>(timeToApproveTrafficPlan : DAY)</i>
		<i>sendApprovedTrafficPlan();</i>	
		<i>main.setTimeSpentInTask(self.name());</i>	
35 waitForCompany	<i>sendProjectTrafficSwitched();</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Project Traffic Switched"
		<i>main.createNewGanttObject(self.name());</i>	
36 receiveCompanyTrafficSwitch	<i>sendProjectWorkAreaEstablished();</i>	<i>main.setTimeSpentInTask(self.name());</i>	"Project Work Area Established"
		<i>main.createNewGanttObject(self.name());</i>	
37 establishProjectWorkArea	<i>main.createNewGanttObject(self.name());</i>	<i>main.setTimeSpentInTask(self.name());</i>	<i>(timeToestablishProjectWorkArea : DAY)</i>

Figure 3.35d. Company Agent Communication

There are four functions for each agent in any states to execute a specific activity. The functions are receiving a message; taking action or processing the message; producing an output from the processed action, which is the reaction and; either sends the message or does nothing. The process to implement the design process of the tender agent behaviours (states, actions, reactions and transitions) is sequentially depicted in Figure 3.36 and is persistent for the CSC tender agents.

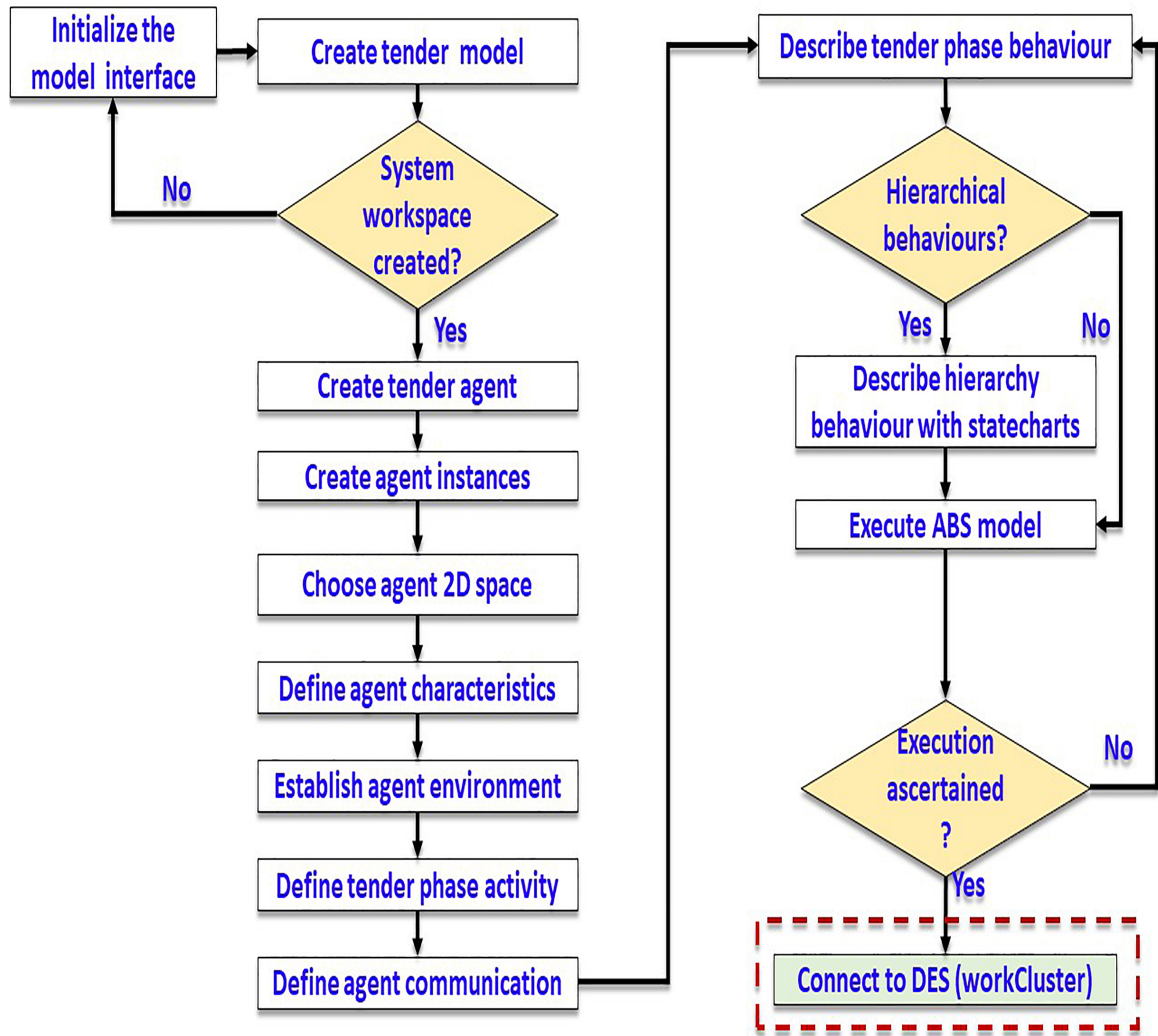


Figure 3.36. Tender agent implementation flowchart

In the implementation flowchart, the step with the red-dotted rectangle shows the connection to the next modeling step implemented in the DES as work clusters, which is the starting position of the DES.

Figure 3.37 is the application of the flowchart for the client agent in Anylogic.

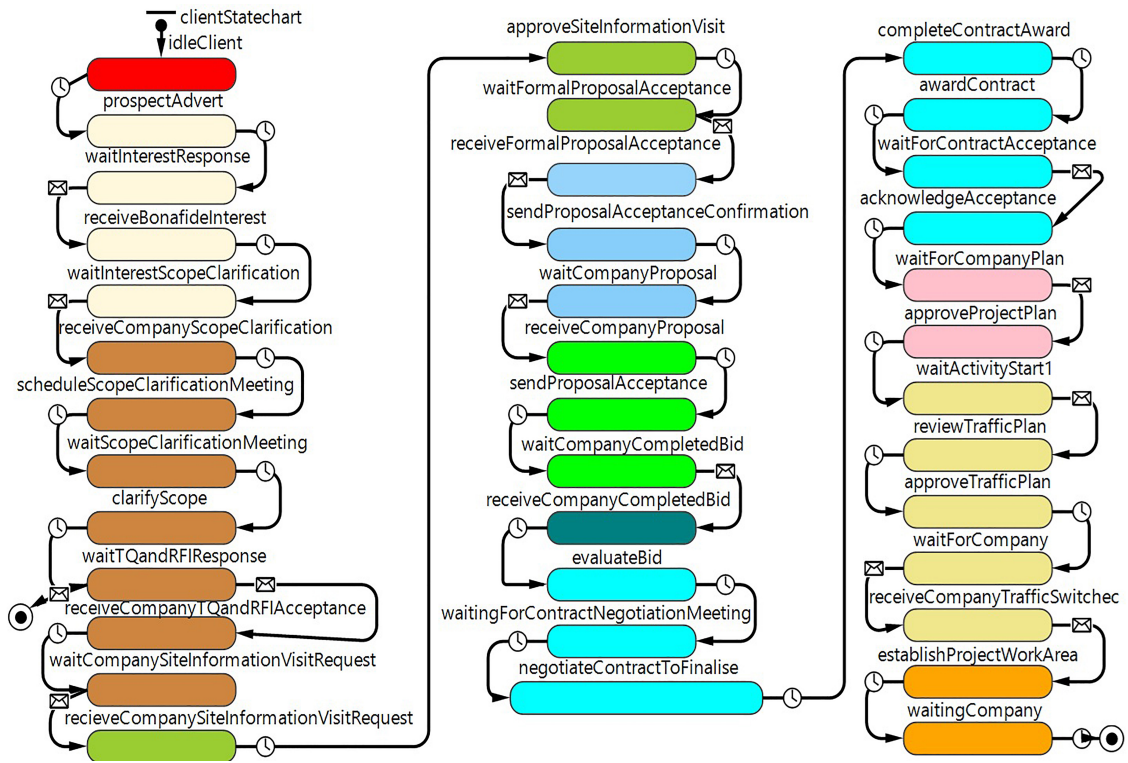


Figure 3.37. Client agent Anylogic statechart

In the figure, the process utilised to create and implement the agents is logically presented. The basic model creation process is namely creating agent, agent characteristics, agent space, agent behaviour, and the description of the agents' behaviours and interactions. At the end of the agent-based platform, the establishment process flow is the connection to the work cluster for DES. In this research, the DES implementation of the construction phase in different locations is the work cluster, and its mechanism is extensively explained in Section 3.8.13.5. The statechart of the client agent implemented in AnyLogic, using the process sequence, is the illustration of Figure 3.37.

The figure depicts the different states of the client during the process of bidding, in terms of providing tender documents clarifications, approvals, meetings, negotiations and the contract execution. The figure includes the states, timeout, messages and transitions. In the tender phase, the main concern of the research is time. The time

influence is on the delay caused by different teams (agents) to either receive or send the message to ensure the completion of the bid before or on the submission deadline. Taking into account the figure 3.32, the next primary agent after the tender statechart and client agent is the CSC agent. According to that figure, the CSC has established teams at different phases of the project collaborating and interfacing to complete any of the phases. As well, the process document analysis is the primary input to the logical process of the created interaction and collaborations between the relevant teams in the project phases. Consequently, the approach for implementation is presented in Section 3.8.13.4.

3.8.13.4 CSC statechart

The creation and implementation of different agents in AnyLogic are utilised for ABS as part of the tender phase in the CSC. In the ABS, the bidding company is largely concentrated with many states, transitions (timeout and messages) and function calls (methods) because of the different teams in the implementation of the project. Apart from the tender agent and client agent in Figure 3.32, other agents are from the CSC. A high-level of presentation of the statechart in Anylogic is depicted in Figures 3.38a to 3.38c consistent with the BPMN, the development is formed from the process and project documents analysis.

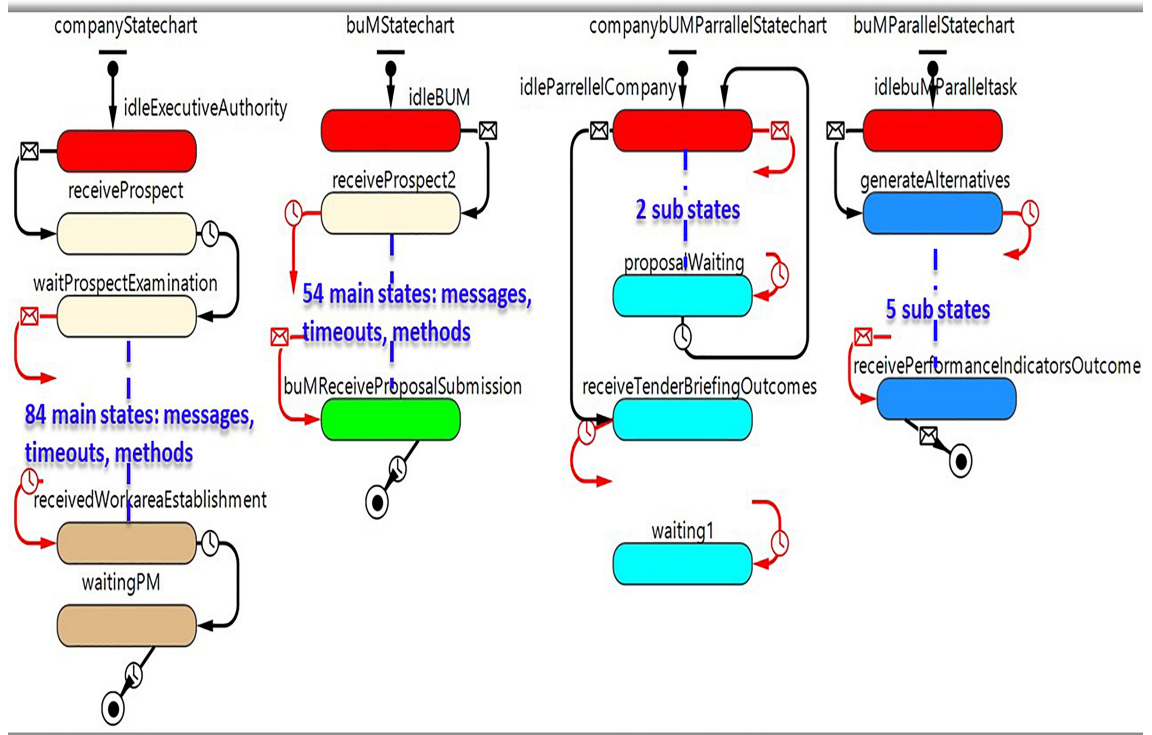


Figure 3.38a. CSC and CSC buM statechart

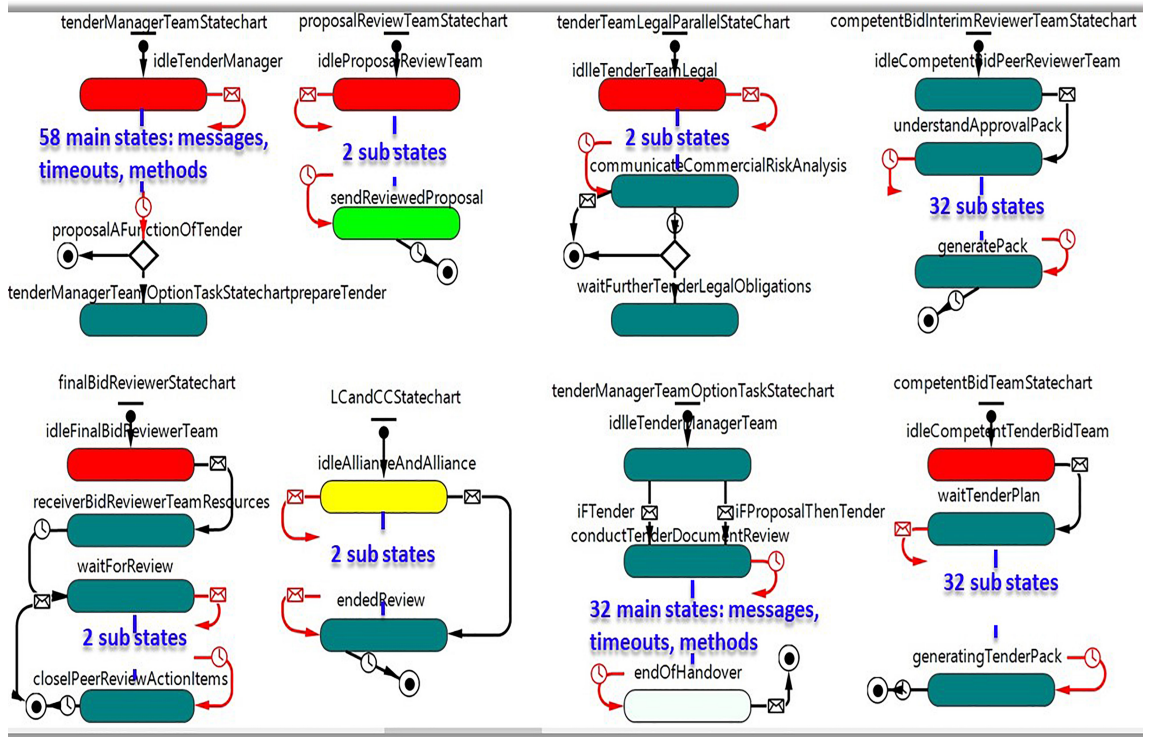


Figure 3.38b. CSC tender management statechart

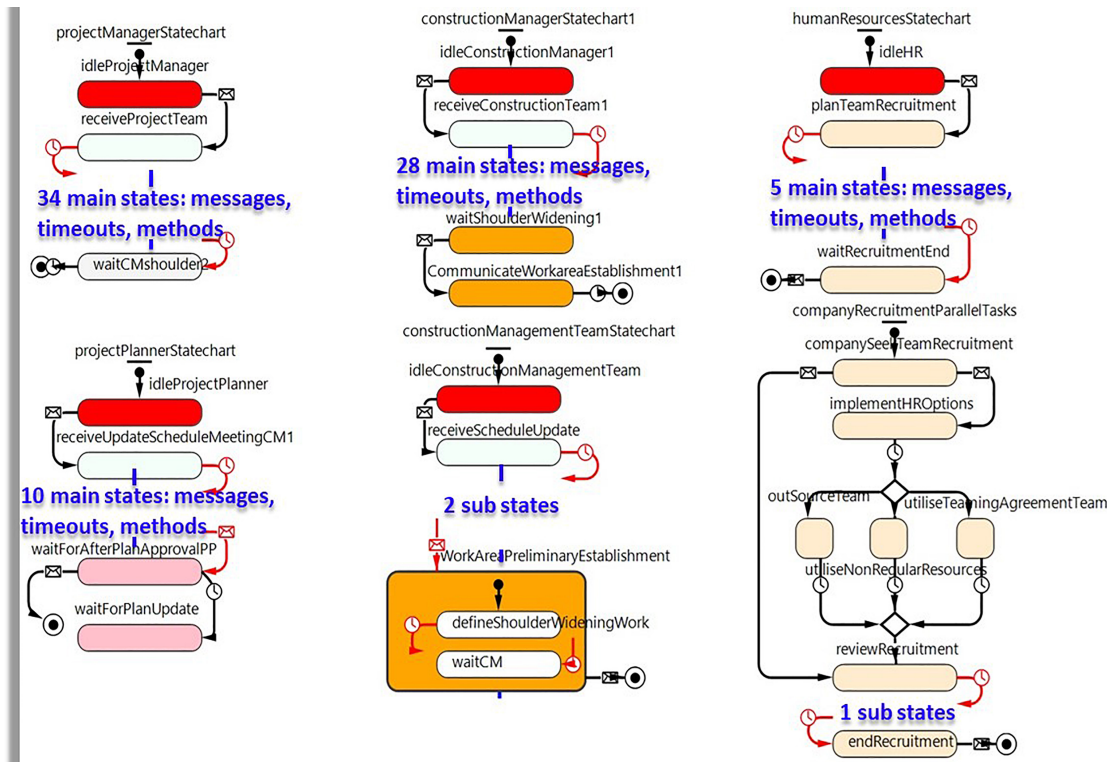


Figure 3.38c. ProjectManager-ConstructionManger-HumanResourcesManager team statechart

As shown in the figure, whereas blue lines show the number of the real states that are connected, the red objects show the transitions required to be connected for valid statecharts and ABS model. In those CSC statecharts, there are messages sending and receiving, and instructions on the activities required to assess the RFP for risks and opportunities as well as submit bid package to the client. The instances of communications presented and implemented in the statechart are consistent with Figure 3.32.

In Figure 3.38a, for example, the buMStatechart has three states shown with more than 54 states comprising messages (sending or receiving) and timeout transitions and communication methods. The same description applies to other agents in the CSC. In the CSC, 18 different agent groups combined their efforts to win the road improvement contract as well as the execution. The programming concepts and mechanism of communication of a large number of agents involved in the complex construction project

environment is a challenge. The utilisation of the Java scripts and AnyLogic provided an opportunity to implement the framework, but required more efforts. Therefore, demonstrating answer to the research question *Q9*, asking:

What are barriers that may be associated with the model integration, and how are they addressed?

The idea of multi-method results to the integration of the individual models, which supports the research question *Q9*. On that note to solve the challenge, Section 3.8.13.5 explores how the tender phase is integrated with the DES, the work cluster agent.

3.8.13.5 Integration of ABS (tender phase) with DES(construction)

The work area establishment in Figure 3.38c is the commencement of construction, as demonstrated with Figures 3.29a to 3.29e in section 3.8.10. The research pursued the steps in Figure 3.39 for the entire contract, in other words, from tender to construction completion.



Figure 3.39. Contract steps

The tender phase consists of a request for proposal (RFP), bid preparation, contract negotiation and contract award. After the tender phase process, then the next step is the preparation for construction and commencement of the construction phase. The implementation of the ABS-DES integration is the responsibility of the construction manager (CM) agent statechart of the CSC, shown in Figure 3.40.

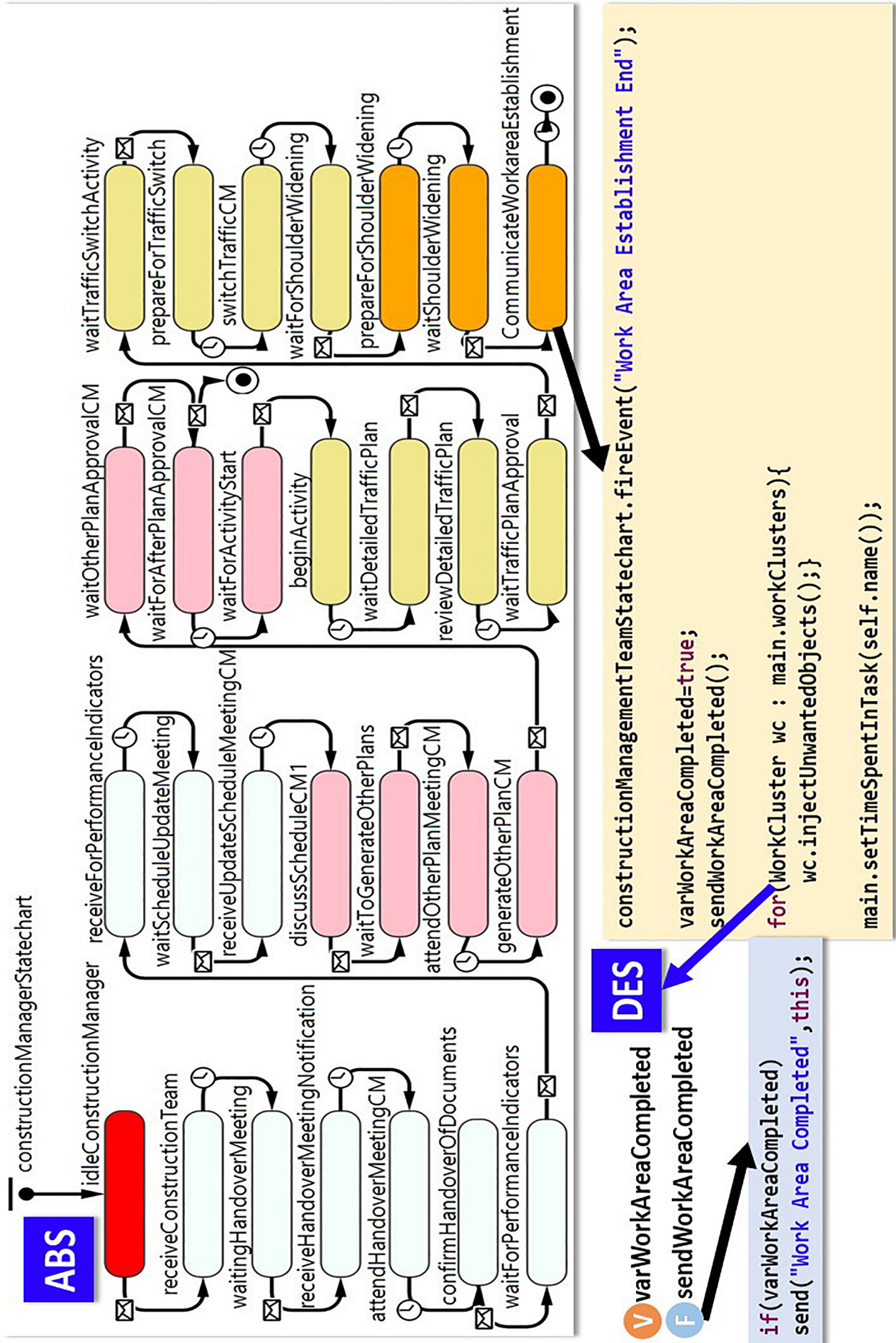


Figure 3.40. Construction manager statechart and DES-ABS integration message javascript set

In the figure, the state, *CommunicateWorkAreaEstablishment*, is the final state of the pre-construction activity in the *constructionManager* statechart. The final state implies that the pre-construction activities is completed. In other to progress from the final pre-construction step to the commencement of construction activities: the work cluster, a variable V: *var WorkAreaCopleted*, and a function F (method): *sendWorkAreaCompleted* are created inside the final state: *CommunicateWorkAreaEstablishment*. The variables and functions are written based on Java script.

After the establishment of the work area, the events moved to clear-shoulder- widening by sending a message to the *workCluster* agent – work areas for construction implemented in the DES modeling. The logic of the integration message is the java codes in Figure 3.40, where V is the variable utilised to describe the function (method), F. During the construction process, the decision for an undercut is made using in-situ soil testing. The in-situ soil testing and relocation of services are described in the BPMN and implemented in AnyLogic, an agent known as the agent *mapOutArea* of the CSC. The integration communication between the in-situ soil testing in the ABS and undercut of construction in DES is defined in Figure 3.41 with the java codes because the undercut process is implemented in DES.

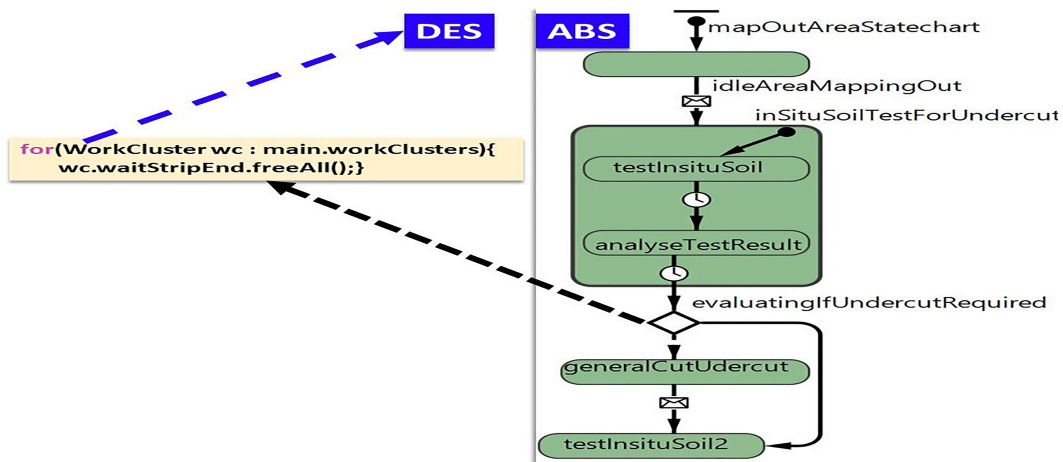


Figure 3.41. Map out area statechart and java code set

So far, the tender phase and the construction phase are integrated, whereby the tender phase is completed and now, the construction implemented with DES, which is the main discussion of the next Section 3.8.13.6.

3.8.13.6 DES Evaluation

The DES and DRS are the model section that evaluates and implement the construction operation. The construction is a system with input, system characteristics and output. The system characteristics are defined because they governs the behaviour of the entire system, thereby determining the nature of input and output of the system. In that regard, the research defined two dominant characteristics: 1) argument characteristic and; 2) spatial characteristic. In the case study, the construction areas are defined as chainage. The areas follow the same process, similar parameters and characteristics that differ by their values about the activity procedure of the construction. The characteristics are defined using data collected during interview, observations and documents from CSC.

Argument characteristics

The research defined an agent, ***Area agent***, which is a container for the characteristics definitions and are depicted in Table 3.20a given the similarities to the parameters and characteristics of each area or chainage.

In the table, while the area node, wasteNode, parkingNode and area are defined as arguments with constant parameters of the construction areas, other features are changing parameters, the variables. The variables' characteristics are defined as triangular and uniform distribution in meters.

Table 3.20a

construction area characteristics

	Name	Type	Initial value	Feature
1	areaNode	PolygonalNode	none	Parameter
2	wasteNode	RectangularNode	none	Parameter
3	parkingNode	RectangularNode	none	Parameter
4	area	double value	none	Parameter
5	numSegmentsToFill	Whole number	none	Parameter
6	depthGenFill	decimal number	triangular(0,0.75,3)	Variable
7	depthGenCut	decimal number	triangular(0,0.6,3)	Variable
8	depthTopsoilStrip	decimal number	triangular(0,0.03,3)	Variable
9	depthSubBase	decimal number	triangular(0,0.39,3)	Variable
10	depthAC14	decimal number	triangular(0,0.06,3)	Variable
11	depthAC20	decimal number	triangular(0,0.085,3)	Variable
12	depthWearingCourse	decimal number	triangular(0,0.06,3)	Variable
13	depthBackFill	decimal number	triangular(0,0.06,3)	Variable
14	volGenFill	decimal number	area*depthGenFill uniform(0,1000)	Variable
15	volGenCut	decimal number	area*depthGenCut uniform(0,1000)	Variable

Table 3.20b

Construction area characteristics

	Name	Type	Initial value	Feature
16	volTopsoilStrip	decimal number	area*depthTopsoilStrip uniform(0,1000)	Variable
17	volSubBase	decimal number	area*depthSubBase uniform(0,1000)	Variable
18	volAC14	decimal number	area*depthAC14 uniform(0,1000)	Variable
19	volAC20	decimal number	area*depthAC20 uniform(0,1000)	Variable
20	volWearingCourse	decimal number	area*depthWearingCourse uniform(0,1000)	Variable
21	volBackFill	decimal number	area*depthBackFill uniform(0,1000)	Variable
22	depthBase	decimal number	triangular(0,0.2,3)	Variable
23	volBase	decimal number	area*depthBase uniform(0,1000)	Variable
24	stripVolumePerPath	decimal number	none	Variable
25	timeToStripPath	decimal number	none	Variable
26	timeSpentStripingPath	decimal number	none	Variable
27	kgToCut	decimal number	volGenCut*uniform(830,2450)/1245.0	Variable
28	kgToFill	decimal number	volGenFill*uniform(830,2450)	Variable
29	currentSegment	Whole number	none	Variable
30	pathNodes	Array list	none	Variable
31	fillSegment	int numSegmentsToFill Sub agent		Variable

The fillSegment defined in Table 3.20a is a characteristics of the **Area agent**. The characteristics of the sub agent, **fillSegment agent**, defined in the Area agent contains the filled segments of the construction areas. On that regard, the instruction of the **Area agent** at the start-up operation for filling works is defined as:

```
set_numSegmentsToFill((int)round(depthGenFill * 1000/uniform(50, 230)));
for(FillSegment f : fillSegments)
    {f.holeToFill.set_capacity(kgToFill/numSegmentsToFill, KILOGRAM); }
```

Spatial characteristics: area agents location network

Each construction area is described by the coordinates of the real location on the ground using an appropriate scale. The different sections of the construction that are defined in the different spatial location inherited the characteristic defined in section 3.8.13.6 because construction operations and sequence are repetitive. In the CSC construction operation, the individual locations are mapped out as chainages. The chainages are used to define the different number of spatial characteristics forming the individual area agents. Accordingly, each chainage is given a unique name and defined in Anylogic with those names. There are 33 different construction locations using the chainages with the following collection of given names depicted as a list of arrays:

theAreas

aA, aB, aC, aD, aE, aF, aG, aH, aI, aJ, aK, aL, aM, aN1, aN2, aN3, aN4, aN5, aN6, aN7, aN8A, aN8B, aN9, aN10, aN11, aN12, aN13, aN14, aN15, aN16, aN17, aN18, aN19.

The construction operations, allocation of resources and the utilisation of resources and the accompanying influences are implemented in each of the areas in the collection. The spatial characteristics is defined using the chainage x and y coordinates, for instance for **aA agent** is a network that defines the location of one of the 33 area agents that are implemented for the areas in **theArea** collection, and shown in Figure 3.42.

In the figure, the paths-nodes collections **pathNode** are the characteristics array list of nodes that described each area and movements of the resources to accomplish the

construction operation for that area.

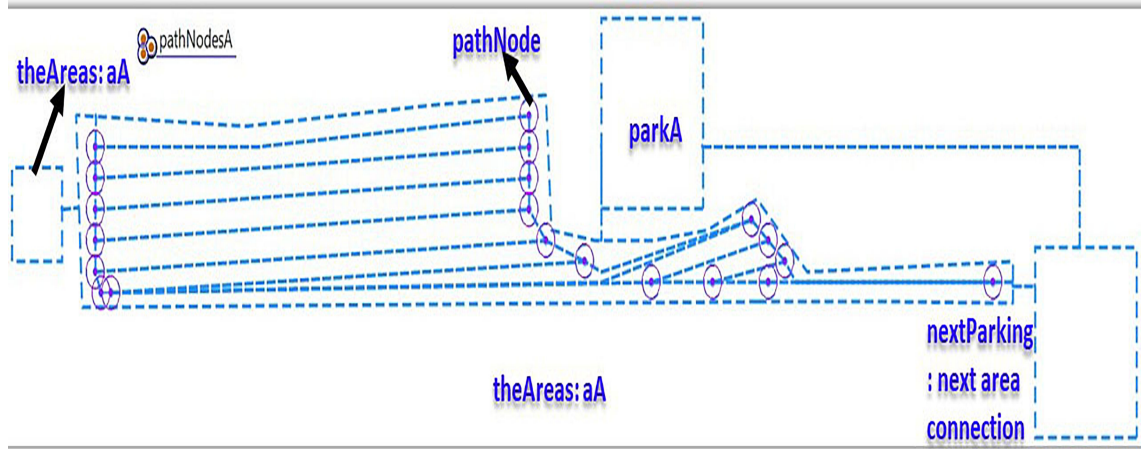


Figure 3.42. Instance of theAreas agent (aA agent)

In the same vein, the movement of the resources agents (excavator, bulldozer, compactor) and process visualisation to understand the simulation results is enhanced by the area agents' paths and nodes. The succeeding Section 3.8.14 presents the logical sequence for the implementation of ABS-DES-DRS in AnyLogic.

3.8.14 ABS-DES-DRS implementation flowchart

Having defined the DES-DRS system characteristics coupled with the hybrid nature of the model, the research objective is integrated of the four paradigms (ABS-DES-DRS-SD) described in the relevant section. The flow chart is one method flowchart to make it a multimethod paradigm. The flowchart is defined distinctively for each paradigm with an interface for the successive paradigm connection by the sequential implementation of one model to another. As represented in Figure 3.36, the dotted red rectangle is the initialisation of the DES and DRS from ABS with DES and DRS having its sequence of configuration, illustrated in Figure 3.43. The flowchart described the work procedure utilised by the CSC and described in the BPMN and DES modeling. The resources agents are the component of the resources pool used for the construction operations.

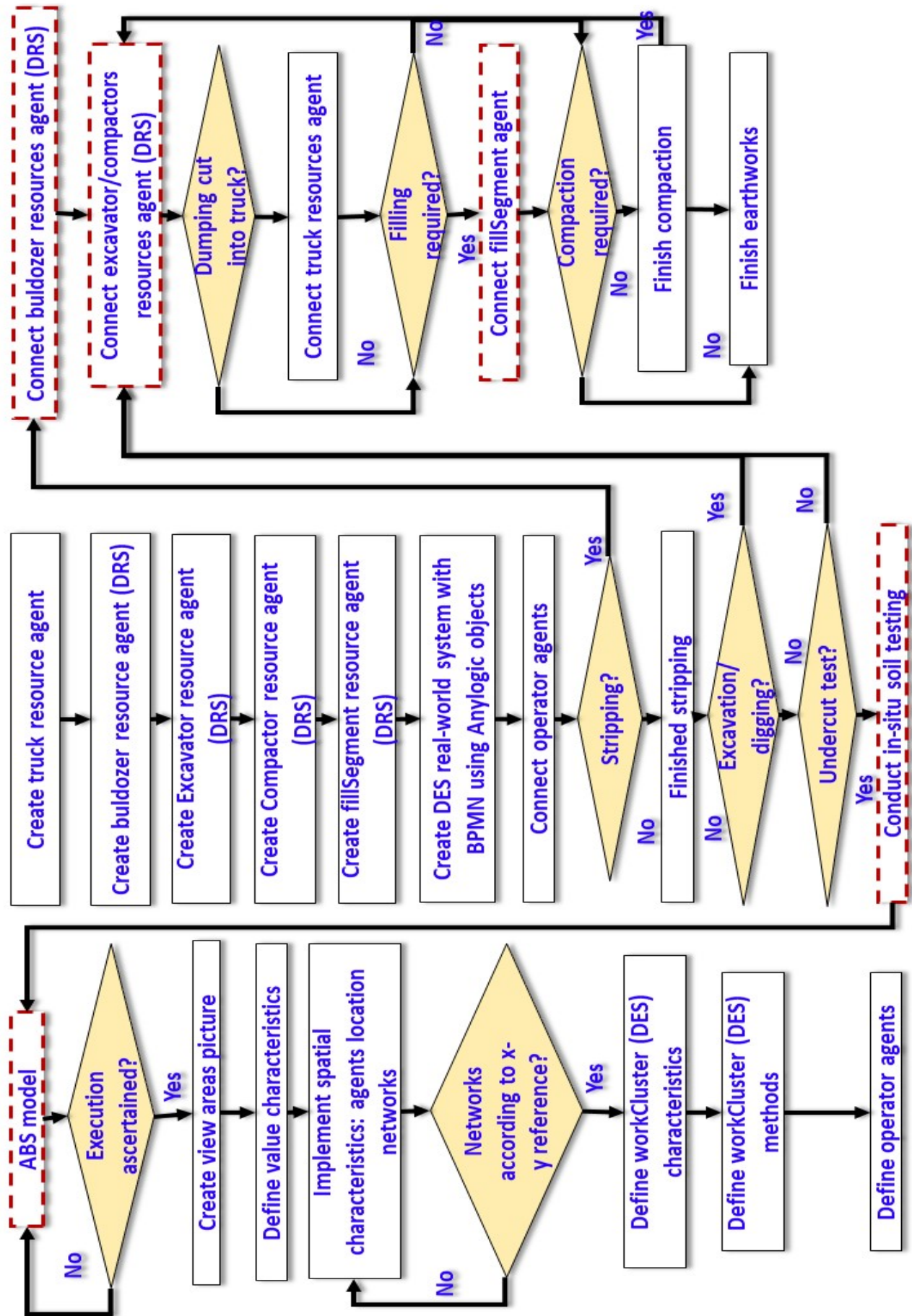


Figure 3.43. ABS-DES-DRS flowchart

At each procedure, decisions are made to determine the needed requirements for resources either to complete that procedure or to proceed to the next step. The resources are described as agents because they have unique characteristics that are not common to other agents such as area agents. In the multi-hybrid framework, the DES and DRS are combined to execute the construction. While DES models the regular discrete events, the remaining activities, including movement of bulk excavated and filling materials are linear and continuous discrete events. In the flowchart, the dotted rectangular shape is the sequential connection between the ABS, DRS and DES. The construction execution agent is the work cluster, and because the ABS implementation is completed, the next consideration of the flowchart is the implementation of DES and DRS by work cluster agent in the next Section 3.8.15.

3.8.15 DES-DRS simulation: workCluster agent

The DES model the construction as a sequence of operations with the entities, namely stripping, excavation, cut/undercut filling and compaction. AnyLogic is utilised to model, simulate and visualise the system behaviour. The DES model in AnyLogic is a combination of construction flowchart objects and AnyLogic process library objects. As discussed previously, each agent has characteristics that determine its behaviour, send the message and receive a message using some instructions or methods.

Having defined the behaviour of the area agents, the operation on those area agents is performed by the **workCluster agent** which is an agent. The **workCluster agent** has characteristics, behaviour and instructions that enhanced it to execute instructions on each area agent. However, those attributes and instructions match and conform with the area agents receiving the operations. To implement the operations on the area agents, the **workCluster agent** has value characteristics presented in Table 3.21.

In the figure, the profile depth of the topsoil stripping, general cut/undercut, general fill, and courses fill are illustrated and are connected to the area value characteristics

Table 3.21

WorkCluster agent value characteristics

	Name	Type	Initial value	Feature
1	initialArea	int	none	Parameter
2	finalArea	int	none	Parameter
8	numSmallUnwantedObjects	int	7	Variable
9	unwantedObjectsDiscarded	int	none	Variable
10	currentArea	int	initialArea	Variable
11	wasteLocation	INode	none	Variable
12	currentPathNode	int	none	Variable
13	revCurrentPathNode	int	none	Variable
14	compactorShouldMove	boolean	false or true	Variable

in Table 3.20a. The **workCluster agent** value characteristics are generated consistent with project team discussion, observation and data collected from CSC appertaining to the area as depicted in a section of the chainage profile shown in Figure 3.44. In addition to the value characteristics and matching instructions, resources are allocated to accomplish the workCluster operation in each area agent during the construction operations. The implementation of workCluster agent utilised the resources agents including **operator agent**, **operator agent**, **bulldozer agent**, **excavator agent**, **compactors agent**, **fillSegment agent**, and **truck agent**.

The **workCluster agent** value characteristics are generated consistent with the interview, observation and data collected from CSC concerning the area as depicted in a section of the chainage profile shown in Figure 3.44.

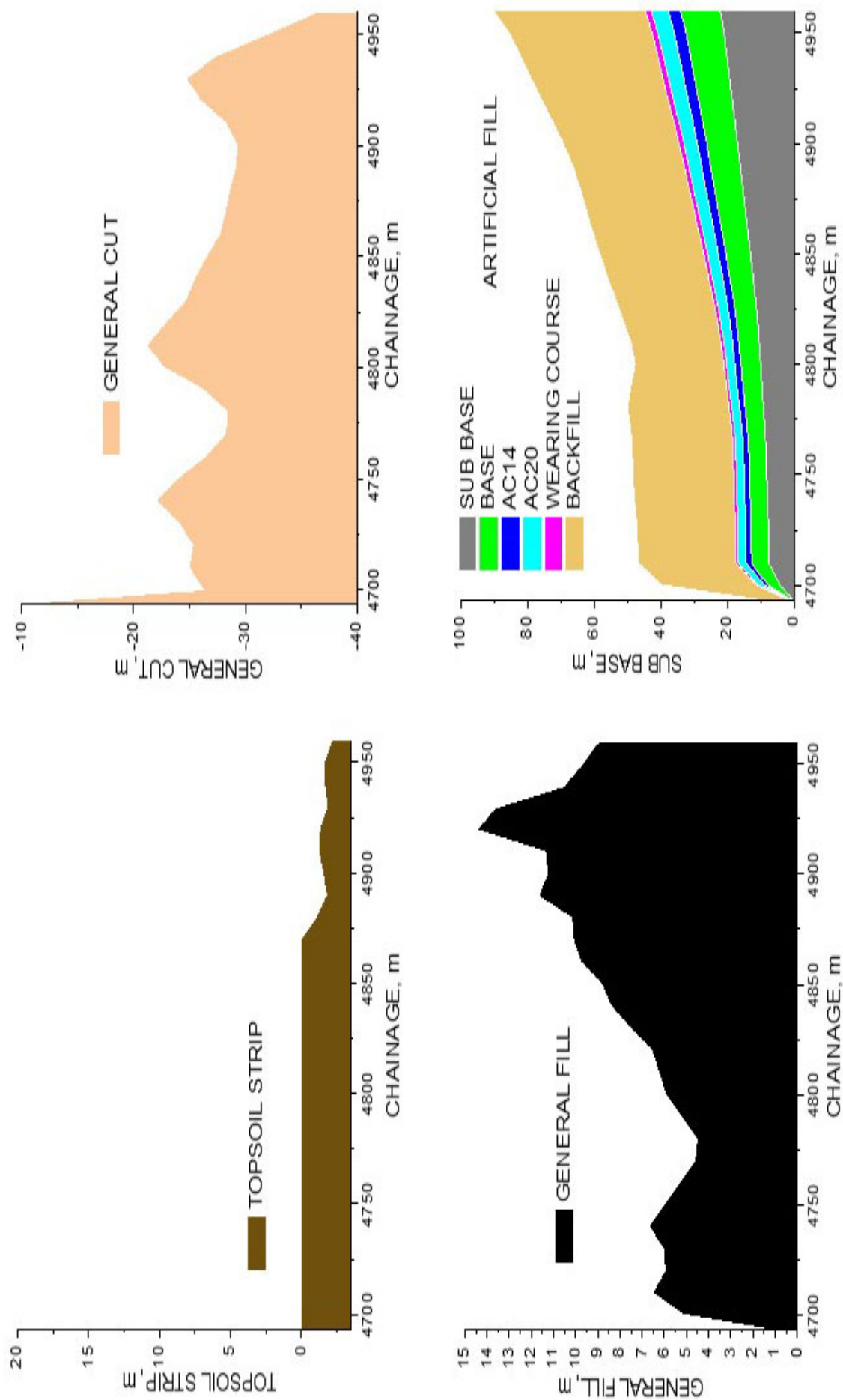


Figure 3.44. Chainage work profile

In a similar definition for agents, the resources agents have behaviour, characteristics, representation and matching instructions required to perform construction operation on the area agents in the workCluster agent. The bulldozer agent, compactor agent and fillSegment agent have inherent DRS models which serve as the primary interface with DES during the construction operations. The resources agents and their characteristics are shown in Figure 3.45.

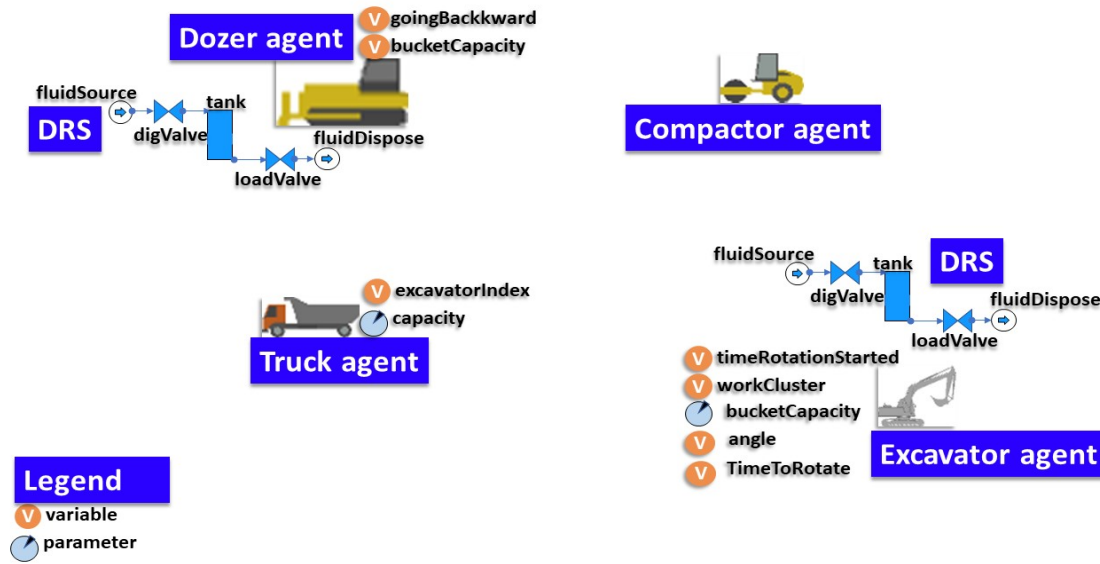


Figure 3.45. Resources agent

The fluid library employed in DRS is either the cut or fill materials. The fluid library, a package in AnyLogic, emanated as a result of the flow of cut and fill materials. The valve in the figure signifies the control operation of cut/undercutting loading and dumping. Correspondingly, the approach utilised in AnyLogic to investigate the activities for the construction execution is the main discussion of the next section, Section 3.8.15.1.

3.8.15.1 Workcluster agent implementation in Anylogic: manual operation

The process-centric activities for the accomplishment of the construction activities are defined in Section 3.8.2, and this section demonstrates those logical activities employed

to achieve the construction project. The model for manual operation is shown in Figure 3.46.

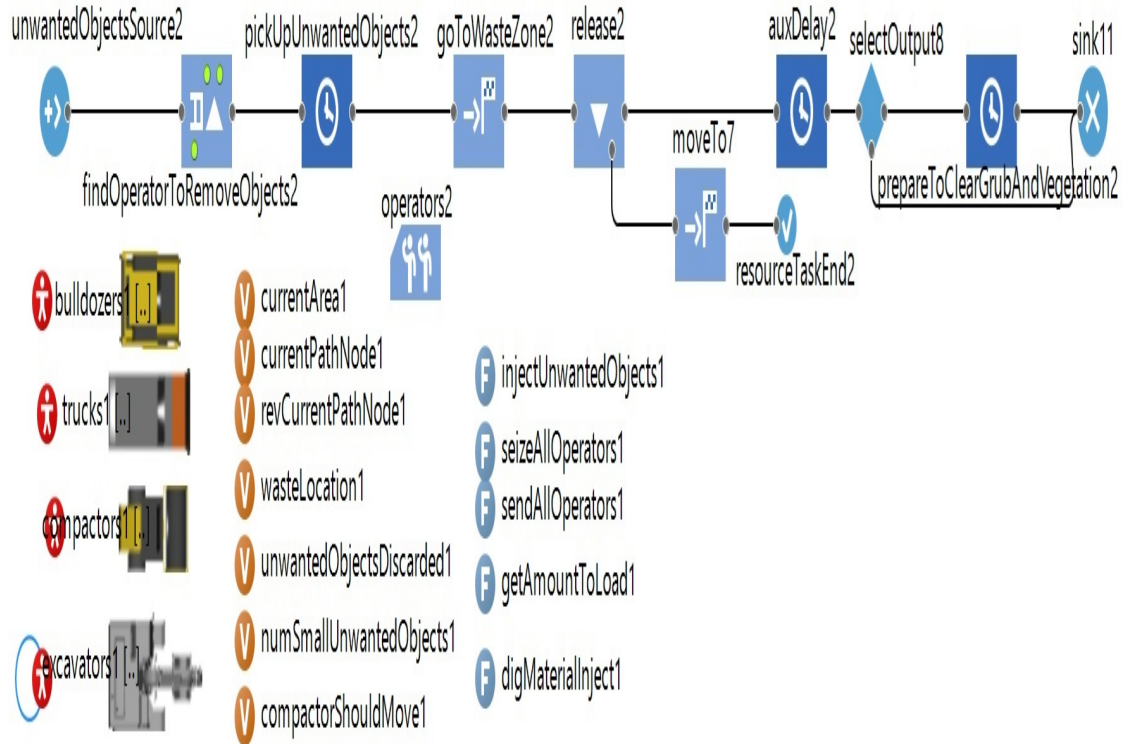


Figure 3.46. Manual cleaning for vegetation grubbing

The figure shows how a process model was created in AnyLogic to prepare the beginning of the stripping section by injecting several unwanted objects to be cleared before the execution of the topsoil stripping operation. The main flowchart object is the unwanted object as grubs to be cleared using operators as the resources. The flowchart objects and AnyLogic process library objects are employed to specify delays, manage resources utilisation and make decisions. Some snapshots steps of manual cleaning implementation in AnyLogic with the relevant java function call are presented in Figures 3.47a and 3.47b. The data for simulation is extracted from the CSC documents data and observation of construction operation.

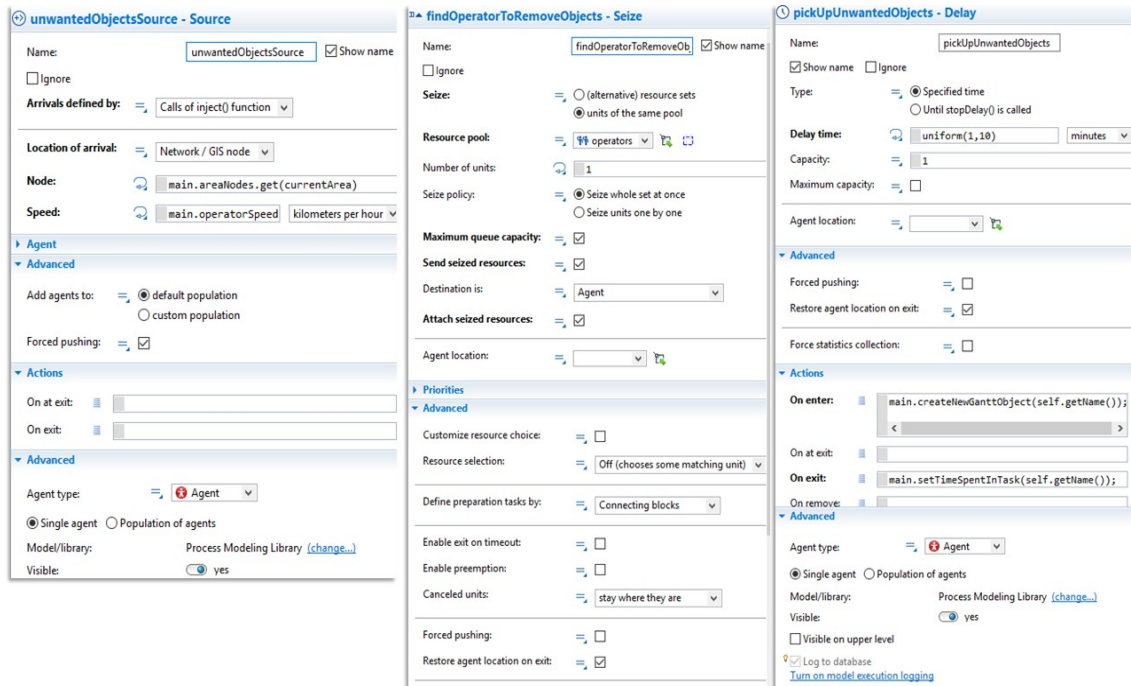


Figure 3.47a. Manual cleaning DES implementation Snapshots

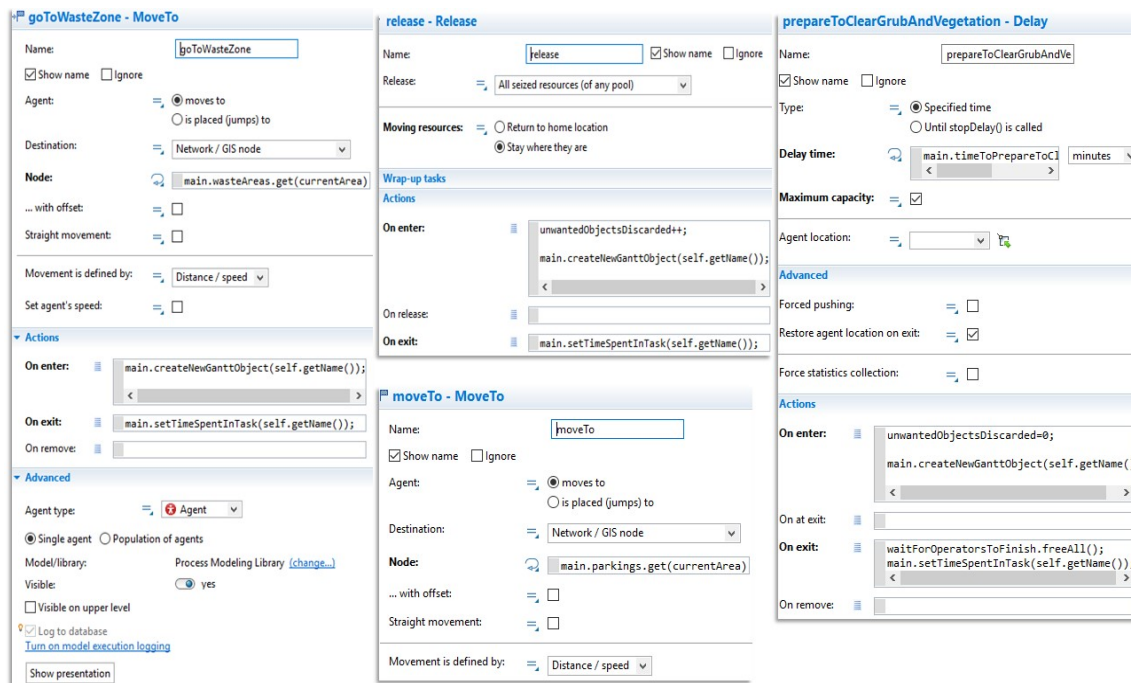


Figure 3.47b. Manual cleaning DES implementation Snapshots

3.8.15.2 Clear grub and vegetation and stripping operation

The model is shown in Figure 3.48.

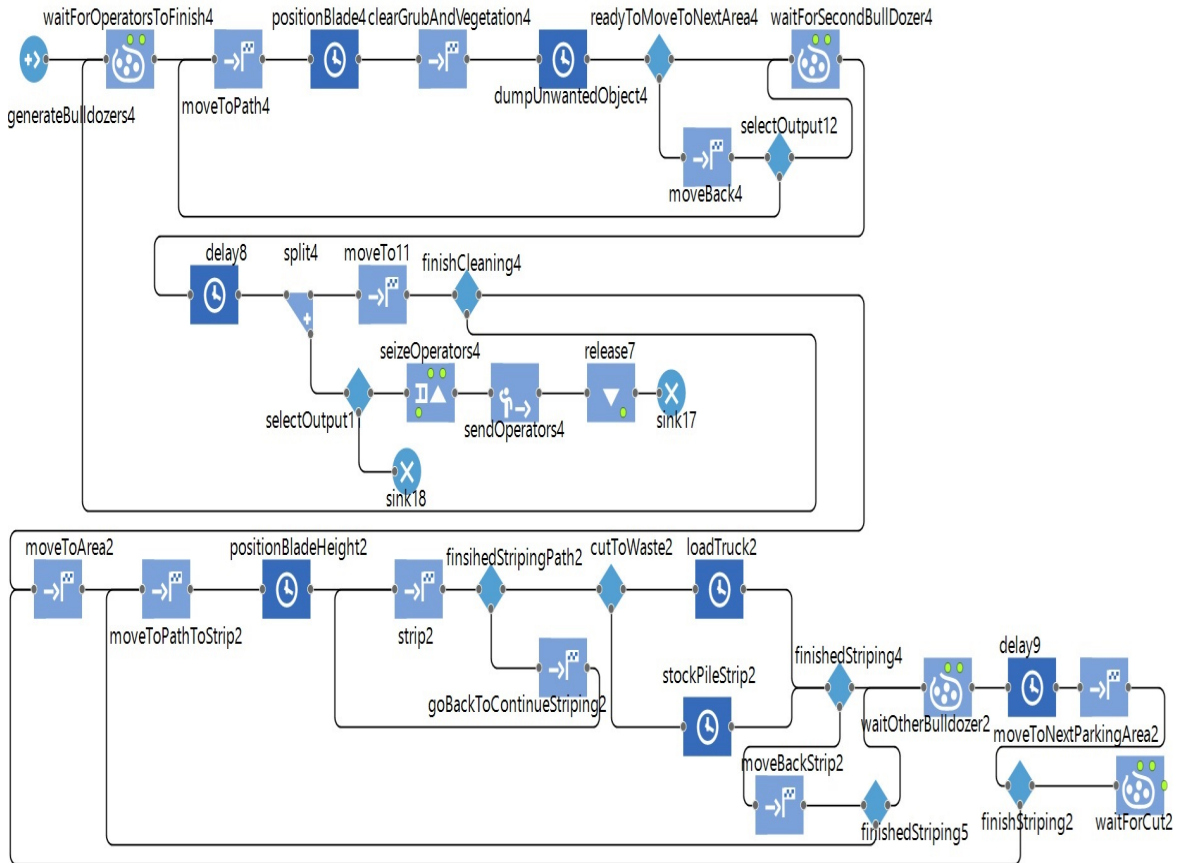


Figure 3.48. Vegetation Grub Stripping DES

The figure shows how a process model was created to execute the removal of vegetation, grubs and stripping. Dozer and operators are the resources agent utilised for the operation, capturing the resources movement-mechanisms and time to move to clear vegetation mechanically. Decisions are made to either use one dozer or more than one dozer. The flowchart objects and AnyLogic process library objects are employed to specify delays, manage resources utilisation and make decisions.

The portraits of stripping implementation in AnyLogic with the relevant java function call are presented in Figures 3.49a and 3.49b. The data for simulation depends on the data collection and observation from CSC.

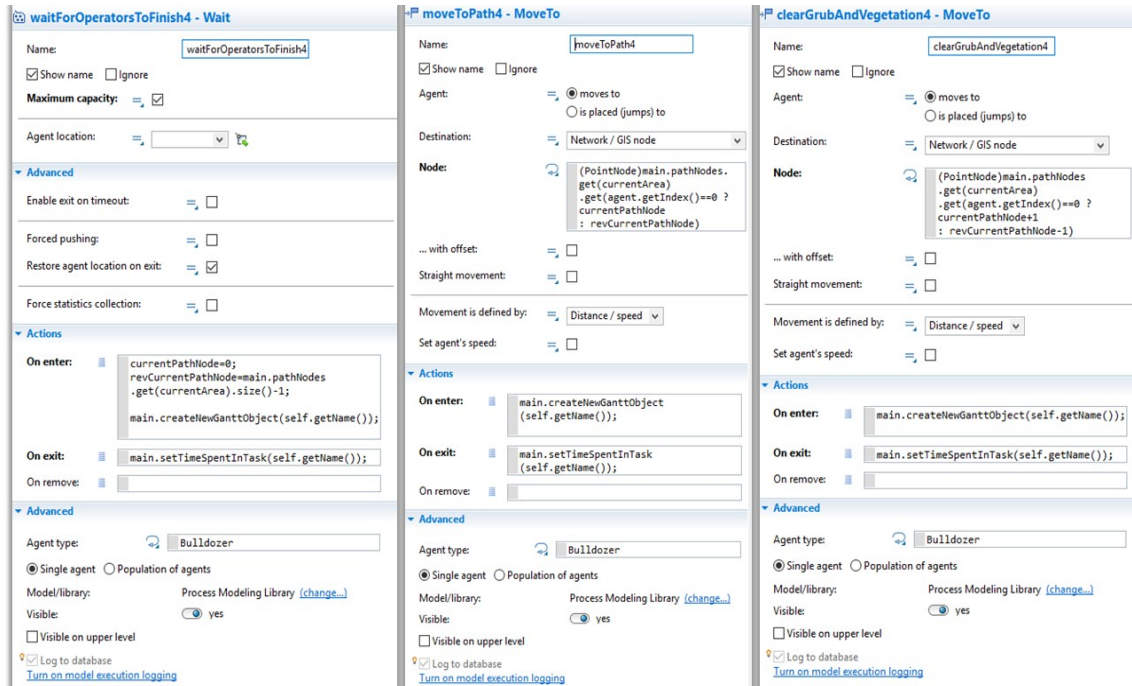


Figure 3.49a. Vegetation Grub Stripping DES implementation Snapshots

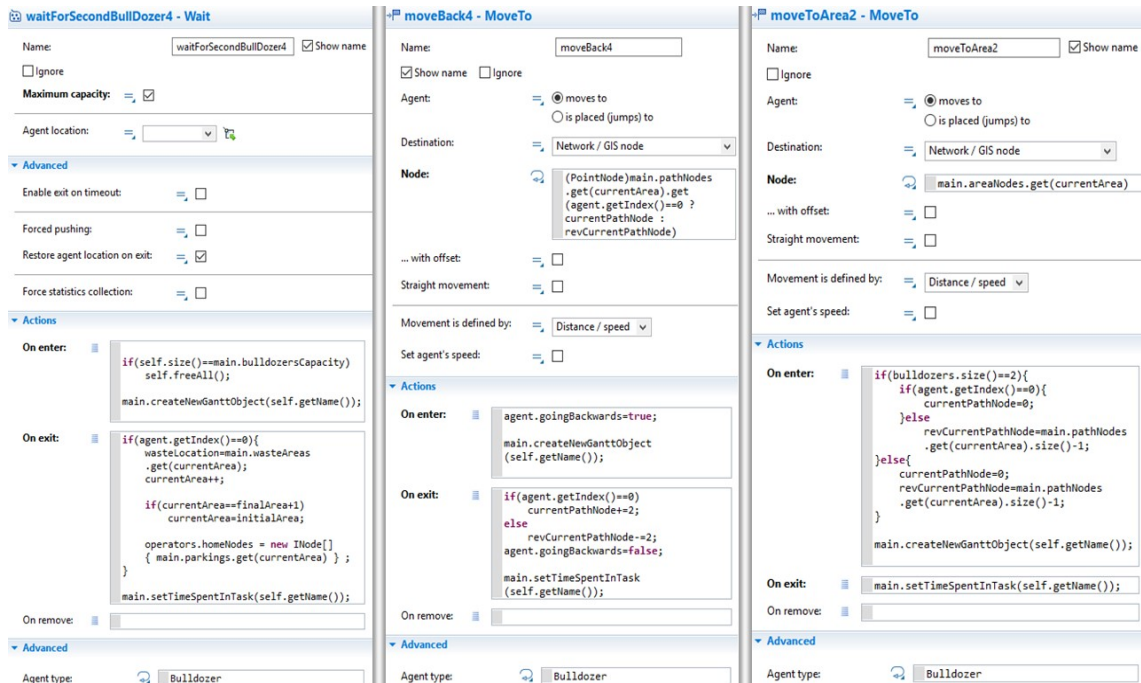


Figure 3.49b. Vegetation Grub Stripping DES implementation Snapshots

3.8.15.3 Cut/undercut filling and compaction operation

The cut and undercut model is shown in Figure 3.50

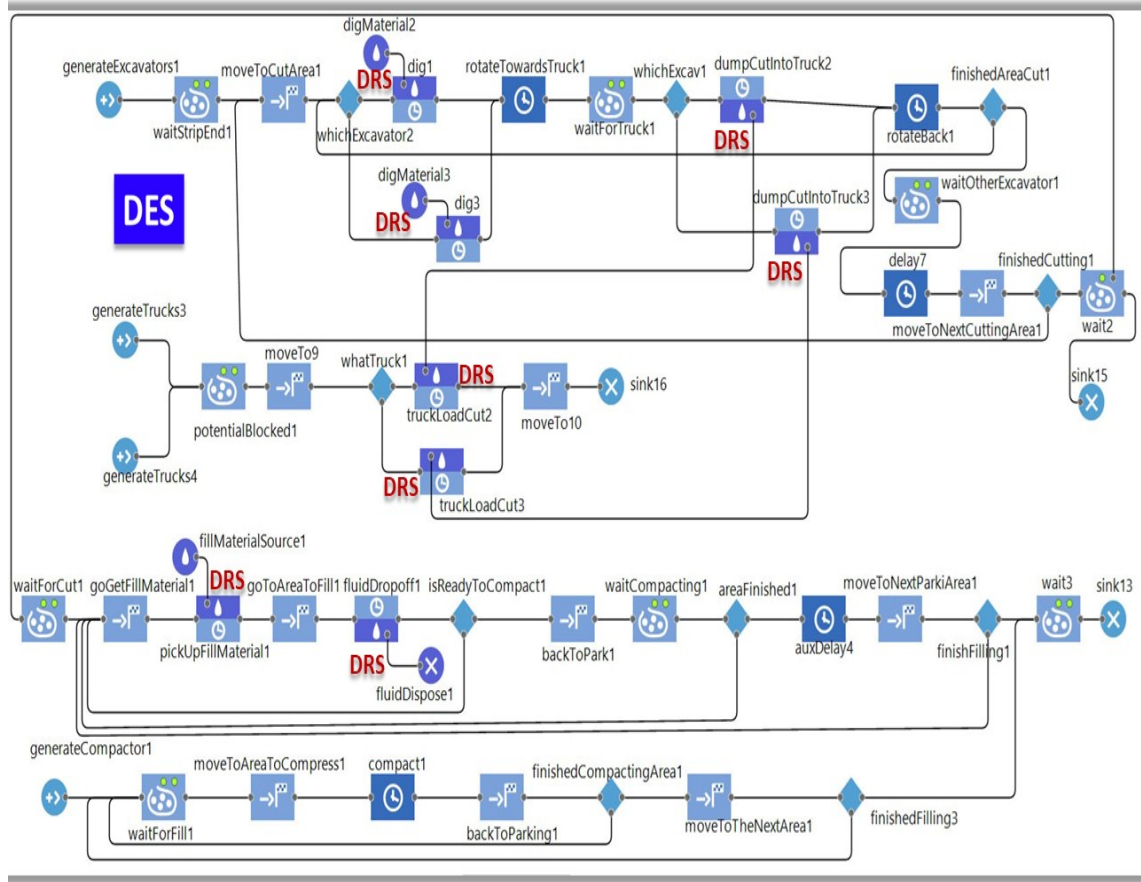


Figure 3.50. Cut undercut Filling Compaction DES

The model shows how a process model was created to execute the removal for cut/undercut, filling and compaction. Excavator, compactor and operators are the resources agent utilised for the operation, capturing the resources movement-mechanisms and time to move to complete the operations mechanically. Decisions are made to either use one specified resources agent or more than one. The flowchart objects and AnyLogic process library objects are employed to specify delays, manage resources utilisation and make decisions. The portraits of cut/undercut, filling and compaction implementation in AnyLogic with the relevant java functions call are presented in Figures 3.51a and 3.51b.

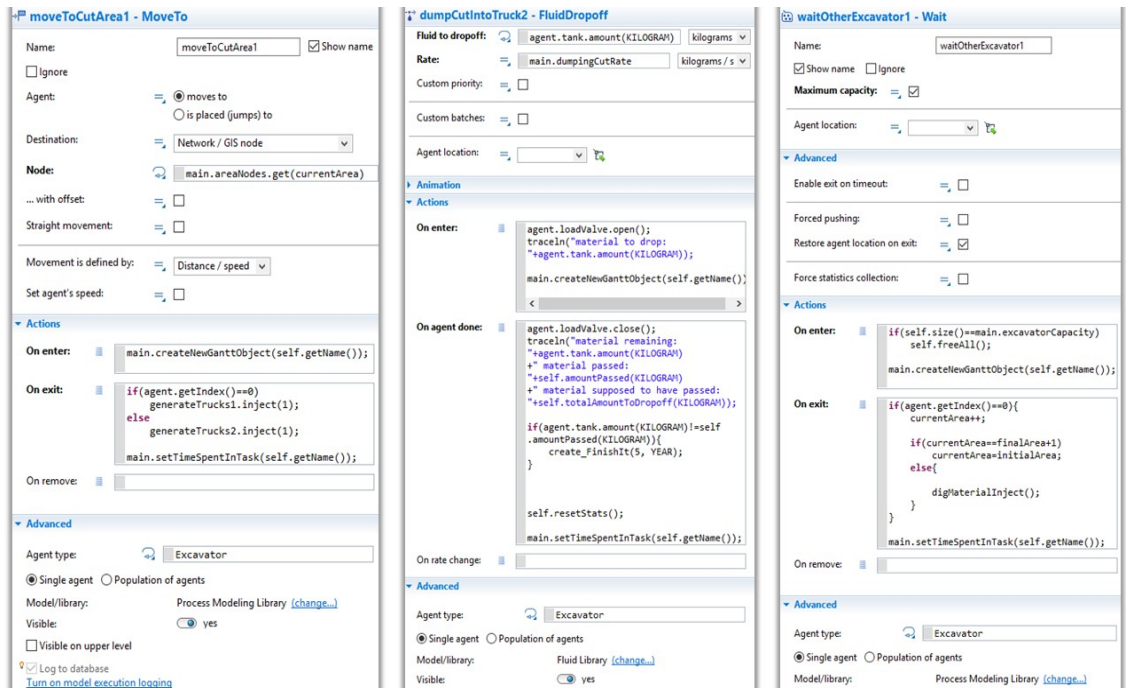


Figure 3.51a. Cut Undercut Filling Compaction DES implementation portraits

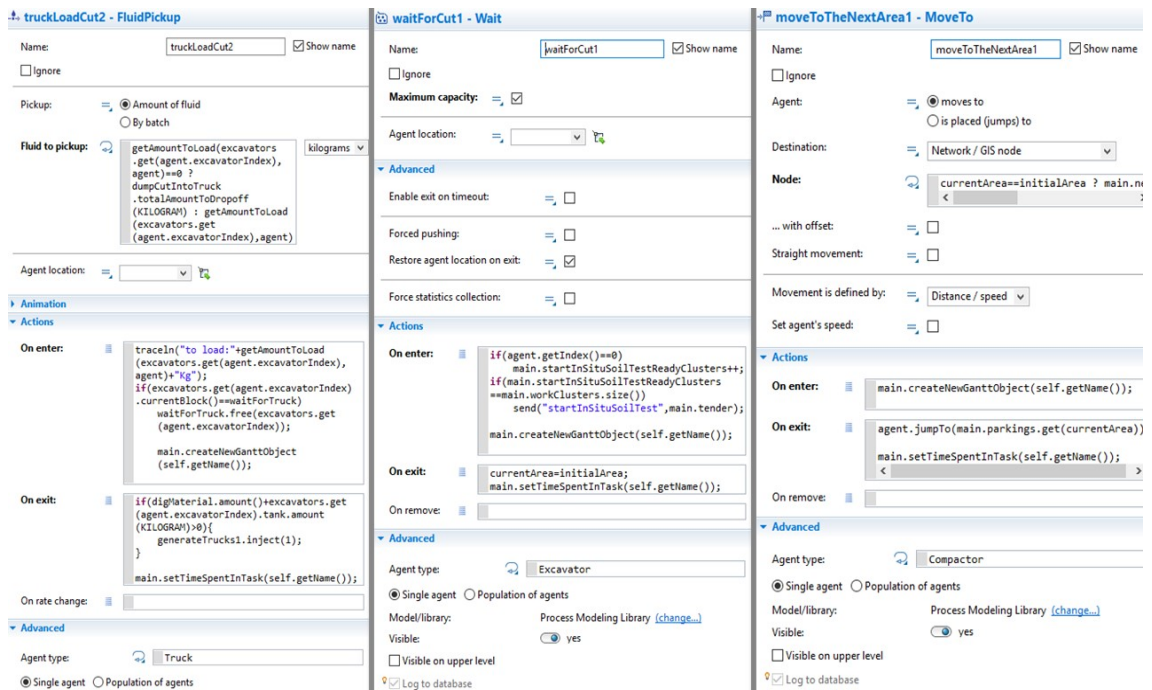


Figure 3.51b. Cut Undercut Filling Compaction DES implementation Snapshots

The data for simulation depends on the data collection and observation from CSC. The entire DES and DRS model is presented in Figure 3.52.

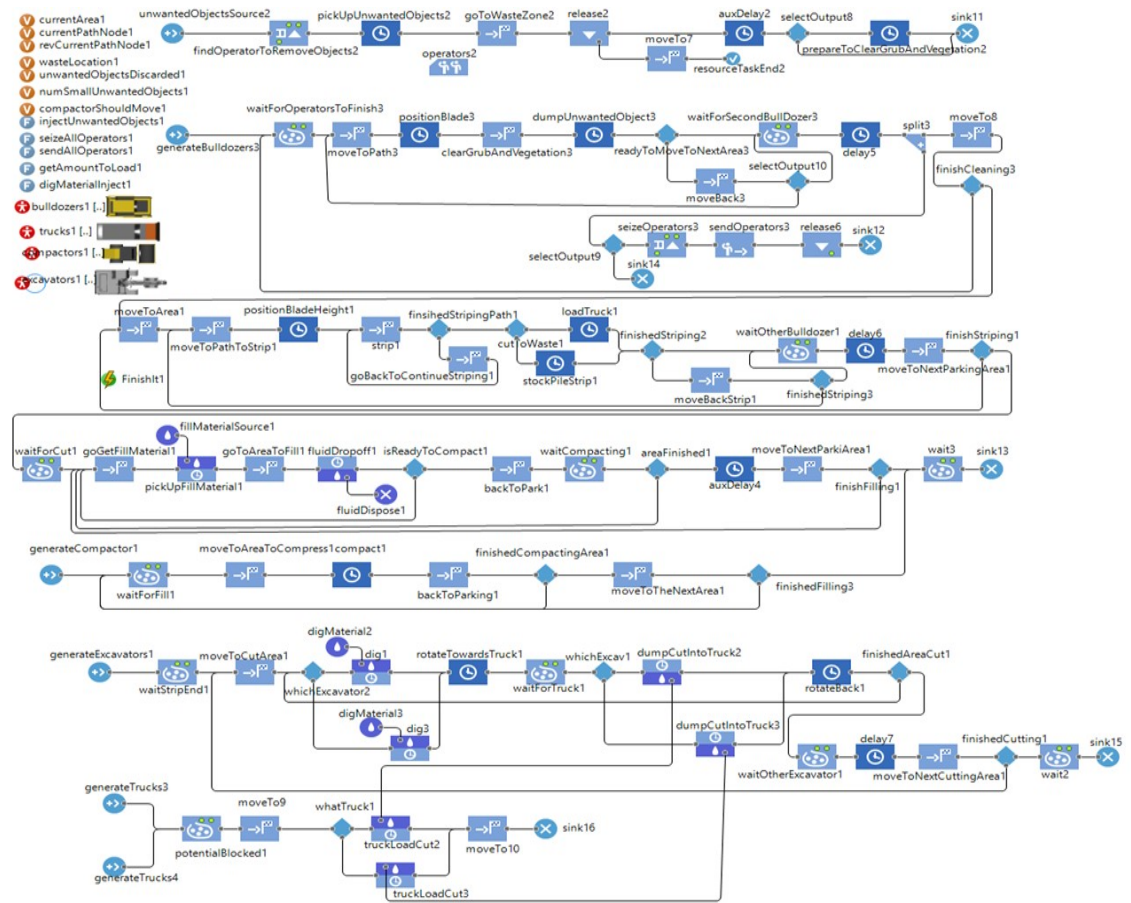


Figure 3.52. DES and DRS Anylogic complete model

Another key feature of this research is the investigations of specific influences, as stated in Section 3.8.2 that affected the different phases of the project. Having accomplished the ABS, DES and DRS implementation of the tender phase and construction phase, considering the idea of the research to integrate the construction multicomponent, the succeeding Section 3.8.16 explains the implementation and integration of those influences with the rest of the model in AnyLogic.

3.8.16 Tender phase and project influences

The construction operations in the deterministic nature of the work environment are expected to commence and complete as planned. In construction tasks, the complexities and scale deter the expected deterministic nature of the construction operation. During

the data collection, groundwater table, access egress and management influences are among the significant challenges that influenced the construction contract beginning from the tender phase. Given the objective of the research to investigate and evaluate the integration of the contract aspects, a dynamic hybrid paradigm is employed to integrate those aspects.

Until this section, the ABS, DES and DRS have been utilised to evaluate the tender phase and construction phase. In this section, the research implemented the influences on the tender phase and construction phase using a combination of SD and ABS, and hybrid integration flowchart is depicted in Figure 3.53.

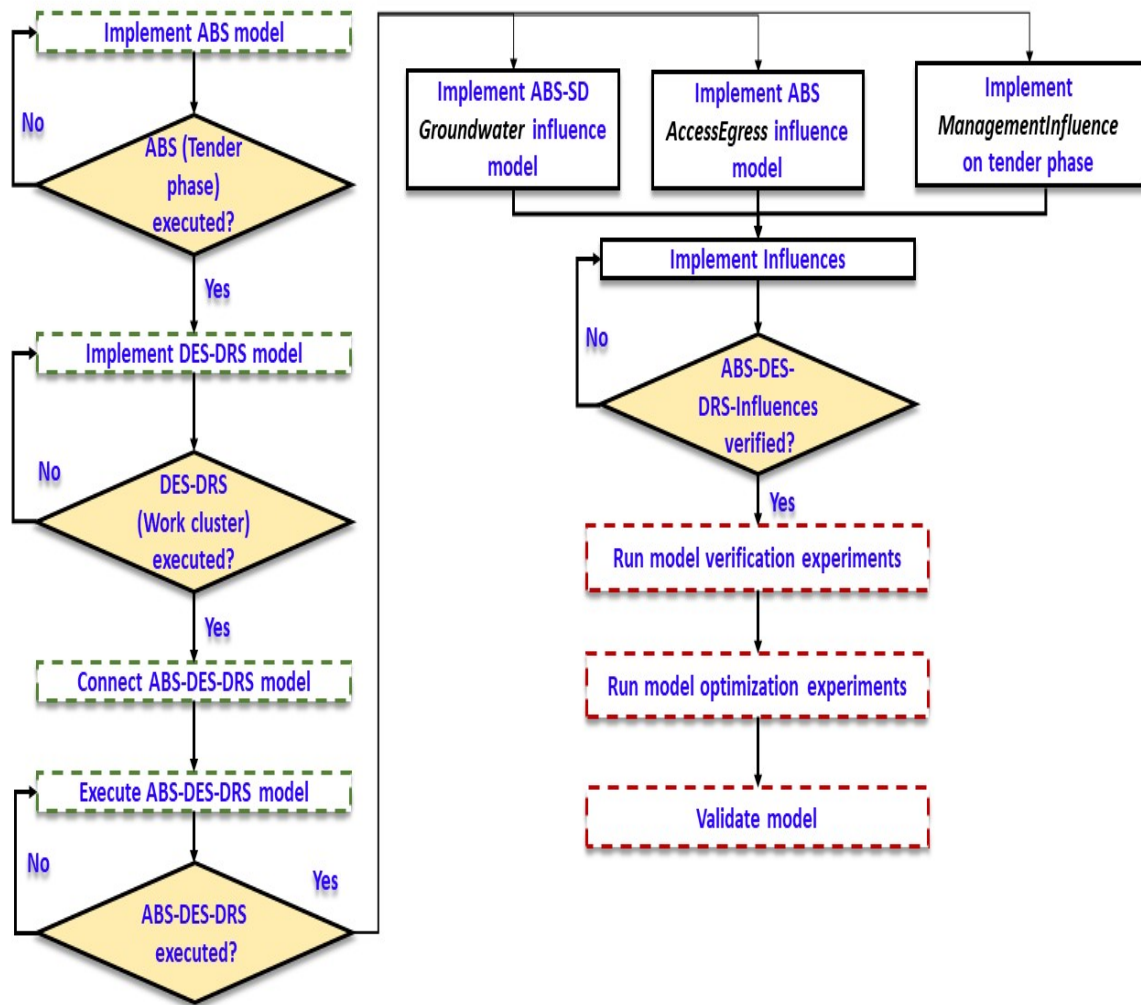


Figure 3.53. Hybrid flowchart

In the figure, the influences are linked to the tender phase agents and work cluster agents during simulation experiments. While the groundwater influence is implemented with a hybrid of ABS and SD (ABS-SD) access egress influence is realised with ABS during construction. Also, the management influence on the tender phase is implemented with Java function or method. The dotted rectangular shapes are part of the entire model implemented in the next chapter.

3.8.16.1 Ground water table influence and analysis on construction operation

The Figure 3.54 illustrates the raining and not raining states and their dynamics as implemented in AnyLogic.

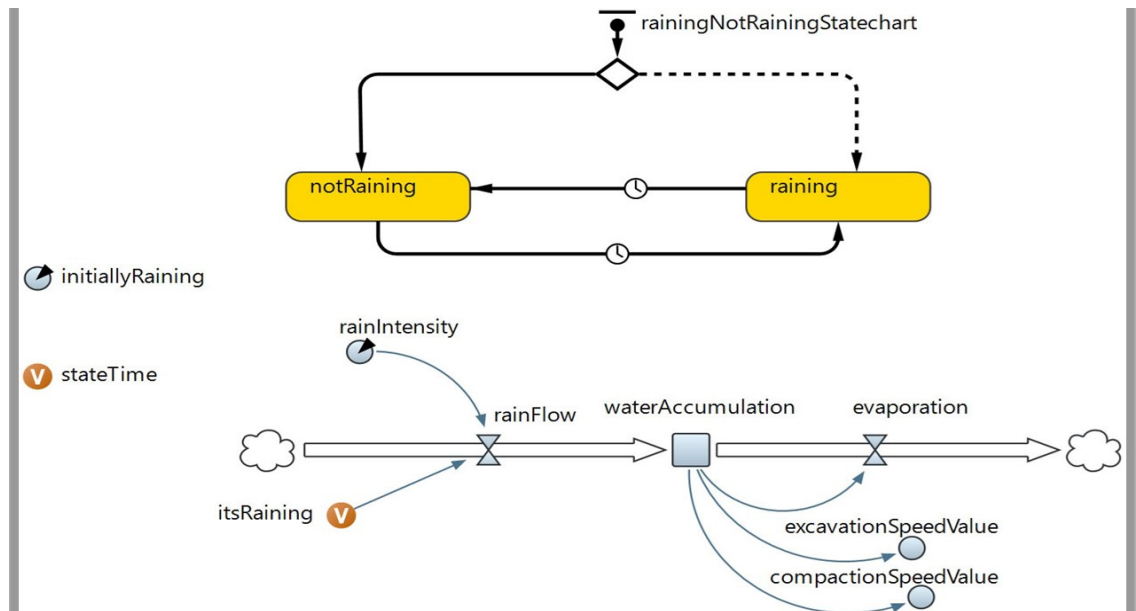


Figure 3.54. Ground water influence

Groundwater impacted the construction operations, especially the excavation speed and compactor speed, which are the main concerns considered in the research. Precipitation is defined as an agent with embedded ABS and system dynamics. As have been implemented in the tender phase, two states are defined: 1) raining, and 2) not raining with timeout transitions. The dynamics of the two states are defined with

the components of system dynamics illustrated in AnyLogic, namely stocks, flows, parameters and variables. Rain intensity increases flow when it is raining.

The more the volume that reaches the ground, the more the soil moisture content. The moisture content is dependent on the soil permeability. So, the more impermeable the soil is the more water it holds. The water percolates in the soil until, at the saturation point where it cannot hold more water, it increases the water table via the groundwater and as the groundwater increases. While the water is in the infiltration process, some volume evaporates. Temperature causes evaporation (water vapours in the air).

The increase in temperature increases water vapour in terms of evaporation from the soil. The effect of precipitation on the construction is implemented during precipitation experiments of ground water effects on excavation speed and compaction speed defined in Section 3.8.9. The rain-flow results to water accumulation that affects the excavator and compactor speeds.

3.8.16.2 Access egress

When construction vehicles enter (access) or exit (egress) the construction workspace, they generate speed differentials in relation to regular traffic using the work area as depicted in Figure 3.55.



Figure 3.55. Access-egress concept

The workers moving on foot in the work area causes speed differentials. Space (low acceleration and deceleration space) available for construction truck to deceleration and accelerate while exiting or entering work area causes speed differentials. More speed differentials cause more accelerations and decelerations, more noise impact, more

inconsistent driver behaviour, the higher probability of zone crash. It also leads to the reduction in work zone capacity and the higher probability of hazards. More decelerations and accelerations more probability of knocking down workers on foot.

In that case, hazards can be considered as hazards occurrence on entering the highway from the work area and entering the work area from the highway. If there are more frequent driveway access (work area driving path or road within the work area), more construction vehicle acceleration and deceleration conflicts occur. Driveway access means the access that provides an ingress (entering)/egress (exit) movement. The research investigated the conditions for time differential and frequency of blocking and unblocking the access around the work areas.

The influence of access egress agent on the work area is implemented during access egress experiment. The Anylogic implementation is depicted in Figure 3.56 using statechart with the normal flow state, blocked flow states, block access message, timeout, time to fix blocked access variable and a dynamic event of time to next access blocked.

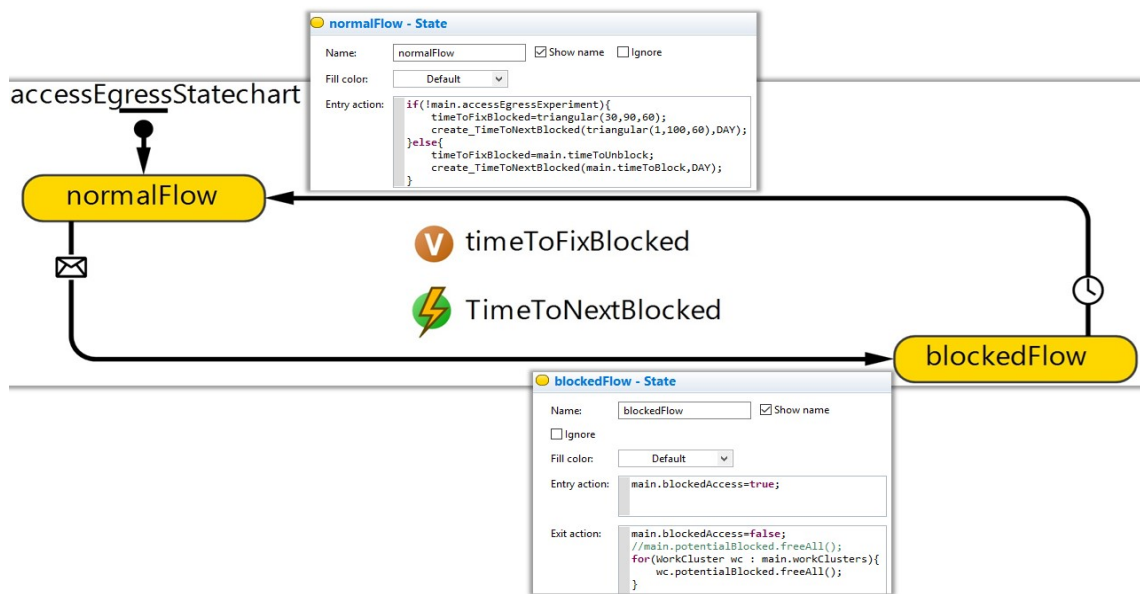


Figure 3.56. Anylogic access-egress implementation

3.8.16.3 Management influences

During the tender phase, CSC project teams are combined to ensure the preparation of the bid, creating plan and bid documents that formed the input for the execution of the construction project contract. The bid submission has a stipulated time as stated by the client during the bid and proposal request; however, the CSC in accomplishing the request, analysed the opportunities and threats in terms of bid or no-bid decision. In that regard, the management of team collaborations during the bidding phase is an important time factor. Again, such management time influences are evaluated in AnyLogic using stochastic time variables and Java method. The variable and method are defined on each activity to investigate the outcomes during influenced and uninfluenced periods. For instance, in one of the tender activities: *time to enumerate work packages*, a `timeToEnumerateWorkPackages` variable is created with initial value as:

$$managementInfluence * triangular(1, 3, 2) \quad (3.29)$$

after defining a management influence parameter:

$$main.managementInfluence \quad (3.30)$$

The screenshots of the implementation in AnyLogic is the illustrations of Figure 3.57.

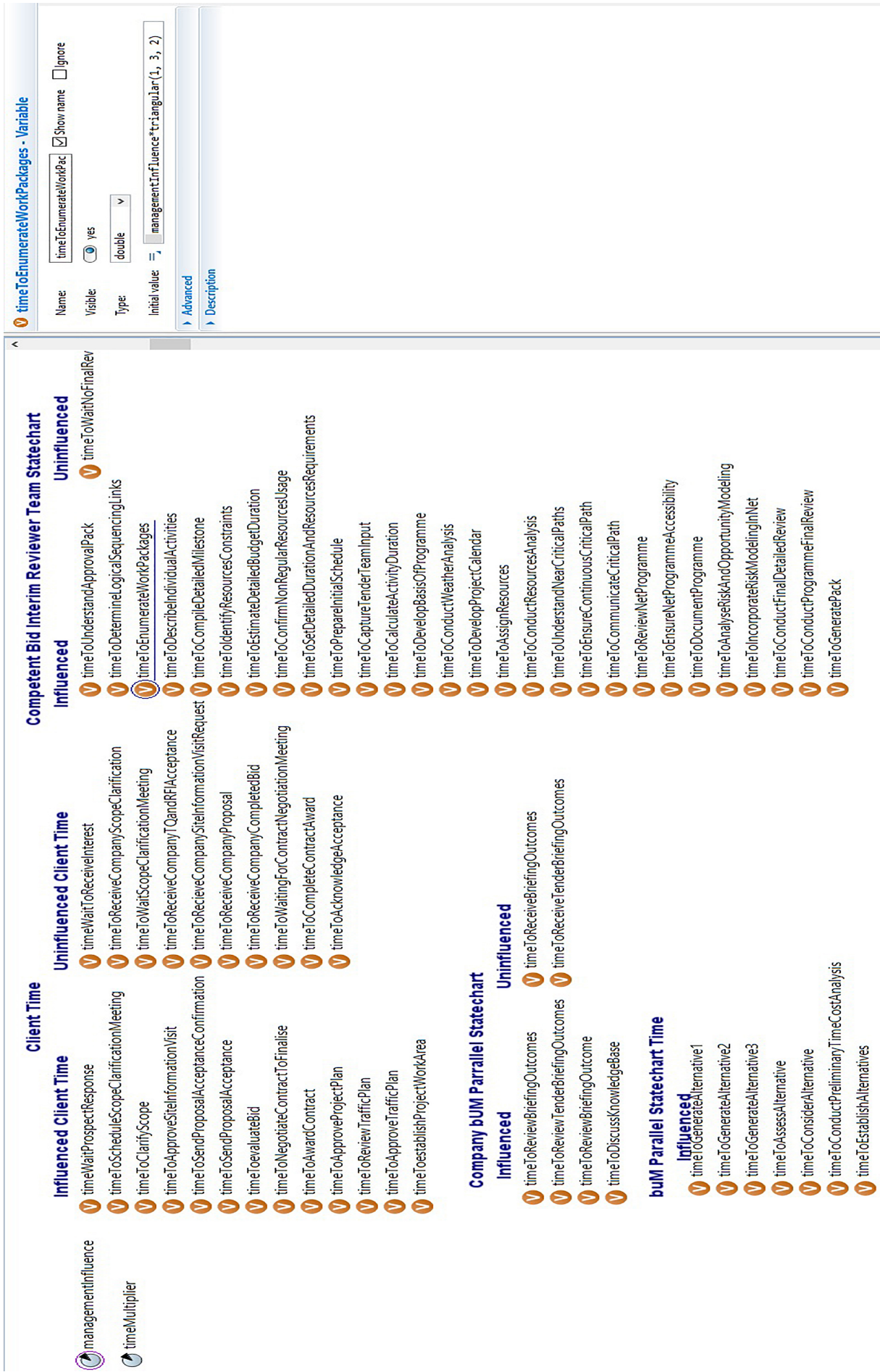


Figure 3.57. Anylogic management influence implementation

In the sections of 3.8.13, the research questions *Q8, Q9, Q10, Q12, partly Q13* respectively, asking:

To what extent can the model assure the flexibility to accept multiple inputs?

What are barriers that may be associated with the model integration, and how are they addressed?

How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?

What is the technique to present the model solution for application by the construction project team to improve the planning decision?

To what extent can the integrated planning solution aid the capability of construction project management?

This is to achieve objective *2*, whereby the research has established a framework simulation model for investigating the flow of real-time planning in tender/bidding and construction phases. The implementation of the multi-hybrid model and influences completed the modeling and simulation; however, another important part of the research is the system optimisation. The implementation of the system optimisation is the main discussion of Section 3.8.17.

3.8.17 Integration of plan with optimisation: system optimization

In the optimisation system and by modifying the number of teams, number of excavators and bulldozers in each team, the researchers want to answer the optimisation questions:

- 1) How can we minimise the number of machines used with the constraint that the project has to be finished before 450 days to achieve optimal and feasible solution?

The optimisation function is defined in Equations (3.31a) and (3.31b):

$$\underset{bs, es, wts, apcs}{\text{minimize}} \quad \sum_{j=1}^N (bs + es) \times \left(\frac{wts}{apcs} \right) \quad (3.31a)$$

subject to

$$300 \leq \sum_{j \in N}^N t_j \leq 450 \quad (3.31b)$$

Where bc , es , wts , $apcs$ and t are the bulldozer capacity, excavator capacity, work teams, area per workcluster and durations respectively. 2) What are the values of the construction parameters for minimizing the objective function to ensure that the behaviour of the model parameters is consistent with real-world characteristics? The idea of the optimisation is the investigations for best use of the resources for an integrated and optimum plan that eventually produces an optimal schedule to enhance decision-making. The optimisation experiment employed OptQuest, a metaheuristic optimiser in AnyLogic, utilised to perform the scatter search optimisation (Borshchev 2013b, Kirby, Dietz, Matson, Pekny, & Wojtalewicz 2015, Laguna 1997, J. Zhao, Kucuksari, Mazhari, & Son 2013). The optimiser is a black box that utilises the system inputs and environment to determine the system outputs or responses. Because of the objective function, the aim is to generate model parameters that minimise the project duration within the specified constraints. To set up the optimisation system:

- (A) The researcher created a variable called *bestInfeasibleObjective*, and three different data sets: *datasetCurrentObjective*, *datasetBestInfeasibleObjective* **and** *datasetBestFeasibleObjective* for collecting output data.
- (B) A collection of bulldozers (*bs*), excavators (*es*), area per cluster (*apcs*) that defines the area for each location, durations (*times*) and objectives (*objectives*). The collections are created using AnyLogic collection object, which is an array list

containing multiple elements of a certain type. The collections are utilised to define the objective function. The collections are initiated at the end of each simulation run with the calculation of their values, for instance in Equation 3.32:

$$ArrayList < bulldozers > equipment = new ArrayList < bulldozers > (); \quad (3.32)$$

- (C) Taking into account the optimisation questions stated above, in AnyLogic the objective function is defined as:

$$(root.bulldozersCapacity + root.excavatorCapacity) \\ * ceil(33.0/(double)root.areaPerCluster) \quad (3.33)$$

where 33 is the number of clusters, *root* is a reference to the AnyLogic *Main*.

- (D) The parameters of the objective function are defined and varied in different experiments, as shown in Table 3.22:

Table 3.22

Optimisation parameters

Parameter	Type	Minimum	Maximum	Step	Suggested
bulldozerCapacity	discrete	1	2	1	2
excavatorCapacity	fixed	1	2	1	2
compactorSpeed	discrete	10			
areaPerCluster	discrete	4	11	1	7
managementInfluence	fixed	1			
managementInfluenceExperiment	fixed	false			
accessEgressExperiment	fixed	false	false		
timeToUnblock	fixed	60			
timeToBlock	fixed	53,6666			
managementInfluenceExperiment	fixed	false			
managementInfluenceExperiment	fixed	1			

- (E) An additional requirement is imposed on the simulation on what to do if the condition is not met. In that case, the definition of best infeasible objectives and best feasible objective with the parameter values. While a set of parameters is feasible if the constraints are met at the end of the simulation and accepted by the optimisation system, the reverse is the case when parameters are infeasible and are rejected by the optimisation engine.

(F) Java class actions are defined in AnyLogic.

(i) before each experiment run, the following codes are executed:

```
datasetCurrentObjective.reset();  
datasetBestInfeasibleObjective.reset();  
datasetBestFeasibleObjective.reset();
```

(ii) succeeding each experiment run, the following codes are executed after model execution:

```
bs.add(root.bulldozersCapacity);  
es.add(root.excavatorCapacity);  
apcs.add(root.areasPerCluster);  
teams.add(ceil(33.0/(double)root.areasPerCluster));  
times.add(root.getTimeStampDays());  
objectives.add (((root.bulldozersCapacity+  
    root.excavatorCapacity)  
    *ceil(33/root.areasPerCluster)));
```

(iii) the following codes are executed after each iteration run:

```
if (isBestSolutionFeasible()) {  
    datasetBestFeasibleObjective.update();  
}  
  
if (!isCurrentSolutionFeasible()) {  
    bestInfeasibleObjective =  
    min( bestInfeasibleObjective,  
        getCurrentObjectiveValue() );  
}
```

```

        if (bestInfeasibleObjective != Double.POSITIVE_INFINITY) {
            datasetBestInfeasibleObjective.update();}

```

(iv) the following codes are executed after each experiment:

```

export.readFile();
for(int i=0;i<times.size();i++){
    export.setCellValue(bs.get(i), 1, i+2, 1);
    export.setCellValue(es.get(i), 1, i+2, 2);
    export.setCellValue(apcs.get(i), 1, i+2, 3);
    export.setCellValue(teams.get(i), 1, i+2, 4);
    export.setCellValue(times.get(i), 1, i+2, 5);
    export.setCellValue(objectives.get(i), 1, i+2, 6);
}
export.writeFile();

```

The optimizer implementation screenshots in AnyLogic is shown in Figures 3.58a to 3.58d to perform scatter search.

Optimization - Optimization Experiment

Name: ☐ Ignore

Top-level agent:

Objective: ☒ minimize ☐ maximize

☒ Number of iterations:

☒ Automatic stop

Maximum available memory: Mb

Parameters

Parameters:

Parameter	Type	Value			
		Min	Max	Step	Suggested
bulldoz...capacity	discrete	1	2	1	2
excavat...apacity	discrete	1	2	1	2
compactorSpeed	fixed	10			
areasPerCluster	discrete	4	11	1	7
manage...luence	fixed	1.0			
manage...riment	fixed	false			
accessE...riment	fixed	false			
timeToUnblock	fixed	60			
timeToBlock	fixed	53.6666			
precipit...eriment	fixed	false			
precipi...nEffect	fixed	1.0			

Model time

Stop:

Start time:

Stop time:

Start date:

Stop date:

Figure 3.58a. Optimization implementation

After simulation run:

```
bs.add(root.bulldozersCapacity);
es.add(root.excavatorCapacity);
apcs.add(root.areasPerCluster);
teams.add(ceil(33.0/(double)root.areasPerCluster));
times.add(root.getTimeStampDays());
objectives.add(((root.bulldozersCapacity+root.excavatorCapacity)
*ceil(33/root.areasPerCluster)));
```

After iteration:

```
if (isBestSolutionFeasible()) {
    datasetBestFeasibleObjective.update();
}
if (!isCurrentSolutionFeasible()) {
    bestInfeasibleObjective = min( bestInfeasibleObjective,
    getCurrentObjectiveValue() );
}
if (bestInfeasibleObjective != Double.POSITIVE_INFINITY) {
    datasetBestInfeasibleObjective.update();
}
```

After experiment:

```
export.readFile();

for(int i=0;i<times.size();i++){
    export.setCellValue(bs.get(i), 1, i+2, 1);
    export.setCellValue(es.get(i), 1, i+2, 2);
    export.setCellValue(apcs.get(i), 1, i+2, 3);
    export.setCellValue(teams.get(i), 1, i+2, 4);
    export.setCellValue(times.get(i), 1, i+2, 5);
    export.setCellValue(objectives.get(i), 1, i+2, 6);
}

export.writeFile();
```

Advanced Java

Imports section:

Additional class code:

Java machine arguments:

Figure 3.58c. Optimization implementation

Current		Best
Iterations completed:	? infeasible	? infeasible
Objective: ↓	?	?
Parameters	Copy best	
bulldozersCapacity	?	?
excavatorCapacity	?	?
compactorSpeed	?	?
areasPerCluster	?	?
managementInfluence	?	?
managementInfluenceExperiment?	?	?
accessEgressExperiment	?	?
timeToUnblock	?	?
timeToBlock	?	?
precipitationInflExperiment	?	?
precipitationEffect	?	?

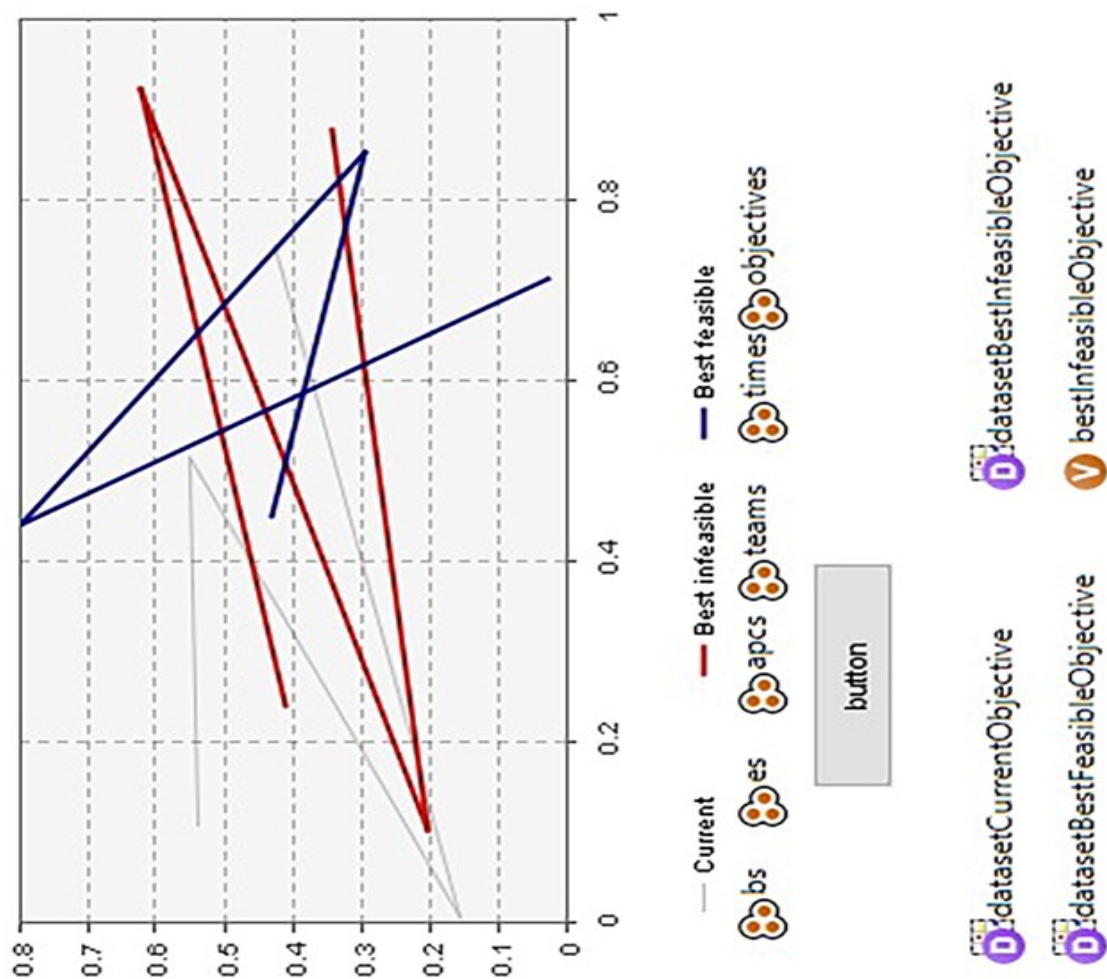


Figure 3.58d. Before optimization interface

In the experiment, the model was tuned to replicate the real data to generate an optimum plan and optimum schedule. In view of the research questions (*Q12 and Q14*), asking:

Q12. What is the technique to present the model solution for application by the construction project team to improve the planning decision?

Q14. How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?

The optimisation system is implemented to enhance the solution to construction project management by generating an optimal plan for the optimal schedule. However, the integration of plan and schedule has been supported by the implementations till this point. Although, how the integration is implemented forms the central theme of the next Section 3.8.18.

3.8.18 Gantt chart implementation

The research goal is the generation of optimised plan to produce an optimised schedule because this research belief is that schedule is the outcome of the plan. In that regard, plan and schedule are integrated to yield optimum schedule and plan. The multi-hybrid simulation, optimisation and variability integration generated the plan. In this research the collection of time to perform each task, after the plan was optimised, is implemented by the creation of instructions using java class in Anylogic main. First, in each task, a Java method was created in the entry and exit of each activity or any activity of interest to obtain the duration required, whereby the method is Equation 3.34:

$$\begin{aligned}
 &OnEnter : \\
 &\quad main.createNewGanttObject(self.getName()); \\
 &OnExit : \\
 &\quad main.areas.get(currentArea).timeSpentStripingPath = 0;
 \end{aligned} \tag{3.34}$$

Second, instructions were created with Java Gantt class, and was implemented in

AnyLogic to facilitate the execution of experiments on the task durations:

```
public class Gantt implements Serializable {

    private double initialTime;
    private String name;
    private double timeSpent;
    private int timesUsed;
    public ArrayList <Double> timeSpentArray;
    public ArrayList <Integer> timesUsedArray;

    public Gantt (double initialTime,String name){

        this.initialTime=initialTime;
        this.name=name;
        this.timeSpent=0;
        this.timesUsed=0;
        timeSpentArray=(new ArrayList<Double>());
        timesUsedArray=(new ArrayList<Integer>());
    }
    public void setTimeSpent( doublecurrentTime){
        this. setTimeSpent+=(currentTime - this. initialTime);
    }
    {
        double getTimeSpent() {
            return this.timeSpent;
        }
        public String getName() {
            return this.name;
        }
        public double getInitialTime() {
            return this.initialTime;
        }
        public void setTimesUsed() {
            return this.timesUsed++;
        }
        public int getTimesUsed() {
            return this.timesUsed;
        }
        public void setInitialTime (double time) {
            return this.initialTime=time;
        }
        public String toString() {
            return super.toString();
        }
    }
}
```

```
private static final long serialVersionUID = 1L;
```

Finally, in the main of AnyLogic where the animation logic is created, *setTimeSpentPerTask* and *createNewGanttObject* instructions are created for Gantt implementation and settings for time spent to execute each task. The array of time spent per task *timeSpentPerTask* is developed to keep a collection of time utilised for each task. The script developed for the methods is depicted in Figure 3.59. In each activity, Equation 3.34 is embedded to enhance the collection of durations from each tasks.

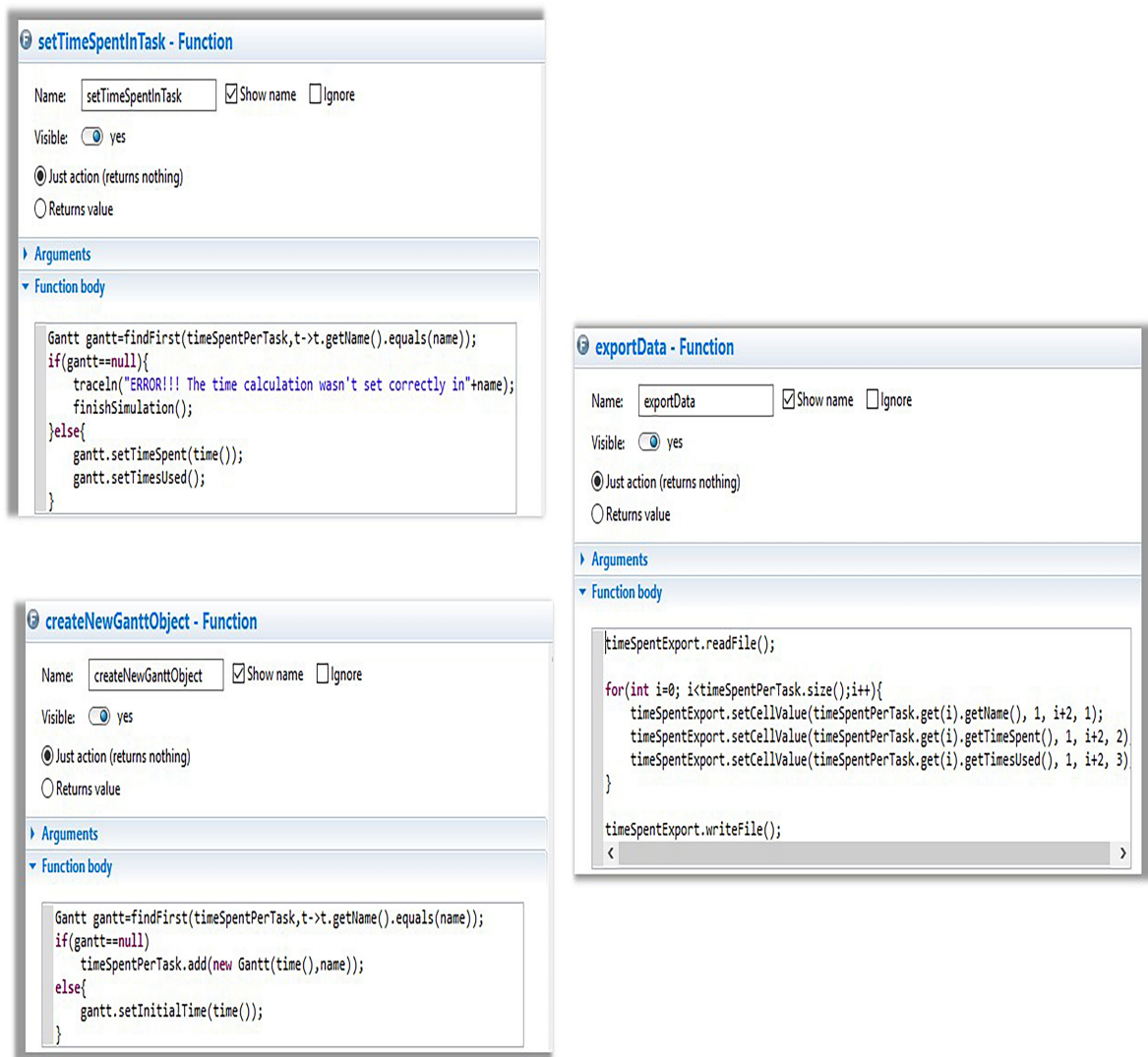


Figure 3.59. Instructions for Gantt implementation

Interestingly, the plan and schedule are integrated into dynamic events to generate integrated planning and scheduling, presented in the next chapter: results and findings. This is significant as an answer to the research questions (*Q13*), asking

To what extent can the integrated planning solution aid the capability of construction project management?

The next part of the research multi-hybrid analysis and implementation is the model simulation experiments, discussed in Section 3.9. The main idea for creating that section is because the research mapped the real world into the simulation model, and the model validation and verification are employed to confirm the mapping.

3.9 Model simulation experiment

The real-time hybrid model was formulated to solve static and dynamic planning and scheduling problem with multi-objectives and construction multi-phases to support effective decision-making. In this chapter, the formulated hybrid model implemented in AnyLogic is tested for solution capabilities to construction planning and scheduling problems. Real data from CSC construction site were engaged for the verifications. This section is divided into two subsections: 1) Model Validation and; 2) model verification.

3.9.1 Model validation

The next part of the simulation and optimisation is the model validation because the research mapped the real world into the simulation model. Model validation is employed to compare the real data with model predictions and is a key aspect of simulation modeling (Consonni, Ballabio, & Todeschini 2010, Y. Ling & Mahadevan 2013, Mayer & Butler 1993, Mullins, Ling, Mahadevan, Sun, & Strachan 2016). Although the validation of the interacting systems and interacting agents is practice-oriented, the

inputs and outputs of the system deserve comprehensive validation (Bharathy & Silverman 2010).

The validation is expected to confirm that the paradigm is representing the phenomenon of the real construction system it is mapping. The verification and validation were operationalised in AnyLogic tool (Borshchev 2013a) with simulation experiments. In the literature review section of the thesis, the advantages of using simulation are extensively presented, and this formed the process design basis that enhanced the research outcomes because the construction system of the research case is dynamic.

Simulation is among the promising technology for analysing that kind of systems exhibiting dynamic characteristics (scale, complexity and uncertainty), unlike the analytical systems which have one degree of freedom.

The development of the framework and formulation of the model are vital to the construction system, but their conversions to executable framework and model are underpinned with simulation. In that case, the current state of the construction system is determined subject to several methods and instructions. The implementation or the execution of the paradigms is feasible only with the availability of an existing modeling tool. The tool is expected to have the capabilities of mirroring the real-world construction system to yield robust and quality solutions.

Besides, software with the capability of defining the behaviours of the system inputs, input environment, flexibilities on integrating object-oriented evaluations and generating a statistical analysis for decision support unique for the research situation is a concern. The use of simulation enhanced updating any of the model parameters as soon as any changes occur. At the same time, while concentrating on achieving the results that are not limited by those concerns, generating a visualisation of the system behaviour is implicit for ascertaining the model, thereby validating the outcomes. Contentedly, AnyLogic has unique features relevant to the research case study implementation.

The objective of the research is the representation of the real-case construction system. The quality of the framework and paradigms solutions depend on their capability to generate experiments that represent the construction system under the research study. The key paradigm is mainly based on a discrete events structure because the main and large amounts of tasks are implemented with DES paradigm. The discrete rate simulation, agent-based and system dynamics are supporting techniques. The research utilised an objective validation technique, which is a comparison of model simulation (Validation experiment in the model) with the information of real world using the CSC contract milestones, depicted in Table 3.23.

Table 3.23

CSC validation data

	Activity	From	End	Duration (days)
1	Tender preparation by contractor	29/01/2015	2/06/2015	102
2	Tender Evaluation by client	2/06/2015	20/06/2015	34
3	Winner announced	20/06/2015	20/06/2015	1
4	Negotiation and Contract Award	20/06/2015	13/08/2015	21
5	Contract Acceptance and Project start	14/08/2015	9/09/2015	19
6	Traffic plan	9/09/2015	13/11/2015	47
7	Traffic switch	16/11/2015	23/11/2015	6
8	Work area establishment	2/12/2015	8/12/2015	4
9	Site preparation	26/01/2016	28/01/2016	3
10	Topsoil strip	29/01/2016	4/02/2016	3
11	Cut	5/02/2016	11/02/2016	4
12	Fill And Compact	5/02/2016	10/02/2016	3

The main resources parameters for the validation experiments are: 2 bulldozers, 2 excavators and work teams defined for the areas under normal conditions. Site preparation, topsoil strip, cut and fill and compacting (last 4 rows of Table 3.23) are values per area. To obtain the real time it takes to complete the project, the model results are multiplied by 33 (number of areas). One of the subjective techniques that formed part of the validation of the model is the visualisation of the simulation presented to the construction team seeking their feedbacks and approval on the construction.

The experiments involved running the equations in a number of iterations,

which generates different outputs in each run implemented in AnyLogic. In the implementation interface, the 12 activities from the validation data in Table 3.23 are divided into milestones datasets (*milestone1, milestone2, milestone3, milestone4, milestone5, milestone6, milestone7, milestone8, milestone9, milestone10, milestone11 and milestone12, milestone13*). In addition, the validation is in relation to the model parameters in Table 3.22. Moreover, after each experiment run and model execution, the following codes are executed:

```

milestones.clear();
for(textcolorpurpleinti=0;i<root.milestones.size();
i++)milestones.add(root.milestones.get(i));
milestone1.add(milestones.get(0));
milestone2.add(milestones.get(1)-milestones.get(0));
milestone3.add(milestones.get(2)-milestones.get(1));
milestone4.add(milestones.get(3)-milestones.get(2));
milestone5.add(milestones.get(4)-milestones.get(3));
milestone6.add(milestones.get(5)-milestones.get(4));
milestone7.add(milestones.get(6)-milestones.get(5));
milestone8.add(milestones.get(7)-milestones.get(6));
milestone9.add(milestones.get(8)-milestones.get(7));
milestone10.add(milestones.get(9)-milestones.get(8));
milestone11.add(milestones.get(10)-milestones.get(9));
milestone12.add(milestones.get(11)-milestones.get(10));
milestone13.add(milestones.get(12)-milestones.get(11));
milestone14.add(milestones.get(13)-milestones.get(12));

```

In the validation experiments, shown in Figure 3.60, the research utilised an experiment design that involved varying the parameters stochastically.

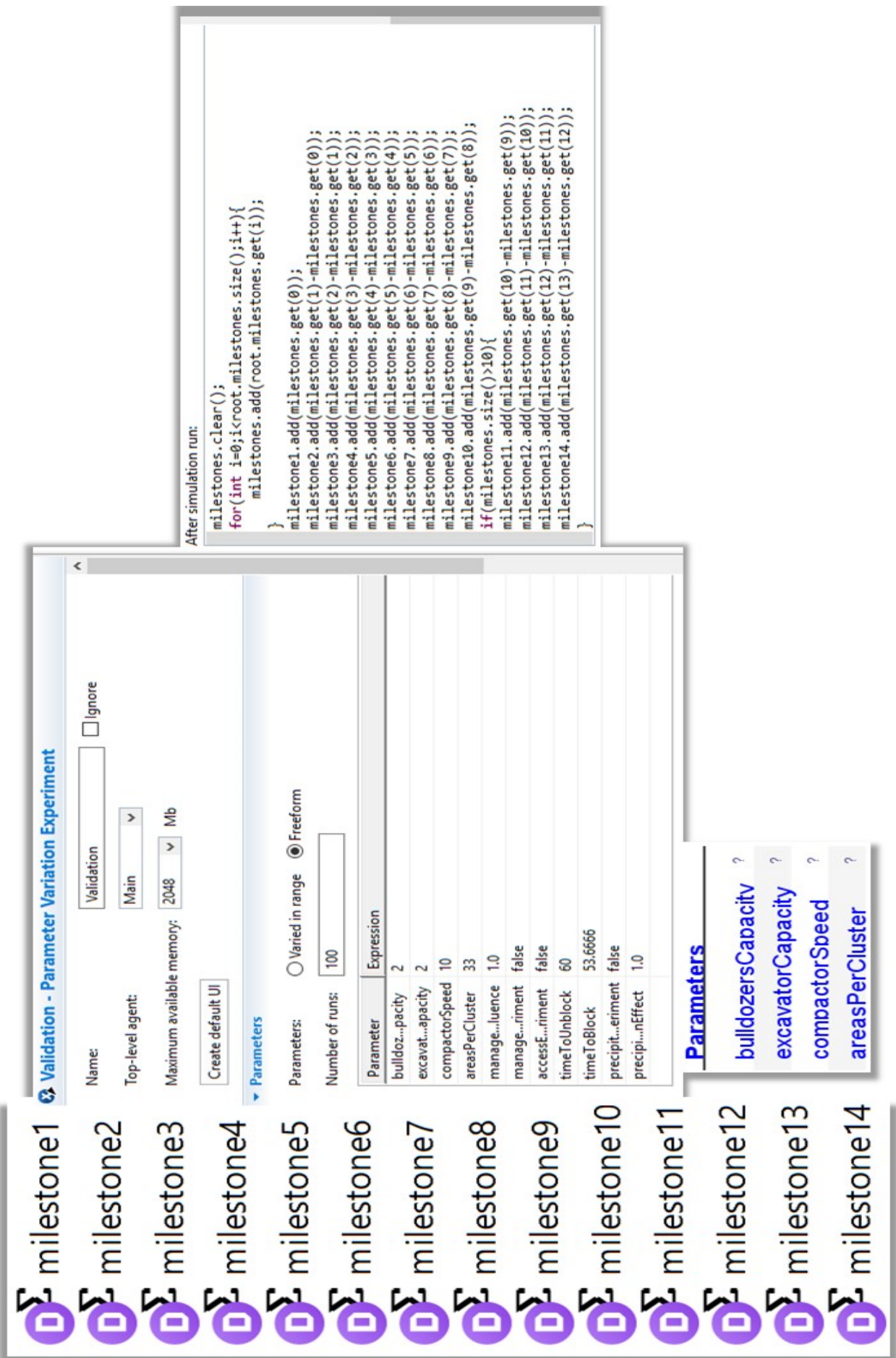


Figure 3.60. Validation interface

The accuracy of the relationship between CSC data and model result as well as the model equation are determined by statistical analysis especially *standard deviation* (*S.D*), *Average AbsoluteError* (*AAE*) and *Absolute RelativeError* (*ARE*) (Coakley, Raftery, & Keane 2014, Moretti, Pizzuti, Panzieri, & Annunziato 2015, Rhodes, Gorman, Upshaw, & Webber 2015, Smith & Mason 1997, Tantithamthavorn, McIntosh, Hassan, & Matsumoto 2017, von Sydow et al. 2015) illustrated in Equations (3.35) to (3.38)

$$Standarddeviation = \frac{1}{N_{data}} \sqrt{\frac{\sum_{i=1}^{N_1} (ModelData_{1i} - RealData_1)^2}{N_{data}}} = 0.135379161 \quad (3.35)$$

$$AverageAbsoluteError(AAE) = \frac{1}{N_{data}} \sum_{i=1}^{N_1} | (ModelData_{1i} - RealData_1) | = 0.468967 \quad (3.36)$$

$$AbsoluteRelativeError(ARE) = \frac{1}{N_{data}} \sum_{i=1}^{N_1} \left| \frac{(ModelData_{1i} - RealData_1)}{RealData_1} \right| \times 100 = 0.189865 \quad (3.37)$$

The *F – test* statistics (Assefa Tsehayae & Robinson Fayek 2016, D. W. Chan, Chan, Lam, Yeung, & Chan 2011, Fellows & Liu 2015b, Mak & Picken 2000) was applied to determine the Null Hypothesis for the variances for the investigation of the similarity of the model results and real data. The implemented *F-test* equation is depicted in Equation 3.38, where $S_{RealData}$ is the real data collected from CSC and $S_{ModelData}$ is the data from the model.

$$F = \frac{S_{RealData}^2}{S_{ModelData}^2} \quad (3.38)$$

The *Null Hypothesis* is either accepted or rejected expressed by Equation 3.39 applied

to whether the value of F exceeds or does not exceed the critical value taken from *t-student distribution* with the assumption that the data have a normal distribution characteristic.

$$df = \frac{\left(\frac{S_{RealData}^2}{N_1} + \frac{S_{ModelResult}^2}{N_2}\right)^2}{\frac{\left(\frac{S_{RealData}^2}{N_1}\right)^2}{N_1 - 1} + \frac{\left(\frac{S_{ModelResult}^2}{N_2}\right)^2}{N_2 - 1}} \quad (3.39)$$

The *F-test* set out no statistical differences between the real data and the model data. The *F-test* of the real data and model data considered the similarity in variances to derive the critical value by fine-tuning the degrees of freedom (df). In Equation 3.39, (df) is evaluated, where N_1 and N_2 are the number of data sets of the real data and model result respectively. In the research, different experiments are conducted using simulation experiment, optimisation experiment, access egress experiment, management influence experiment, precipitation of groundwater influence experiment, risk analysis on equipment use, and time spent per task experiments. The experiments facilitate the verification of the performance of the model and the associated parameters, and the verification is the central theme of Section 3.10.

3.10 Model verification

This section, the verification analysis utilised simulation experiments to commence on the execution of different experiments. Performance analysis of the hybrid model was implemented to ascertain that the results are attainable from the integrated paradigms. The first subsection is the experiments on parameter variations and analysis of management influences on the time to complete the tender phase, which consists of RFP opportunities analysis, tender or proposal submission, alliancing and contract negotiation.

The second subsection is the *AcessEgress* analysis and influences on different work zones. The third subsection analysed the effect of groundwater on excavator and compactor speed intending to analyse productivity. The fourth subsection of the chapter verifies the risks of equipment utilisation. The fifth subsection investigates time spent per tasks which were implemented with java class called Gantt. The Gantt script was utilised to extract the time utilised to perform each task. The complete model verifications were implemented in AnyLogic parameter sensitivity using Monte Carlo simulation interfaces.

The Monte Carlo experiments generated internal and random data points until a point is identified within the input parameters. One of the Anylogic features is the adeptness in providing probability distribution functions. The research conducted model experiments on the chances for different possible outcomes. The outcomes presented a range of possibilities for decision support to the project management team on any of the choices of probabilities for implementation.

3.11 Summary

This chapter recognised simulation modeling and optimisation as the essential components of planning and scheduling problems. The chapter introduction presented the main themes of the entire research design and method, which formed the formation of the chapter layout and content. The research requirements re-established the goals of the research in relation to the research questions and research objectives. Another critical factor to the research is the methodology paradigm that presented the selection of postpositivism and pragmatism with the opportunity for pluralist data, experiment setting, validation and verification.

With the research paradigm defined, the research process illustrated the research logical flow diagram. The research moral concepts and ethical consideration, as well as the

approval, is presented in the research ethical approval. The research case background and rationale explained the justification for the selected case study. Due to the nature of the research to combine different elements of the construction system, the rest of the research elements including research design, research method, research analysis and implementation are demonstrated into two main subjects: 1) Initial problem formulation of influencing factors and construction project time management and; 2) Process-based Multi-hybrid Method. In each of the themes, the research design discussed the background, ideas and formulations of the research.

The research design provided insight into CTM-CTF-IM and multi-method analysis and evaluation in hierarchical planning to enhance decision-making. While the relationship of the CTF-CTM-IM variables was examined with DBN, an in-depth analysis with the multi-hybrid model is utilised to explore and evaluate the construction project system components by activities, resources and influences. The model facilitated the development of a new concept of hybrid models centred on the system behaviour and attributes of each activity in the road improvements project.

The research design was followed by the research method, which explained the data collection instrument, data collection method, unit of analysis and data validity and reliability. Data was gathered from the case study company through discussions, observations, and process documents for the bidding phase of the road improvement project and construction phase of the construction activities. Data analysis involved reviewing, categorising, synthesising, and interpreting the information attained from the case-study company. The analysis produced themes both within the academics' as well as across the company needs. The case study, coupled with the data sources, enhance the development of a framework with an industry focus.

The research design developed the central schemes that governed the analysis and the implementation of the research. The collected data from the case study, in addition to the framework and simulation model developed in the research design, aided the

research analysis and implementation. In that context, to test the functionality of the combined main subjects, this research applied the real-world road improvement project, which includes some of the influences during the tender phase and construction phase of the project. The analysis consists of building the framework in the DBN and AnyLogic software, and implementation to attain real world validations: both internal and CSC validations that support the research result as well as the verification experiments. Before the discussion on the model validation and verification, the approach to obtain optimum plan using optimisation were discussed, as well as the method to implement the integration of plan and schedule through a Gantt chart. The following chapter explores the results and findings of the methodology that validated and accomplished the research questions and objectives.

Chapter 4

Results

4.1 Introduction

This chapter goal is a concise presentation and description of the research results, with tables and figures illustrating the essential data used to accomplish the research objectives. The discussion includes results' summary statements and draws attention to the research objectives and research questions. Moreover, the results are presented systematically to align with the research methodology. The result descriptions are logically divided into three distinct sections in relation to the research questions outlined in Table 4.1: 1) the outcome of the literature review; 2) the initial problem formulation of influencing factors and construction project time management and; 3) the process-based multi-hybrid method.

Table 4.1

Research questions

	Research Questions
Question Q1	What is the current approach for static and dynamic planning in construction projects, and what form of the plan is produced?
Question Q2	How can the approach be categorised to identify its constraints to solving dynamic planning and scheduling problem?
Question Q3	What are the barriers to the utilisation of the current solutions for planning problems?
Question Q4	What are the expected strategies if pursued, positively influence the real-world planning system and improve system solutions?
Question Q5	What are the relationships between construction time management and influencing factors in construction projects necessary to gain insight about reducing time overrun in construction projects?
Question Q6	What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?
Question Q7	What mechanism can best integrate multi-decision support for planning and scheduling of construction projects?
Question Q8	To what extent can the model assure the flexibility to accept multiple inputs?
Question Q9	What are barriers that may be associated with the model integration, and how are they addressed?
Question Q10	How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?
Question Q11	How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?
Question Q12	What is the technique to present the model solution for application by the construction project team to improve the planning decision?
Question Q13	To what extent can the integrated planning solution aid the capability of construction project management?
Question Q14	How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?

The chapter layout and content is shown in Figure 4.1.

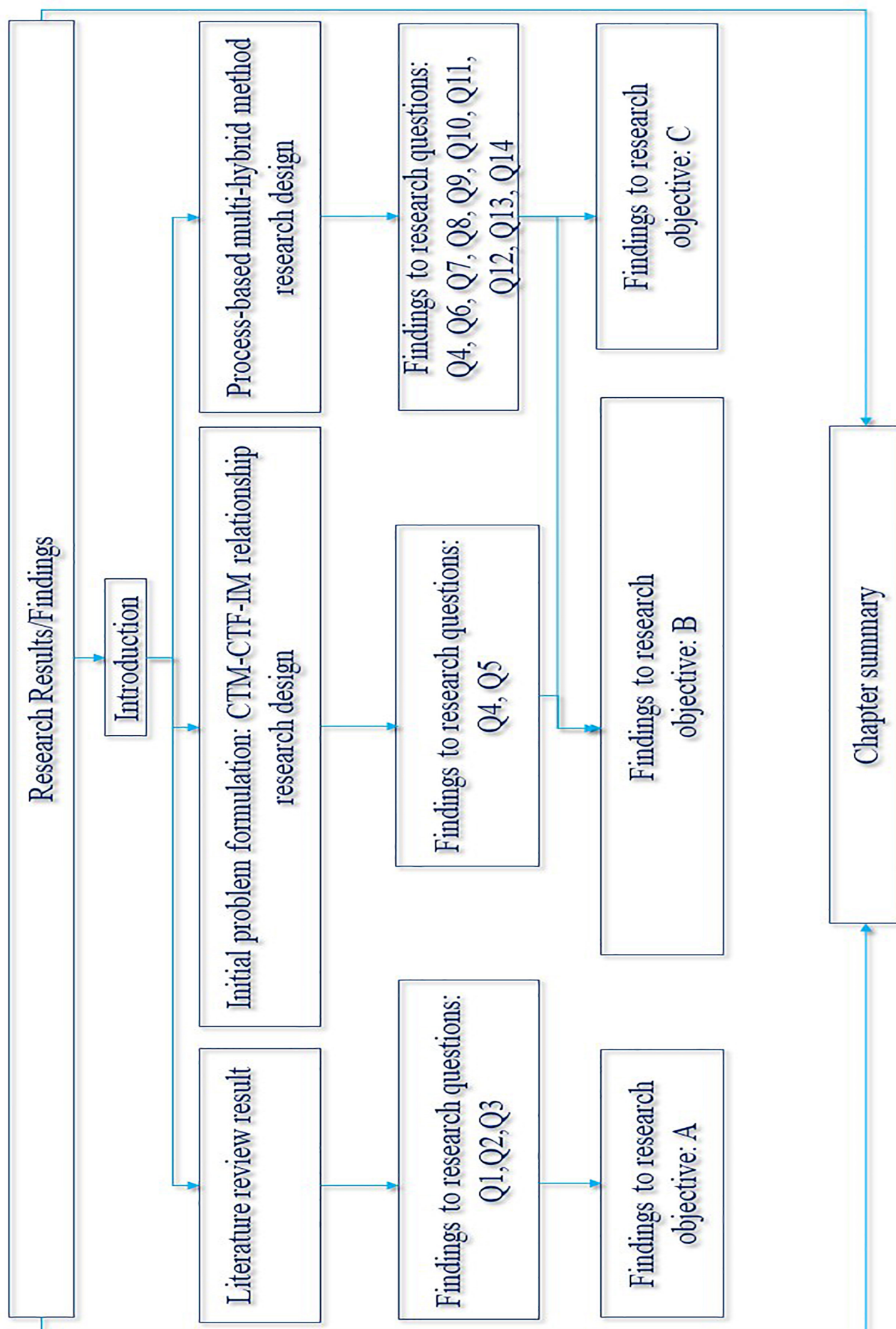


Figure 4.1. Chapter 4 layout and content

4.2 Literature review results/findings

Referring back to research question Q1, the question aimed to present current approach for static and dynamic planning in construction projects, and what form of the plan is produced, shown in Figure 4.2 from the literature review.

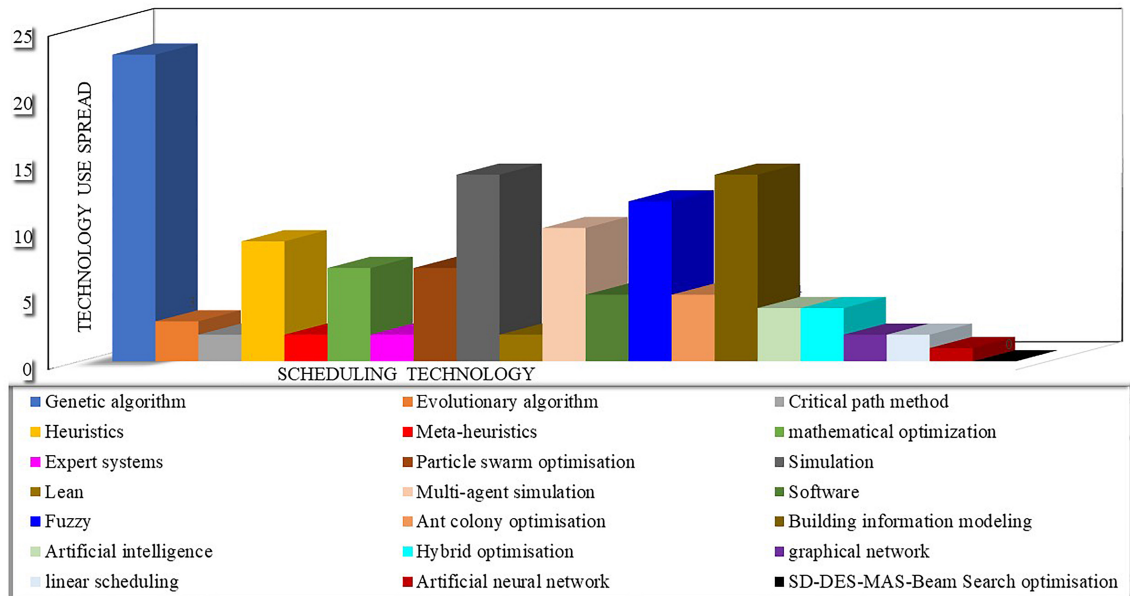


Figure 4.2. Current static and dynamic planning and scheduling systems

From the graph, the genetic algorithm is significantly utilised more than other methods. Other prominent systems are a simulation, heuristics, building information modeling, fuzzy set theory, mathematical optimisation, multi-agent simulation, commercial software, artificial intelligence and hybrid optimisation. The system that stands out in the figure is the application of multi-hybrid of SD-DES-ABS-Scatter Search optimisation, which is lacking in the literature. Strong evidence of different methods from the figure supports the comprehensive search for a suitable approach to ensure the system dynamics nature of construction project planning and scheduling. However, the diverse methods are a confirmation that continuous improvement is required in construction system planning and scheduling. Furthermore, seeking those methods is likely to confirm that dynamic nature of the construction project embraces overrun

in time, and possibly in other project outcomes. Surprisingly, the most striking observation from the figure is the inability of those methods to utilise the combined features of multi-hybrid systems.

The identification of those systems, however, at this level of research, presented the solution to Question *Q2* that asked how can the current practice be categorised to determine static and dynamic planning? From the methods, Figure 4.3 illustrates the planning and scheduling classification.

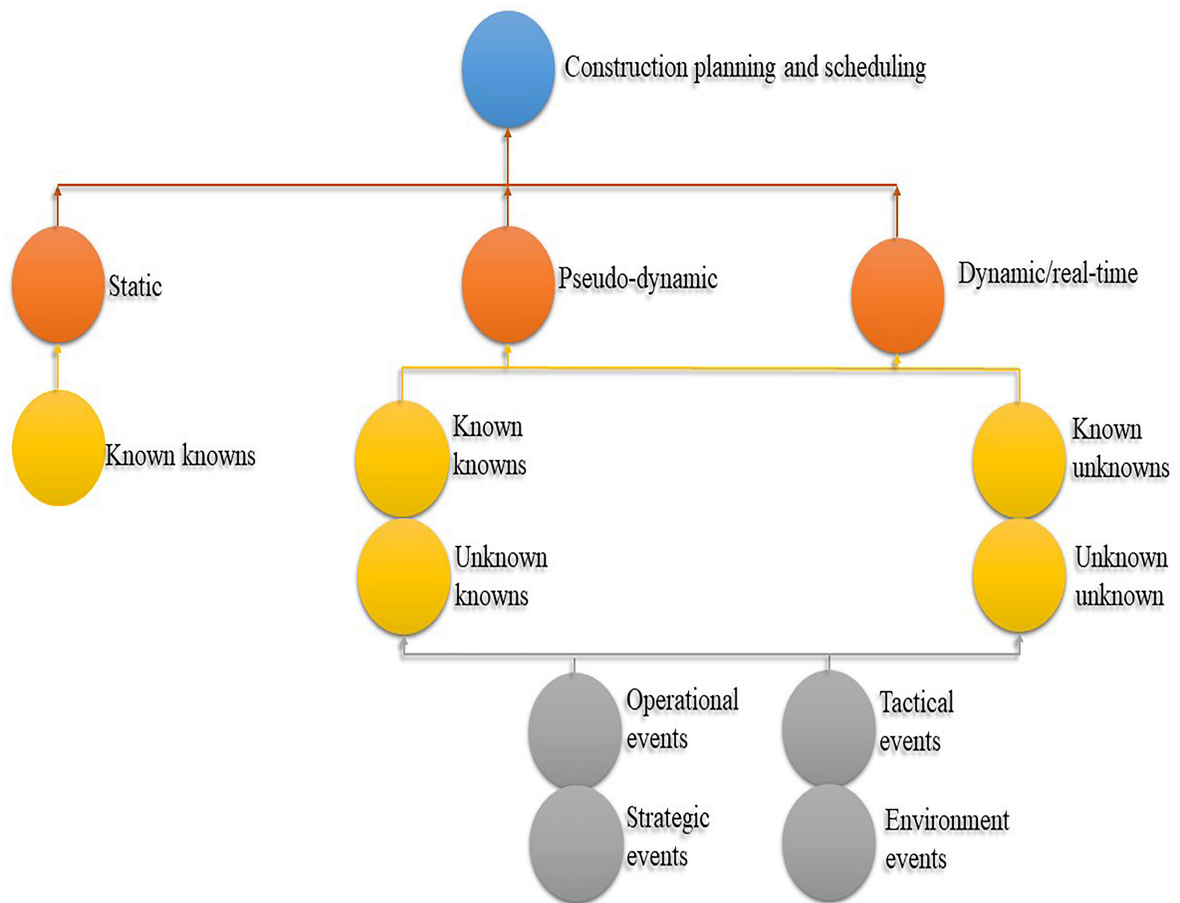


Figure 4.3. Planning and scheduling classification

In the figure, the classifications are illustrated based on their characteristics. There are static methods, transition method between static and dynamic method, and dynamic method. An essential feature of static scheduling is the lack of variability integration. In the pseudo-dynamic planning and scheduling, a specific form of variabilities is likely

to be incorporated, probably from the knowledge management system. In the region of dynamic scheduling is where the simulation system can enhance integrating a large number of variabilities. The strength of simulations from a strategic, tactical and operational level is a remarkable outcome from the literature review. The design of those simulations are expected to be remove the impediments limiting the utilisation of those methods to solve planning and scheduling problems, namely of the challenges presented in Figure 4.4.

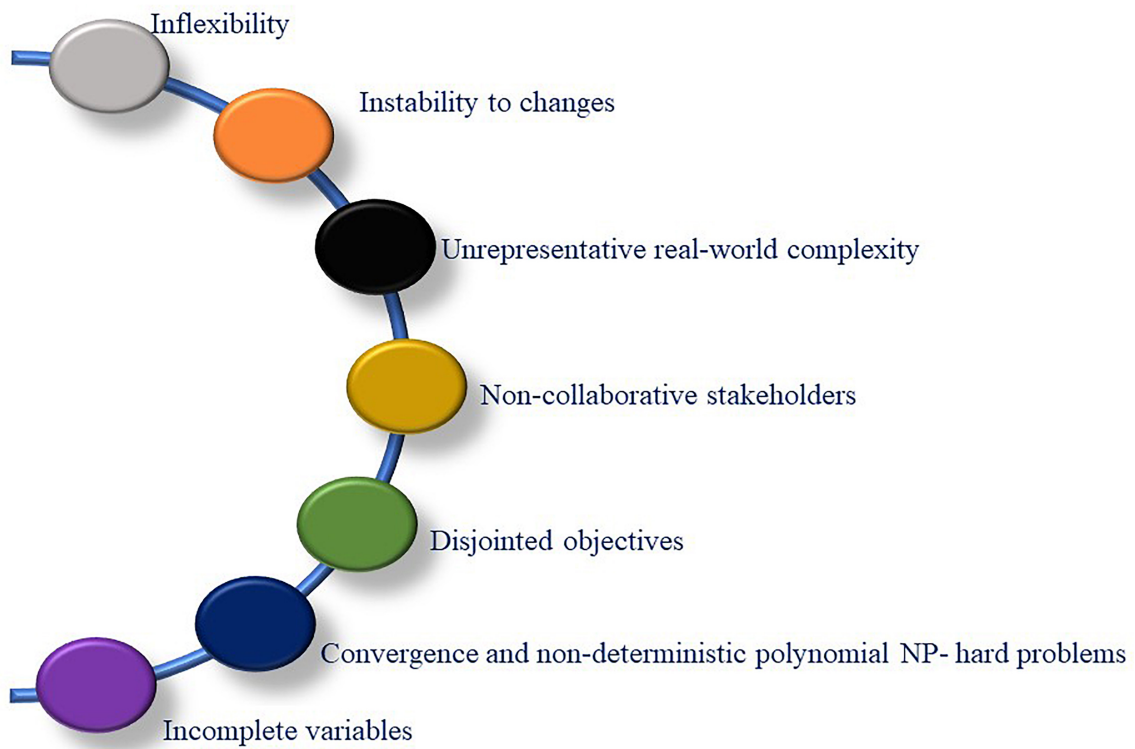


Figure 4.4. Methods impediments

The most important feature of those impediments is the need to create a solution that responds to the challenges in those methods. Hence, those limitations are reviewed with the research Question *Q3* that pursues the barriers hindering the utilisation of the current solutions for planning and scheduling problems. The approach utilised in this research integrated the impediments.

4.3 Initial problem formulation: CTM-CTF-IM relationship research design results/findings

The description of the CTM-CTF-IM relationship established three propositions in CTM, one proposition in CTF, and three propositions in IM, presented in Table 4.2.

Table 4.2

Research CTM-CTF-IM propositions

Proposition	
Proposition 1:	There is a positive relationship with a proactive process to mitigate the negative effects of different CTF.
Proposition 2:	There is a negative relationship without any system to mitigate the negative effects of different CTF.
Proposition 3:	The negative influence of CTF on CTM strategies relationship generates overwhelming performance in project criteria better than the initial strategies.
Proposition 4:	The construction key performance criteria: time, cost, quality, safety, scope, function, and contractors profit that determine the success or failure in outcomes are dependent and in tandem. The negative impact on one criteria generates resultant impacts on other criteria.
Proposition 5:	All the CTF have a direct impact on the overall project performance. The presence of these CTF is likely to have a negative relationship on CTM and project performance. The tackling approaches and policies on CTF determines the level of negative influences on project performances and the possibilities of a positive impact on the project criteria.
Proposition 6:	Some or a negligible amount of inefficient strategy at an initial project phase can generate a negative outcome in the integrated phase, even though the CTM in other phases are efficient.
Proposition 7:	The interaction of CTF-CTM of one phase, creates cascading effects and uncertainty in the subsequent phases. In this proposition, we set the experiment with efficient and inefficient CTM and observation set to affected for the 7 time steps, one time step for each phase.

The results is based on the research design, methodology and implementation in 3.7.

In proposition 1, there is always uncertainty in construction projects due to CTF. The

outcome is positive with various approaches for proactive management of the impact, resulting from CTM-CTF interactions. The proposition emphasised that success is dependent on the capability of the tactics to mitigate the impact and achieve the overall project success criteria, as shown in Figures 4.5 and 4.6.

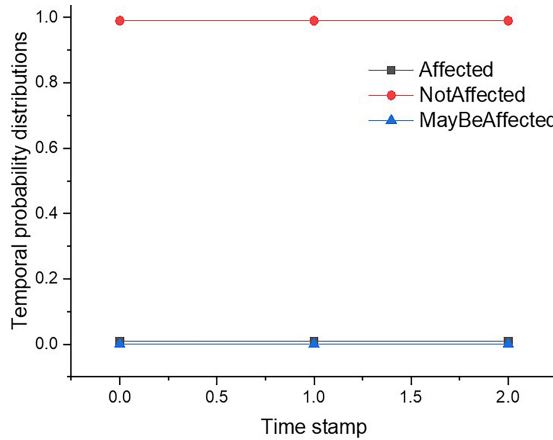


Figure 4.5. Temporal probability distribution for CTF-efficient CTM observation

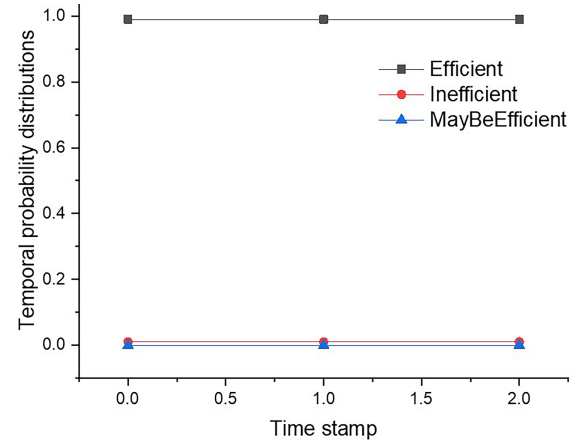


Figure 4.6. Temporal probability distribution for CTF affected and efficient CTM observation

Figures 4.5 and 4.6 illustrate the observation from CTM-CTF interaction and the CTM efficient strategy to mitigate CTF effects. Three-time steps are applied to analyse the propagation of the CTF effects in the integrated project phases with efficient CTM in the phases. In that case, the CTF influenced the CTM but did stop the construction team in realising the schedule project objective.

Irrespective of the negative implication CTF, the project team utilised CTM strategies to ensure success in the schedule. The demonstration implies that CTM has an interrelation between CTF for achieving a successful project and depends on the project complexity. The construction project outcome is negative when the construction team lacks the knowledge of the complexities and ambiguities inherent in CTF. The lack of this insight results in an unaware-construction team that can subject itself to failure stated in proposition 2 and shown in Figures 4.7 and 4.8.

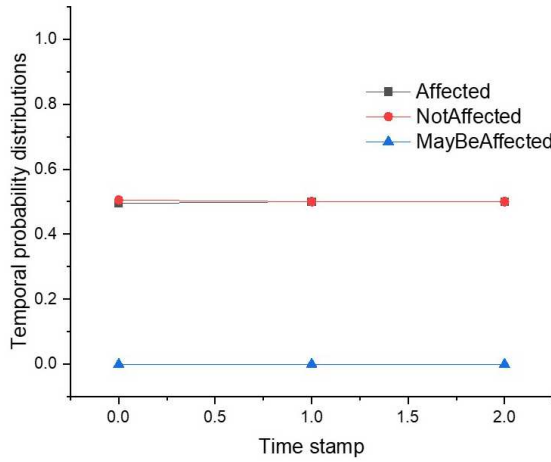


Figure 4.7. Temporal probability distribution for CTF-efficient CTM observation

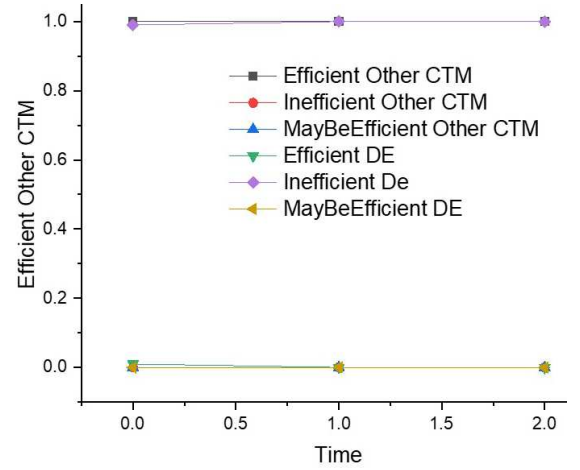


Figure 4.8. Temporal probability distribution for inefficient Design Phase CTM and efficient CTM in other phases

The inefficient strategy in the design phase, irrespective of efficient strategy in other CTM phases, constrained success. In this condition, the inefficient CTM strategies of the design team perform below expectations with the interactions of CTF influence and eventual yielded failure in the project criteria. The result is projected slips on the defined duration and effects transferred to cost, quality, scope, function and contractors' profit. The time stamp observation in Figure 4.9 represents the similarity in CTM affected and CTM not affected.

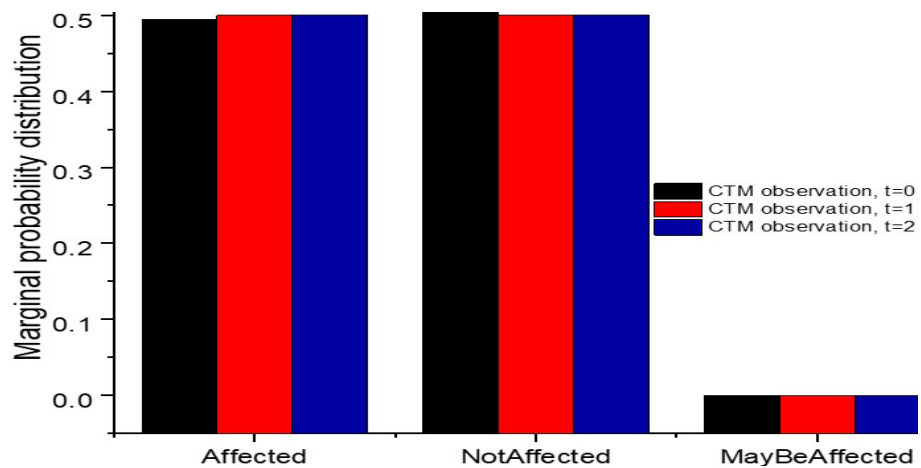


Figure 4.9. Proposition 2 time stamp observations

Therefore, the strategy requires the need for intervention decision at a certain cost to enhance success. Correspondingly, the DBN is unrolled to apply intervention on the dynamic Bayesian network. The affected CTM increased from at $t = 0$ to $t = 2$. Conversely, there is a decrease in CTM that is not affected because of the efficient CTM in the other phases. Although, CTM at different phases and time steps are efficient, nevertheless, there is a need for intervention and control.

As shown in Figure 4.10, a defined CTM at different phases and time steps are efficient; however, there is a need for intervention and control on the inefficient CTM.

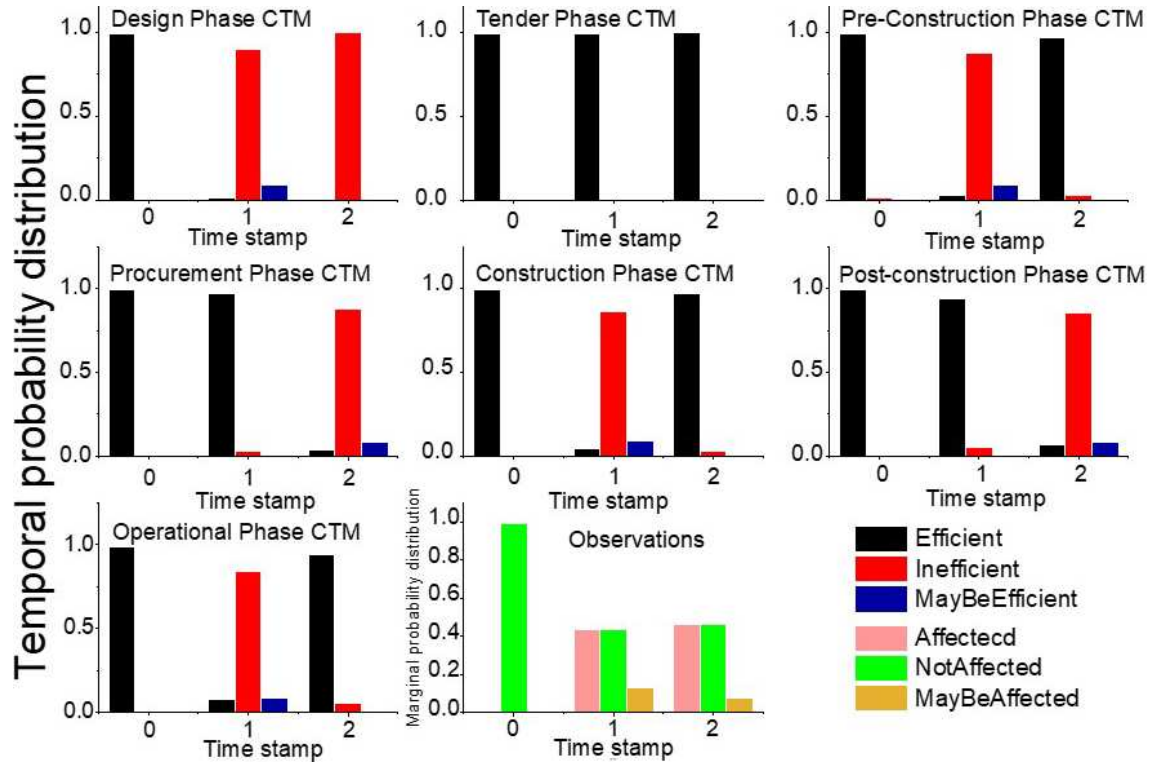


Figure 4.10. The CTF-CTM-DBN observation not affected with CTM affected

The control is implemented by restraining the CTF interactions with CTM. In this scenario, the CTM is efficient with unaffected observation. The support for the propositions is the integration of CTM strategies with efficient proactive and reactive policies and system created good results in project performance. Construction team acceptance of CTF as a challenge for better improvement resulted in a favourable performance in the criteria (Brown et al. 2007). Similarly, the construction team has

a certain level of efficient CTM strategies. However, it improved better compared to the strategy without CTF influence, hence ensured success in project performance. Summing up the propositions together at every level of CTM strategy, displayed in Figures 4.11 to 4.13.

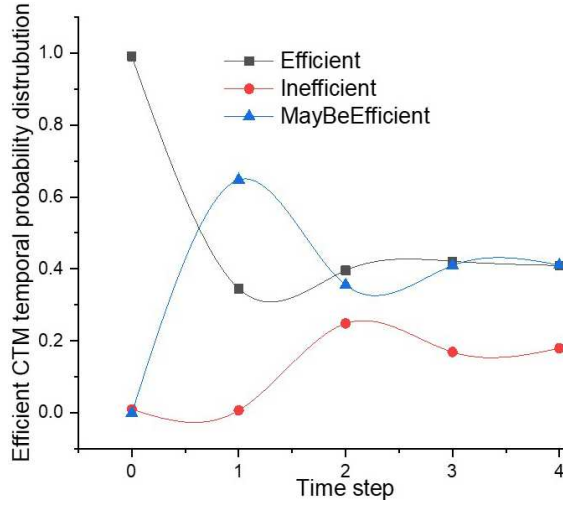


Figure 4.11. Efficient CTM at $t=0$ and different CTM at different time stamp

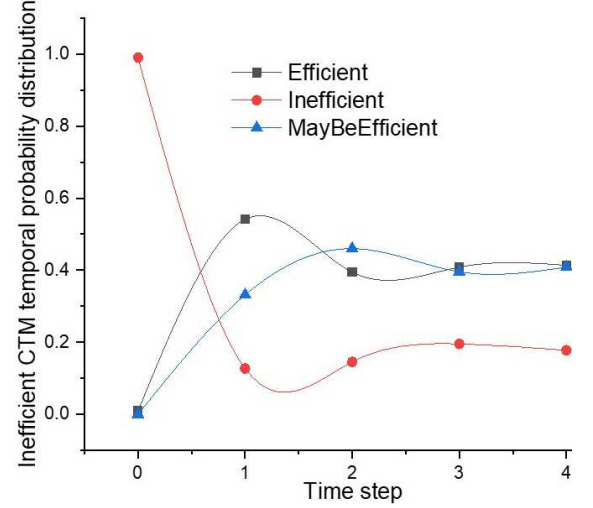


Figure 4.12. Inefficient CTM at $t=0$ and different CTM and time step

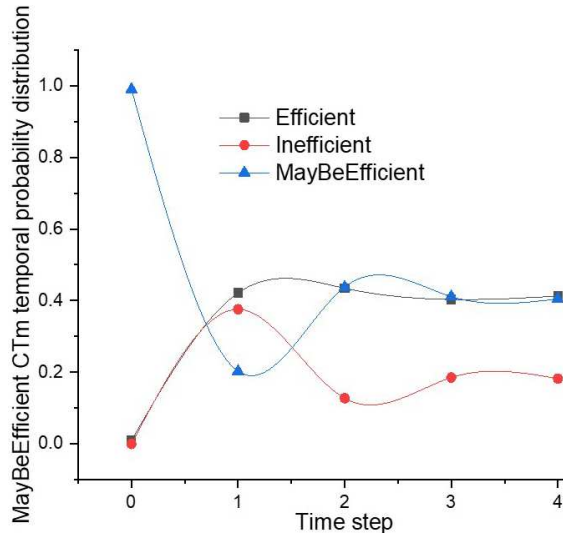


Figure 4.13. MayBeEfficient CTM at $t=0$ and different CTM and time step

There is a distinct tendency of the different phases performing to the point of being affected and not affected as well as others not affected, laid out in Figures 4.14 to 4.16.

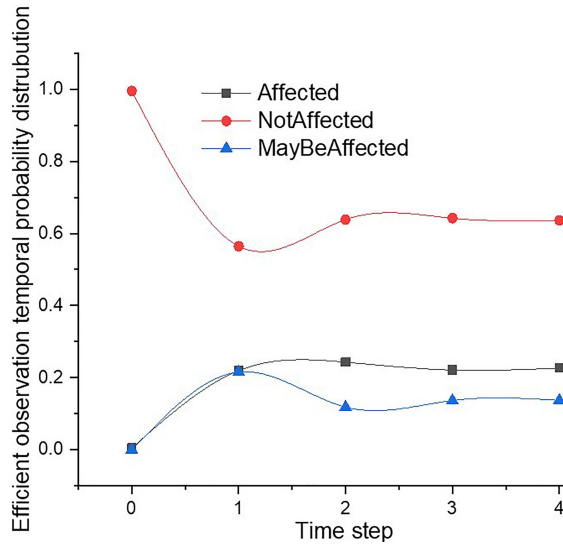


Figure 4.14. Efficient observation at $t=0$ and different CTM at different time stamp

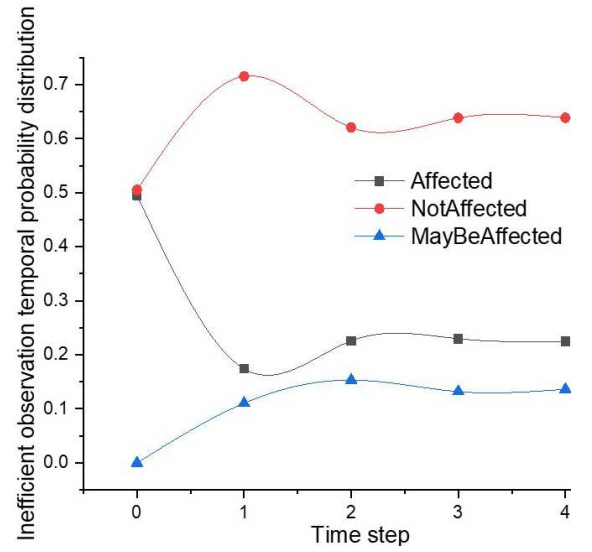


Figure 4.15. Inefficient observation at $t=0$ and different CTM and time step

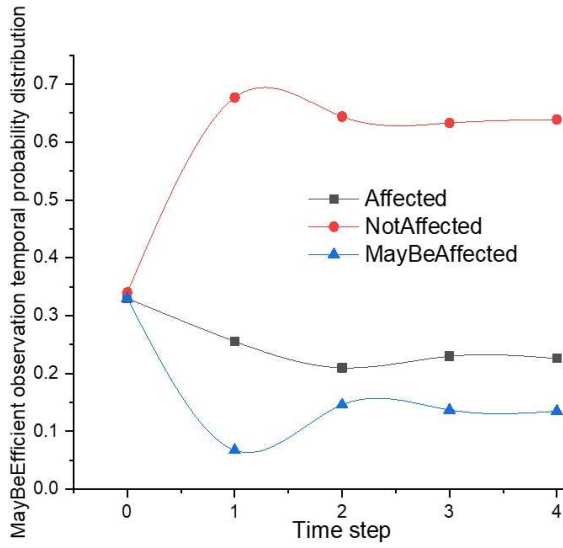


Figure 4.16. MayBeEfficient observation at $t=0$ and different CTM and time step

The relationship between CTM-CTF-IM was implemented based on equations and a combination of discrete and continuous data, after unrolling of the dynamic Bayesian network. The discrete data are *Present*, *Absent*, with *Efficient*, *Inefficient* and *MayBeEfficient* states. It also contains the probability distributions of the time required to manage each phase and the results of the implementation shown in Equations (4.1) to (4.4) and (4.6).

Tender phase discretisation

$$\begin{aligned}
TE_CTM_CTF1_E = & \\
& Choose(CTF1 = "Present", TE_CTM_CTF1 = "Efficient", \\
& \quad Triangular(1, 25, 30), \\
& Choose(CTF1 = "Present", TE_CTM_CTF1 = "MayBeEfficient", \\
& \quad Triangular(28, 29, 30), \\
& Choose(CTF1 = "Present", TE_CTM_CTF1 = "Inefficient", \\
& \quad Normal(0, 31), \\
& Choose(CTF1 = "Absent", TE_CTM_CTF1 = "Efficient", \\
& \quad Triangular(1, 25, 30), \\
& Choose(CTF1 = "Absent", TE_CTM_CTF1 = "MayBeEfficient", \\
& \quad Triangular(28, 29, 30), \\
& Choose(CTF1 = "Absent", TE_CTM_CTF1 = "InEfficient", \\
& \quad Normal(0, 31)))))) \\
& Mean = 18.6777; Standard Deviation = 6.33394; \\
& Minimum = 6.33394; Maximum = 29.9111;
\end{aligned} \tag{4.1}$$

The continuous data was discretised to generate the histogram distribution shown in Figures 4.17 to 4.20 and 4.22

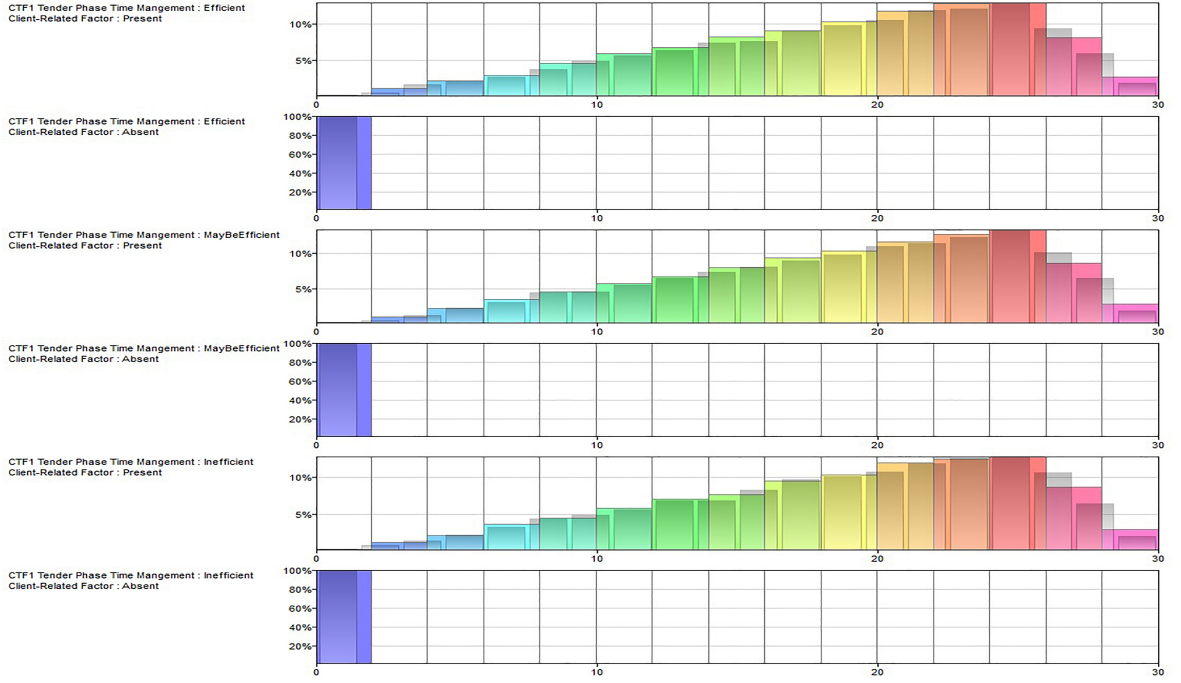


Figure 4.17. Tender phase discretisation

Design phase discretisation

$$\begin{aligned}
 DE_CTM_CTF1_E = & \\
 & Choose(CTF1 = "Present", DE_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 100, 120), \\
 & Choose(CTF1 = "Present", DE_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(110, 120, 240), \\
 & Choose(CTF1 = "Present", DE_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 130), \\
 & Choose(CTF1 = "Absent", DE_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 100, 120), \\
 & Choose(CTF1 = "Absent", DE_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(110, 120, 240), \\
 & Choose(CTF1 = "Absent", DE_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 250)))))) \\
 \text{Mean} = & 73.6788; \text{Standard Deviation} = 25.848;
 \end{aligned}$$

$$\text{Minimum} = 1.75384; \text{Maximum} = 119.675;$$

(4.2)

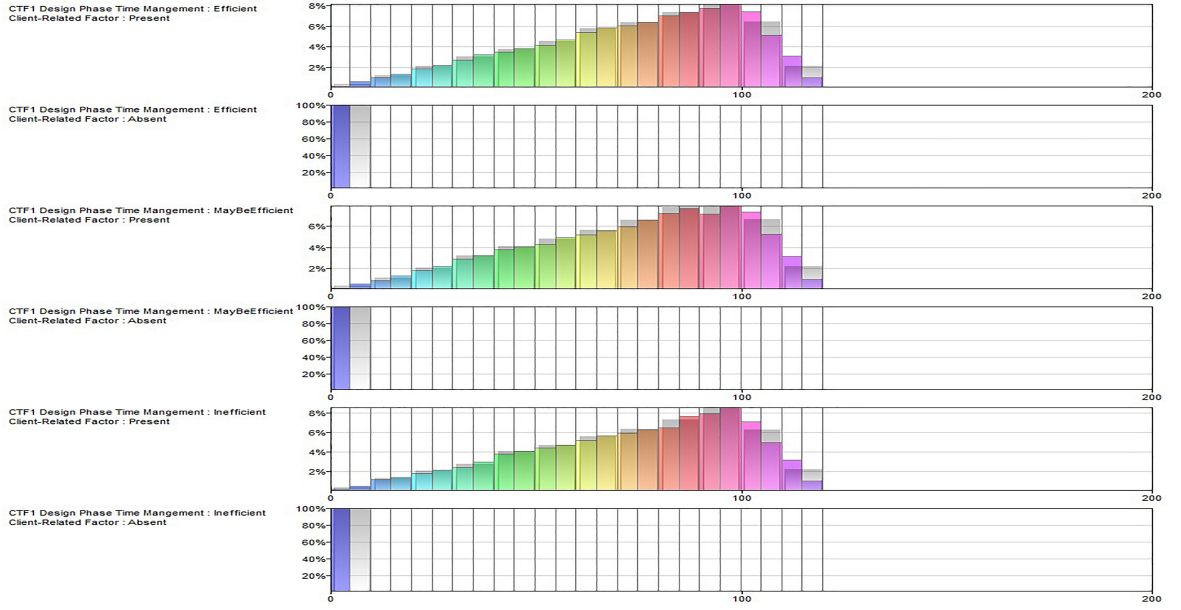


Figure 4.18. Design phase discretisation

Procurement phase discretisation

$$\begin{aligned}
 PC_CTM_CTF1_E = & \\
 & Choose(CTF1 = "Present", PC_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 100, 120), \\
 & Choose(CTF1 = "Present", PC_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(110, 120, 240), \\
 & Choose(CTF1 = "Present", PC_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 130), \\
 & Choose(CTF1 = "Absent", PC_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 100, 120), \\
 & Choose(CTF1 = "Absent", PC_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(110, 120, 240), \\
 & Choose(CTF1 = "Absent", PC_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 250)))))) \\
 \text{Mean} = & 74.1575; \text{Standard Deviation} = 25.9022;
 \end{aligned}$$

$$\text{Minimum} = 1.09216; \text{Maximum} = 119.242;$$

(4.3)

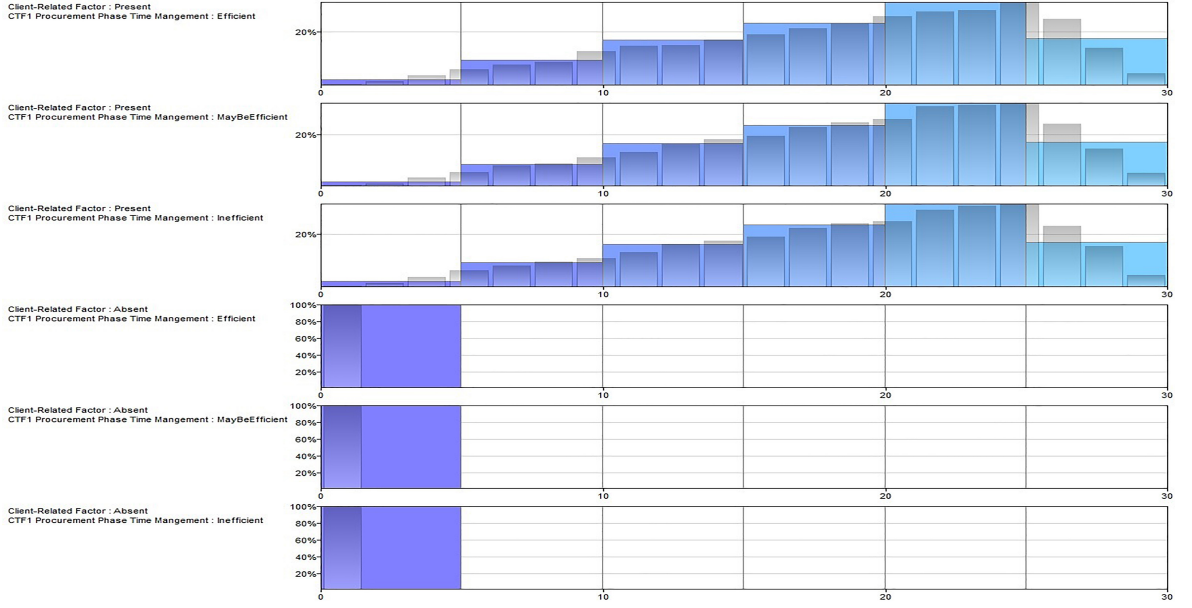


Figure 4.19. Procurement phase discretisation

Preconstruction phase discretisation

$$\begin{aligned}
 PrC_CTM_CTF1_E = & \\
 & Choose(CTF1 = "Present", PrC_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 25, 30), \\
 & Choose(CTF1 = "Present", PrC_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(28, 29, 30), \\
 & Choose(CTF1 = "Present", PrC_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 31), \\
 & Choose(CTF1 = "Absent", PrC_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 25, 30), \\
 & Choose(CTF1 = "Absent", PrC_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(28, 29, 30), \\
 & Choose(CTF1 = "Absent", PrC_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 31)))))) \\
 & Mean = 18.6296; Standard Deviation = 6.31902;
 \end{aligned}$$

$$Minimum = 1.16631; Maximum = 29.9506;$$

(4.4)

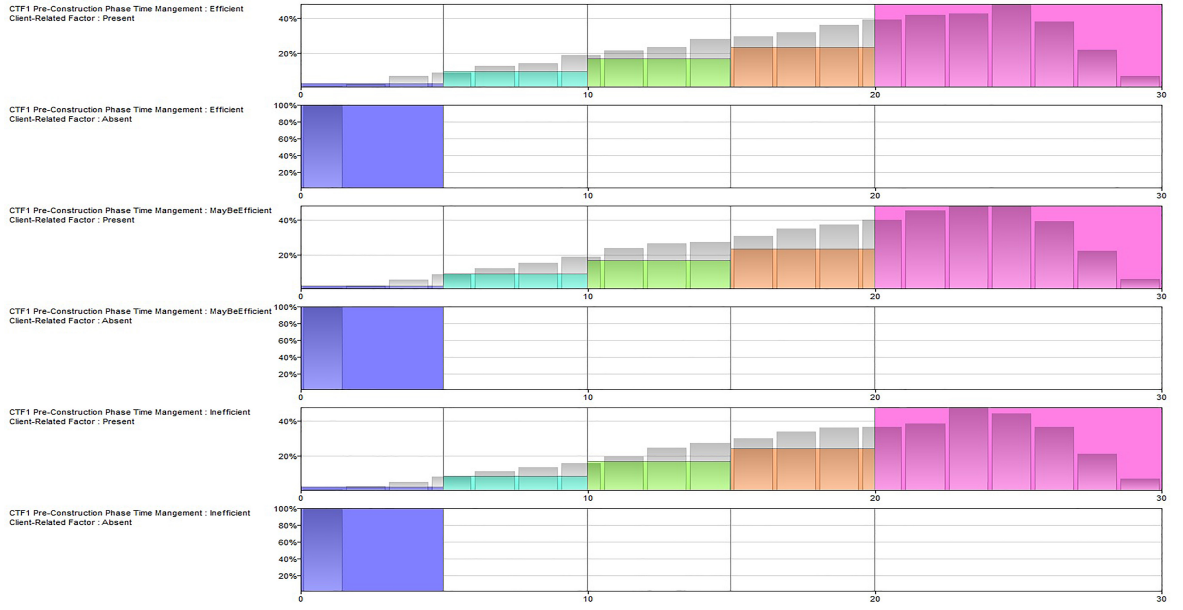


Figure 4.20. Preconstruction phase discretisation

Construction phase discretisation

$Co_CTM_CTF1_E =$

$Choose(CTF1 = "Present", Co_CTM_CTF1 = "Efficient",$
 $Triangular(1, 100, 120),$
 $Choose(CTF1 = "Present", Co_CTM_CTF1 = "MayBeEfficient",$
 $Triangular(110, 120, 240),$
 $Choose(CTF1 = "Present", Co_CTM_CTF1 = "Inefficient",$
 $Normal(0, 130),$
 $Choose(CTF1 = "Absent", Co_CTM_CTF1 = "Efficient",$
 $Triangular(1, 100, 120),$
 $Choose(CTF1 = "Absent", Co_CTM_CTF1 = "MayBeEfficient",$
 $Triangular(110, 120, 240),$
 $Choose(CTF1 = "Absent", Co_CTM_CTF1 = "Inefficient",$
 $Normal(0, 250))))))$

Mean = 73.3376; Standard Deviation = 26.1267;

Minimum = 2.20802; Maximum = 119.792;

(4.5)

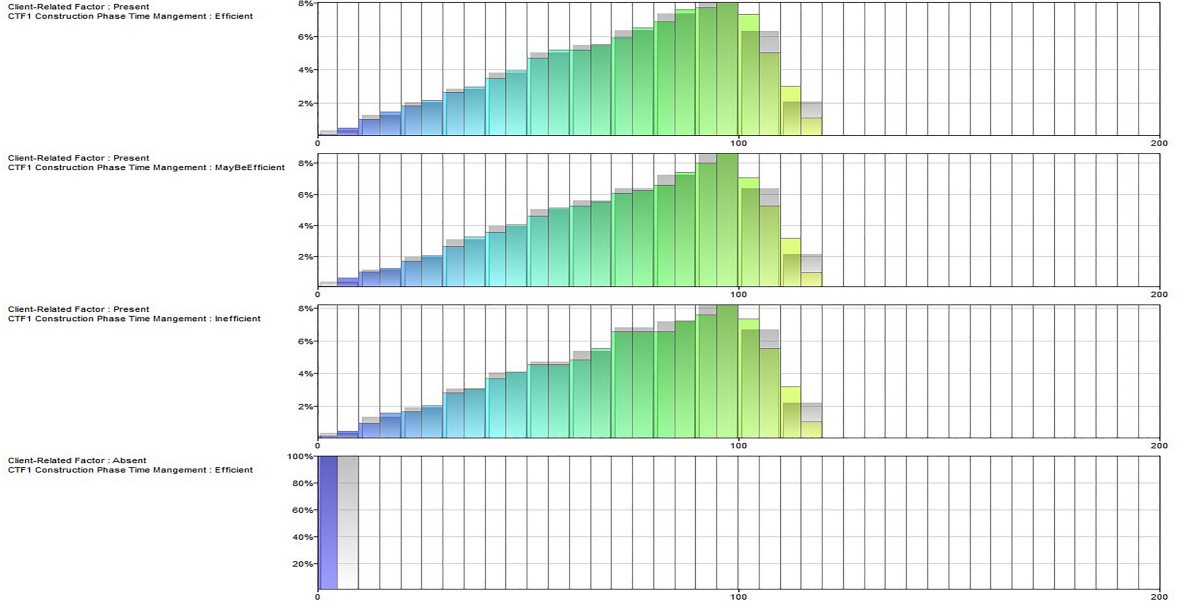


Figure 4.21. Construction phase discretisation

Postconstruction phase discretisation

$$\begin{aligned}
 PoC_CTM_CTF1_E = & \\
 & Choose(CTF1 = "Present", PoC_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 25, 30), \\
 & Choose(CTF1 = "Present", PoC_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(28, 29, 30), \\
 & Choose(CTF1 = "Present", PoC_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 31), \\
 & Choose(CTF1 = "Absent", PoC_CTM_CTF1 = "Efficient", \\
 & \quad Triangular(1, 25, 30), \\
 & Choose(CTF1 = "Absent", PoC_CTM_CTF1 = "MayBeEfficient", \\
 & \quad Triangular(28, 29, 30), \\
 & Choose(CTF1 = "Absent", PoC_CTM_CTF1 = "Inefficient", \\
 & \quad Normal(0, 31)))))) \\
 \text{Mean} = 18.6328; \text{Standard Deviation} = 6.32254;
 \end{aligned}$$

$$\text{Minimum} = 1.10736; \text{Maximum} = 29.8927;$$

(4.6)

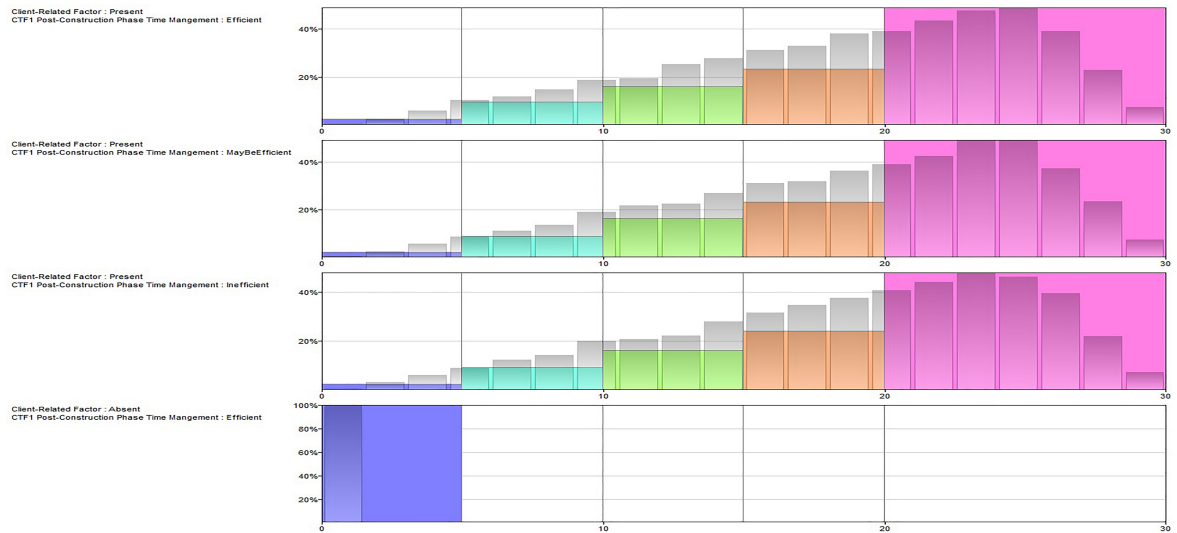


Figure 4.22. Postconstruction phase discretisation

The resulting joint probability distribution is:

Affected CTM = 0.5032; NotAffected CTM = 0.4968;

At every project stage, specific performance criteria and planning could translate the stage to either success or failure. A failure in a preceding stage is likely to lead to a failure in the succeeding stage unless adequate mechanisms are positioned in place to realign the project. The client owns the project, and their interactions and actions have a significant impact on project performance. In many projects, the client has an internal team to supervise the project. For instance, the team decision-making approach, team effectiveness and team relationship with the contractors and sub-contractors influence the outcomes of the project objectives (G. Wu et al. 2017).

While client team management capabilities enhance time management strategies for success, uncoordinated and inexperienced client team could as well result to project failure. Contractors' capability and capacity (Proverbs & Holt 2000), supplier global value chain and networks, available and effective resources have a direct and predominant impact on the project performance based on the level of influence on CTM. There are CTF that are not within the control of the stakeholders, but still,

their impact can be ameliorated using CTM strategies that rely on experience, effective policies, lessons learned and good judgment. Concerning proposition 8, the joint probability distribution (JPD) in the previous time steps generates uncertainty in the subsequent time step resulting in a joint probability distribution showing unfavourable impact without intervention. The relationship between construction project time management (CTM), construction project influencing factors (CTF) and associated impact (IM) implemented using DBN has provided knowledge for decision-making in construction project management. Those findings, which are lacking in the current body of literature, can provide valuable insight into CTF influence and how managers can apply the relationship framework to improve time management performance at different project phases. Consequently, provided the answer to the posed Question **Q5** asking:

What are the relationships between construction time management and influencing factors in construction projects necessary to gain insight about reducing time overrun in construction projects?

4.4 Process-based multi-hybrid method findings

The results of this section are simulation, model integration simulation, validation of the model, simulation verification, optimisation and Gantt results. This result section is the outcome of the research method and implementation in Section 3.8.

4.4.1 Hybrid model integration experiment

The experiment is set up by specifying the amount of the resources agent - the number of bulldozers, number of excavators and number of work areas (work clusters), shown in Figure 4.23.

SIMSIM

Run

Number of Bulldozers

Number of Excavators

Areas To Work Per Team

Simulation - Simulation Experiment

Name: ☐ Ignore

Top-level agent:

Maximum available memory: Mb

Parameters

bulldozerCapacity:	bulldozerCap.getInitialValue()
excavatorCapacity:	excavatorCapacity
compactorSpeed:	10 meters per second
areaPerCluster:	areaPerCluster
managementInfluence:	1.0
managementInfluenceExperiment:	☐
accessEgressExperiment:	☐
timeToUnblock:	60 minutes
timeToBlock:	53.6666 days
precipitationInfluenceExperiment:	☐
precipitationEffect:	1.0

Paste from clipboard

Model time

Execution mode: ☐ Virtual time (as fast as possible) ☒ Real time with scale

Stop:

Start time:

Start date:

Stop times:

Stop date:

Randomness:

Random number generation:
☐ Random seed (unique simulation runs)
☒ Fixed seed (reproducible simulation runs) Seed value:
☐ Custom generator (subclass of Random):

Figure 4.23. Integration simulation experiment set-up

To begin the simulation experiment of the integrated models, the researcher specified the initial values of the parameters. In the execution of the model, the tender phase statecharts come to the final timeout transition turned into the red before linking to the DES-DRS. The simulation model integration through the animation shows the construction contract from tender phase to the construction operation. In the tender phase, the nineteen (19) statecharts reached the last states through the last transitions. However, client statecharts, company statecharts, and map out area statecharts did not exit the final timeout transition. This is because their exiting from their final states is a function of the DES-DRS work cluster agent as depicted in Figure 4.24, where other 16 company statecharts reached either their final states or timeout, symbolised by the red outlines on the states and transition.

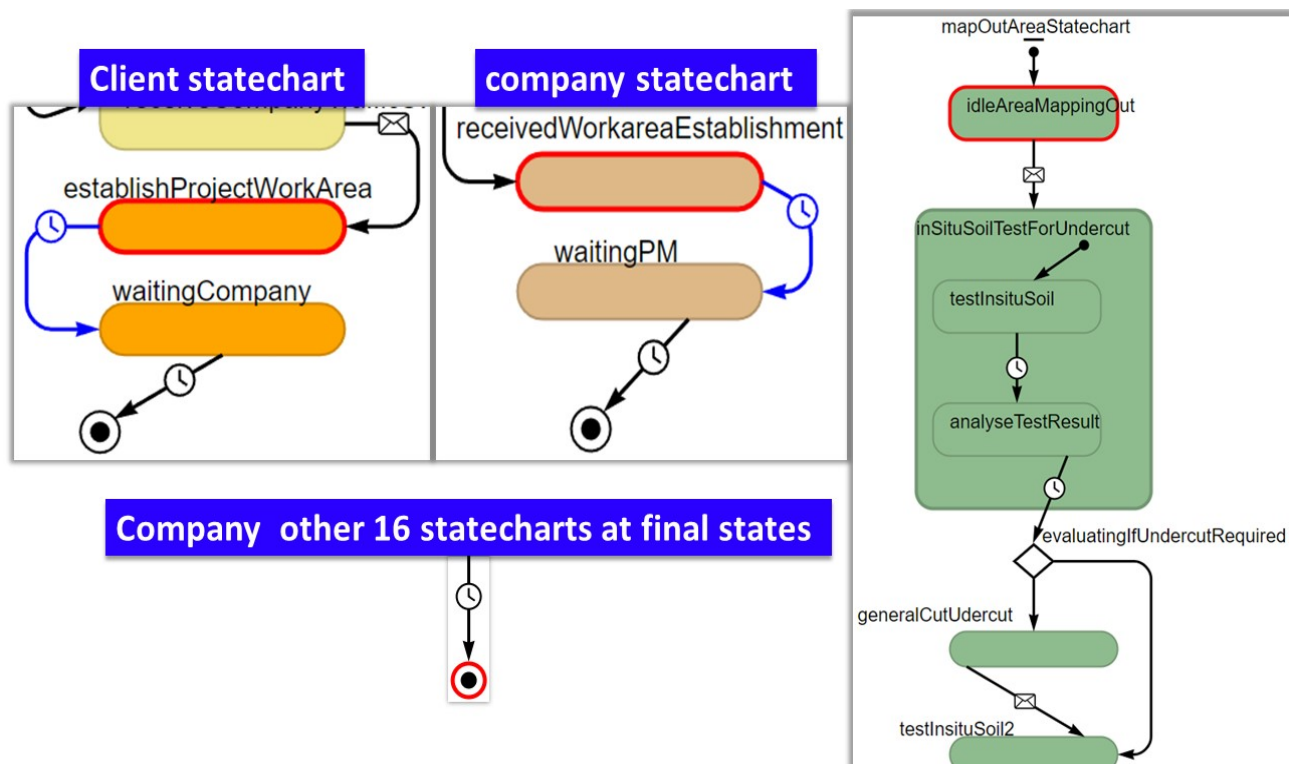


Figure 4.24. Tender phase ABS integration Result

The construction process through the simulation animation demonstration commenced from stripping, excavation, filling and compaction as shown in Figures 4.25 to 4.28.



Figure 4.25. Work cluster DES-DRS integration Result: waiting the ABS integration

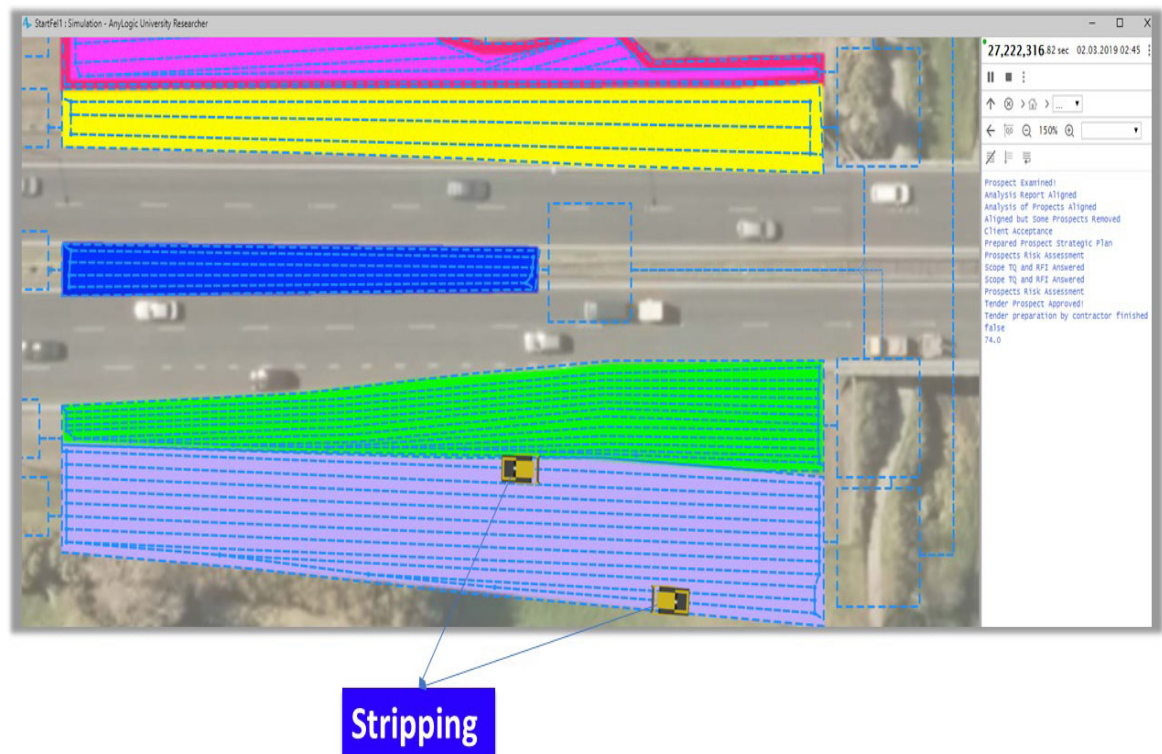


Figure 4.26. Work cluster DES-DRS integration Result: stripping

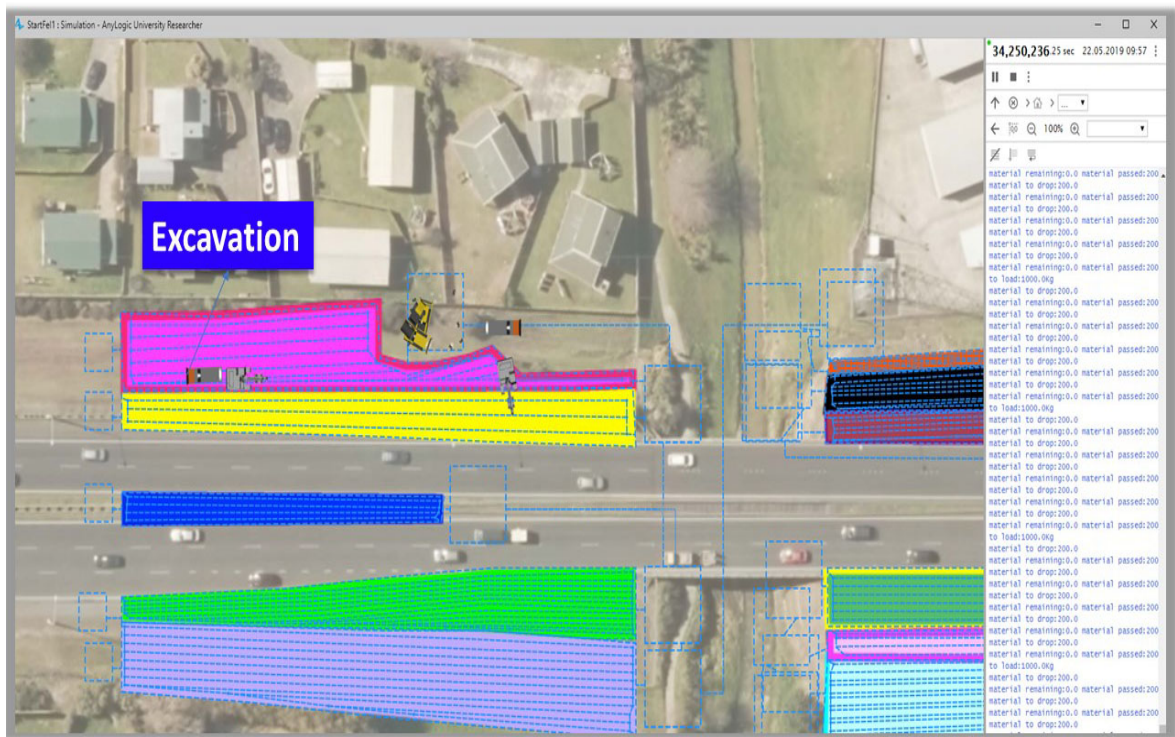


Figure 4.27. Work cluster DES-DRS integration Result: Excavation

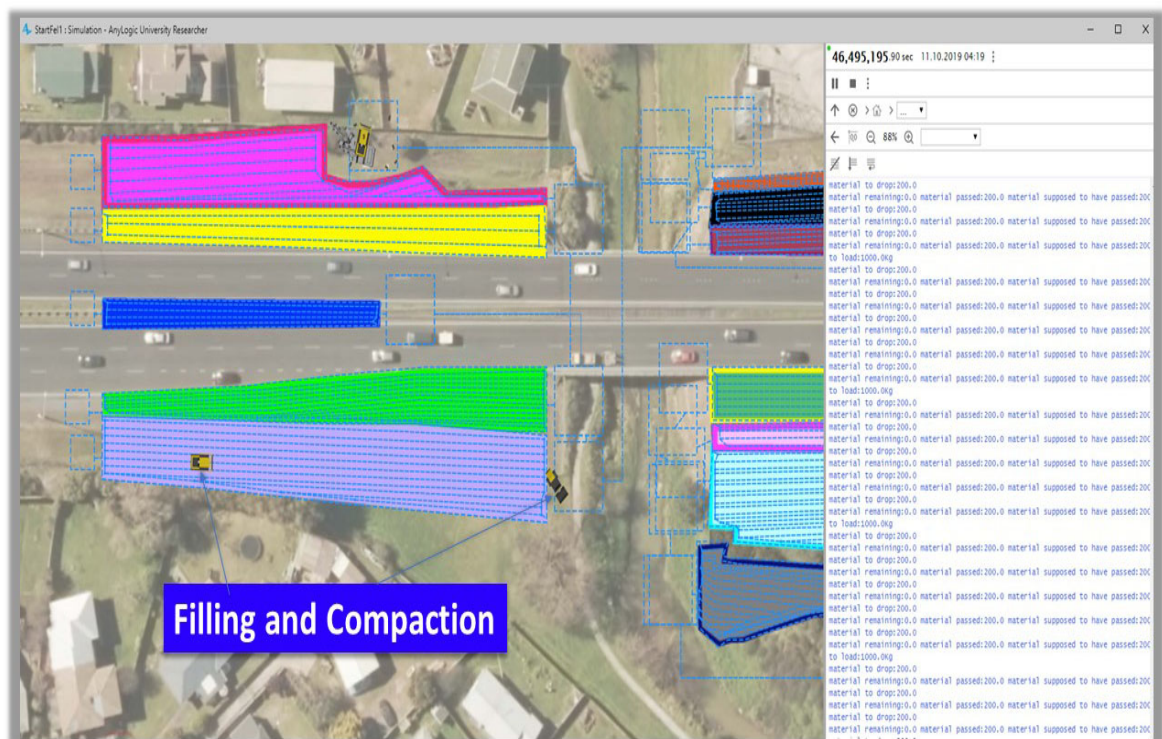


Figure 4.28. Work cluster DES-DRS integration Result: Filling and compaction

In the integration experiment, the study did not collect any statistics, instead to confirm the ease of integration of the paradigms. The goal of model integration is the generation of an effective project plan to produce an effective schedule. Moreover, the research integrated the planning problem, associated characteristics and multi-components of the model, thereby accepting different and multi-inputs. Likewise, while the platform of the study has incorporated the challenges of the multimethod, it supported the project team for decision-making to generate optimum plan and schedule. Therefore, the research provides tangible answers to the posed Questions *Q6, Q8, Q9, Q11, Q12 and support to Q13* asking: *Q6: What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?*

Question *Q8: To what extent can the model assure the flexibility to accept multiple inputs?*

Question *Q9: What are barriers that may be associated with the model integration, and how are they addressed?*

Question *Q10: How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?*

Question *Q11: How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?*

Question *Q12: What is the technique to present the model solution for application by the construction project team to improve the planning decision?*

Question *Q13: To what extent can the integrated planning solution aid the capability of construction project management?*

4.4.2 Model validation

In the validation experiments, the research utilised an experiment design shown in Figure 3.60 and input data in Table 3.23 that involved varying the parameters stochastically, and implemented as described in Section 3.9.1. The experiments involved different iterations, which generates different outputs in each run. The model was run ten times, and the results are shown in Table 4.3.

Table 4.3

Validation result

Activity	From	End	Real Duration (days)	Model result (days)
Tender preparation by contractor	29/01/2015	2/06/2015	102	100.6
Tender Evaluation by client	2/06/2015	20/06/2015	34	34.8
Winner announced	20/06/2015	20/06/2015	1	2.8
Negotiation and Contract Award	20/06/2015	13/08/2015	21	18.7
Contract Acceptance and Project start	14/08/2015	9/09/2015	19	25.2
Traffic plan	9/09/2015	13/11/2015	47	48.5
Traffic switch	16/11/2015	23/11/2015	6	6
Work area establishment	2/12/2015	8/12/2015	4	4.6
Site preparation	26/01/2016	28/01/2016	3	2.3
Topsoil strip	29/01/2016	4/02/2016	3	2.4
Cut	5/02/2016	11/02/2016	4	4.3
Fill And Compact	5/02/2016	10/02/2016	3	2.1

The table shows the real case durations and the model durations. The simulations integrated the need to evaluate the influences caused by the negative precipitation effect, abnormal management effect and access-egress condition. The accuracy of the relationship between CSC data and model result as well as the model equation determined by statistical analysis of Equations (3.35) to (3.37) including *standard deviation (S.D)*, *Average Absolute Error (AAE)* and *Absolute Relative Error (ARE)*, presented in Table 4.4.

The table shows that the real case data and model values are close enough to conclude that it passed the validation objective, which is a close association or insignificant

Table 4.4

Statistical result

	Statistical term	value
1	Standard deviation	0.135379161
2	Average absolute error	0.468967
3	Standard deviation	0.189865

outlier as shown in Figure 4.29.

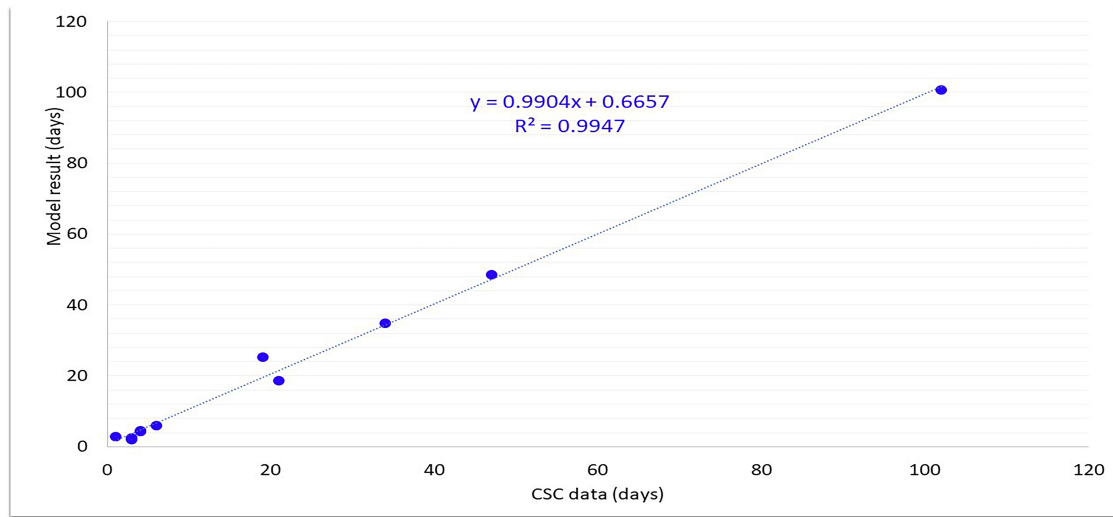


Figure 4.29. Validation correlation between real-data and model data

In addition to the statistical table 4.4, The *F test* set out no statistical differences between the real data and the model data, whereby the significance level was determined using *t-student distribution* distribution using Eqs. (3.38) and (3.39), and the result of the test are shown in Table 4.5.

In the access egress condition, the time to fix the access follows a triangular distribution: triangular (30,90,60) in hours and the frequency in which a blocked entrance occurs follows a triangular distribution of triangular (1,100,60) days.

Table 4.5

F-test result

	Variable 1	Variable 2
Mean	20.58	21.05
Variance	871.17	859.15
Observations	12	12
df	11	11
F	1.01	
P(F ₁ =f) one-tail	0.49	
F Critical one-tail	2.82	

4.4.3 Management Influence Analysis

To analyse the influence of good or bad management on the tender phase, the *managementInfluence* variable was changed from 0.5 to 1.5 by performing parameter variation. A lower value of this variable implies better management. A value of 0.5 indicates a 50% reduction in the times where good management can have influence from 10 days in a normal condition to 5 days with good management. A value of 1.5 implies a 50% increase in the times where bad management can have an influence, (i.e. from 10 days in a normal condition to 15 days with bad management).

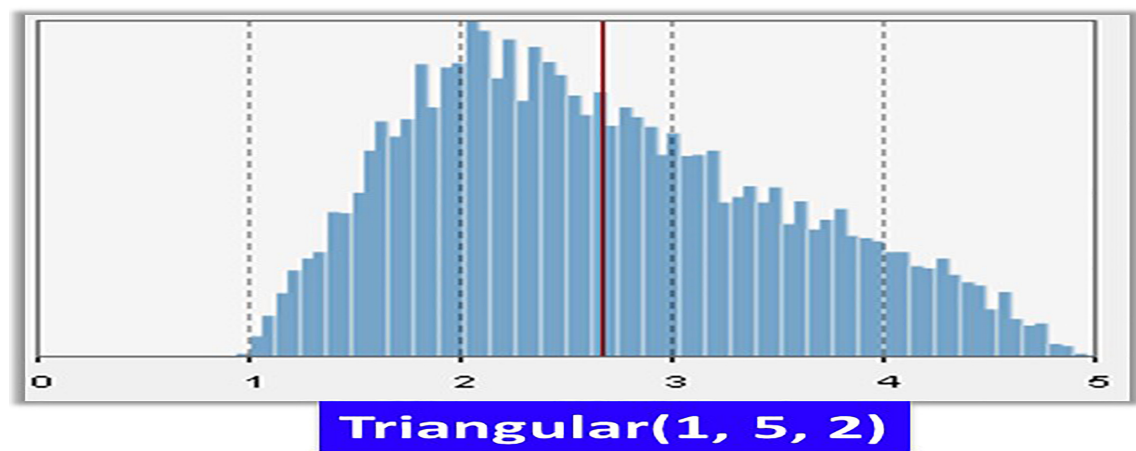
The value of this variable is subjective, and it is not possible to know how much a manager can influence. Is it 50%? Is it 90%? Is it only 5%? It does not matter because we want to prove that different values of the influence end up having a different value in the time it takes for the work completion. The parameter variation is defined in Table 4.6 with management influence as the only variable in the experiment.

In the evaluation of management influence experiment, the research defined a management influence parameter (*managementInfluence*) and time multiplier parameter (*timeMultiplier*). In the different states of ABS in the tender phase, variables of management influence are defined with triangular distributions because of the accurate values are not optimistic from the CSC. As an instance, one of the states has a triangular value distribution shown in Figure 4.30.

Table 4.6

Management influence parameter variation

	Parameter	min	maxstep	
1	BuldozerCapacity	2		
2	excavatorCapacity	2		
3	compactorSpeed	10		
4	areasPerCluster	33		
5	managementInfluence (days)	0.5	1.5	0.1
6	managementInfluenceExperiment	TRUE		
7	accessEgressExperiment	FALSE		
8	timeToUnblock (minutes)	60		
9	timeToBlock (days)	53.66		
10	precipitationInfExperiment	FALSE		
11	precipitationEffect	1		

*Figure 4.30.* Time variable triangular distribution

The real-time interface for the management influence in Anylogic is shown in Figure 4.31.

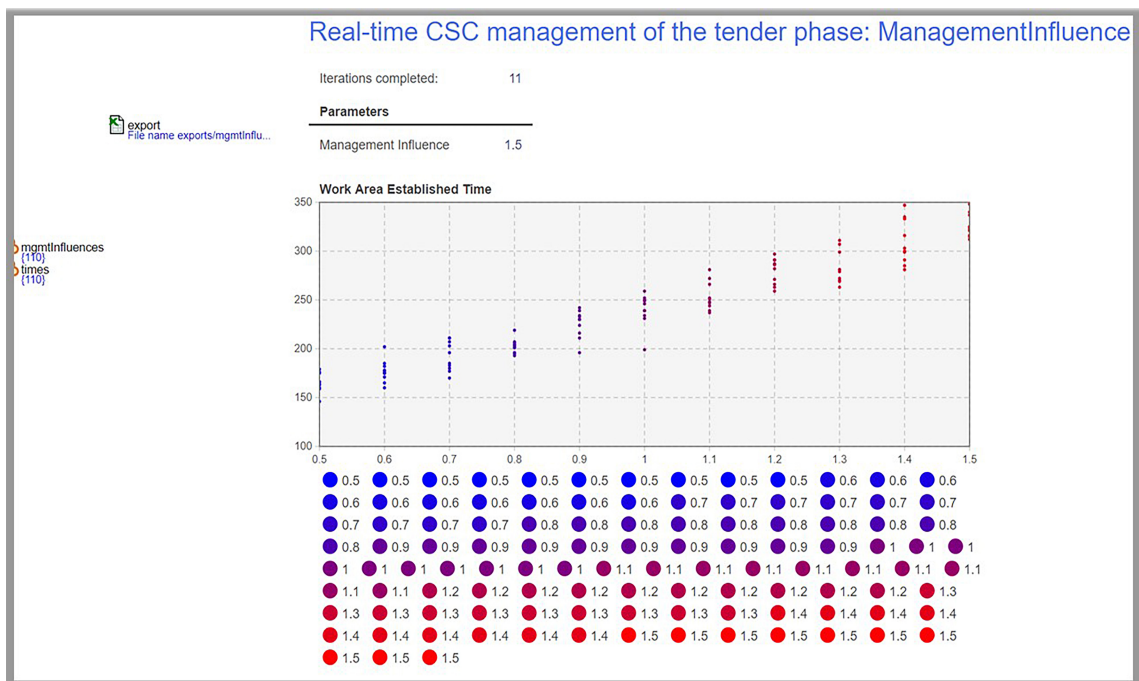


Figure 4.31. Real-time Management influence interface

The plots in Figures 4.32 to 4.35 show 10 replications for each value of the *managementInfluence* variable (from 0.5 to 1.5 and from 1.5 to 5.0 with a step of 0.1 shown on the X-axis or horizontal axis). In the vertical or Y-axis is the number of days it takes to have the work area established, which is equivalent to getting to the waitingCompany state in the tender phase.

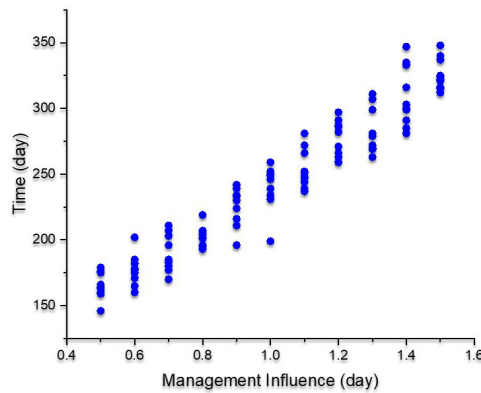


Figure 4.32. Management influence duration of tender phase (0.5 - 1.5)

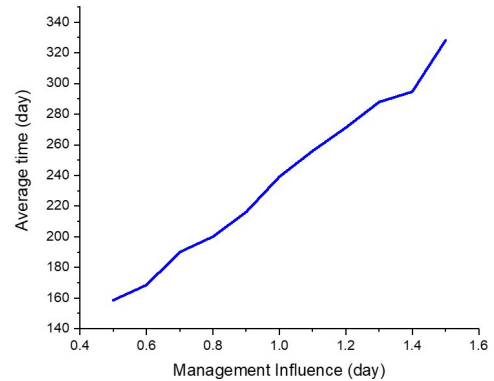


Figure 4.33. Management influence average duration of tender phase (0.5 - 1.5)

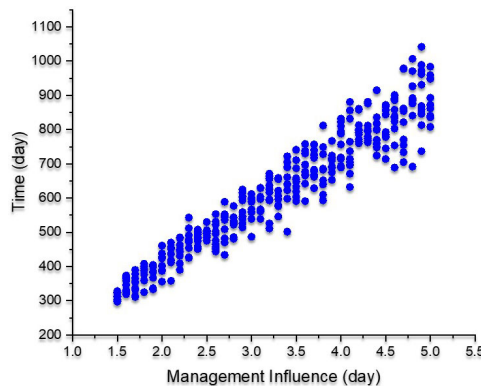


Figure 4.34. Management influence duration of tender phase (1.5 - 5.0)

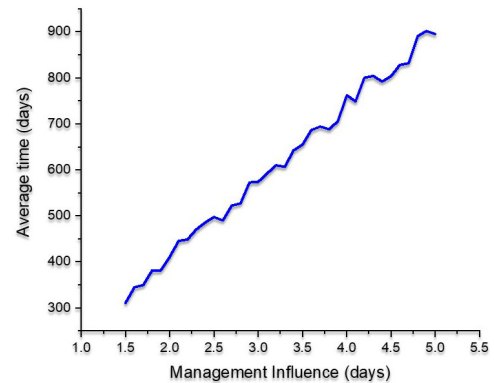


Figure 4.35. Management influence average duration of tender phase (1.5 - 5.0)

The summary result presented in Table 4.7 shows the management influence concerning the resulting time to finish the tender and establish the work area.

Table 4.7

Management influence parameter variation result summary

Management (days)	influence	Average time
0.5		158.6
0.6		168.5
0.7		190
0.8		200.1
0.9		216.1
1		239.2
1.1		256
1.2		271.2
1.3		287.9
1.4		294.6
1.5		328.1

4.4.4 Access egress analysis

A typical access egress condition is the one in which the time to fix the access follows a triangular distribution: triangular (30,90,60) hours. The frequency in which a blocked entrance occurs follows a triangular distribution of triangular(1,100,60) days. To test how the access-egress influence affects the system, the research generated a better condition in which it takes less time to unblock the access and where there is a reduction in the frequency of access blockage.

Similarly, the research can implement the opposite that makes the condition worse by increasing the time it takes to unblock the access and where there is a reduction in the frequency of access blockage. In the evaluation of access influence experiment, the research defined access egress collections (*timeToBlockArray*, *timeToUnblockArray* and *times*) on the work clusters. The parameter definition for the access egress experiment is set out in Table 4.8 using management influence as the only variable for the experiment while keeping other parameters constant.

Table 4.8

Access egress influence parameter variation

	Parameter	min	max	step
1	BuldozerCapacity	2		
2	excavatorCapacity	2		
3	compactorSpeed	10		
4	areasPerCluster	33		
5	managementInfluence (days)	1		
6	managementInfluenceExperiment	FALSE		
7	accessEgressExperiment	TRUE		
8	timeToUnblock (minutes)	1	241	60
9	timeToBlock (days)	1	241	60
10	precipitationInfExperiment	FALSE		
11	precipitationEffect	1.0		

The real-time interface in Anylogic of access egress influence is shown in Figure 4.36. The plot in Figure 4.37 and Table 4.9 show the combinations that were tested and the obtained results.

From the result, the normal average for time to block is 60 days and the time to unblock is 60 minutes. If the time to block is increased to more than 60 days, no matter what the time to unblock is, the result will be the same and there will be no variation in the time it takes to finish the whole project. Nevertheless, if we increase the frequency in which the access is blocked to a certain rate (1 time per day), keeping the same time to unblock, the number of days that the project is delayed is of (696-682) 14 days, which is nothing considering the unrealistic condition where the access is blocked for an hour every day on average for 2 years. The conclusion is that the access-egress has little influence when we try to improve it over typical conditions, but it can become a problem if it gets worse.

AccessEgressInfluence - Parameter Variation Experiment

Name: ☐ Ignore

Top-level agent:

Maximum available memory: Mb

Parameters

Parameters: ☒ Varied in range ☐ Freeform

Number of runs:

Parameter	Type	Value		
		Min	Max	Step
bulldoz...capacity	Fixed	2		
excavat...capacity	Fixed	2		
compactorSpeed	Fixed	10		
areasPerCluster	Fixed	33		
manage...luence	Fixed	1.0		
manage...riment	Fixed	false		
accessE...riment*	Fixed	true		
timeToUnblock	Range	1	241	60
timeToBlock	Range	1	241	60
precipit...eriment	Fixed	false		
precipi...nEffect	Fixed	1.0		

Model time

Stop:

Start time: Stop time:

Start date: Stop date:

After simulation run:

```
timeToBlockArray.add(root.timeToBlock);
timeToUnblockArray.add(root.timeToUnblock);
times.add(root.getTimeStampDays());
```

Figure 4.36. Real-time access egress interface

Table 4.9

Access egress influence parameter variation result

Time To Block (Days)	Time To UnBlock (Minutes)	Time (Minutes)
121	1	682
181	1	682
241	1	682
61	61	682
121	61	682
1	1	682
61	1	682
181	61	682
241	61	682
61	121	682
181	121	682
121	121	682
241	121	682
121	181	682
241	181	682
181	181	682
181	241	682
121	241	682
241	241	682
61	181	683
61	241	683
1	61	696
1	181	703
1	121	712
1	241	748

4.4.5 Groundwater table influence

Precipitation effect variable is created with values from 0.1 to 1, where 1 is the normal precipitation state. The lower the variables, the worse the precipitation effect (for instance more mud after rain reduces the speed of the machines). The idea is to analyse the precipitation influence. In the evaluation of the experiment for groundwater influence, the research defined two collections on the work clusters, which are an array of precipitation influences and influence times. The parameter definition for the groundwater influence experiment is set out in Table 4.10.

Table 4.10

Groundwater influence parameter variation

	Parameter	min	max	step
1	BuldozerCapacity	2		
2	excavatorCapacity	2		
3	compactorSpeed	10		
4	areasPerCluster	33		
5	managementInfluence (days)	1		
6	managementInfluenceExperiment	FALSE		
7	accessEgressExperiment	FALSE		
8	timeToUnblock (minutes)	60		
9	timeToBlock (days)	53.67		
10	precipitationInfExperiment	TRUE		
11	precipitationEffect	0.1	0.9	0.2

Using groundwater (precipitation) influence as the only variable for the experiment while keeping other parameters constant, the real-time interface in AnyLogic of groundwater influence is shown in Figure 4.38.

The plot in Figure 4.38 and Table 4.11 show the precipitation effect with the time it takes to complete the project. The plot in Figure 4.39 and Table 4.11 show the combinations that were tested and the obtained results, respectively.

PrecipitationInfluenceAnalysis - Parameter Variation Experiment

Name: ☐ Ignore

Top-level agent:

Maximum available memory: Mb

Parameters

Parameters: ☒ Varied in range ☐ Freeform

Number of runs:

Parameter	Type	Value		
		Min	Max	Step
bulldoz...capacity	Fixed	2		
excavat...capacity	Fixed	2		
compactorSpeed	Fixed	10		
areasPerCluster	Fixed	33		
manage...luence	Fixed	1.0		
manage...riment	Fixed	false		
accessE...riment	Fixed	false		
timeToUnblock	Fixed	60		
timeToBlock	Fixed	53.6666		
precipi...riment*	Fixed	true		
precipi...nEffect	Range	0.1	0.9	0.2

After simulation run:

```

Color color = lerpColor( (getCurrentIteration() - 1)
/ (double)(getMaximumIterations() - 1), blue, red );
chart0.addDataSet(root.precipitationInfDataset,
format( root.precipitationEffect ), color, true,
Chart.INTERPOLATION_LINEAR, 1, Chart.POINT_CIRCLE );
pInfluences.add(root.precipitationEffect );
times.add(root.getTimeStampDays());

```

Figure 4.38. Real-time groundwater influence interface

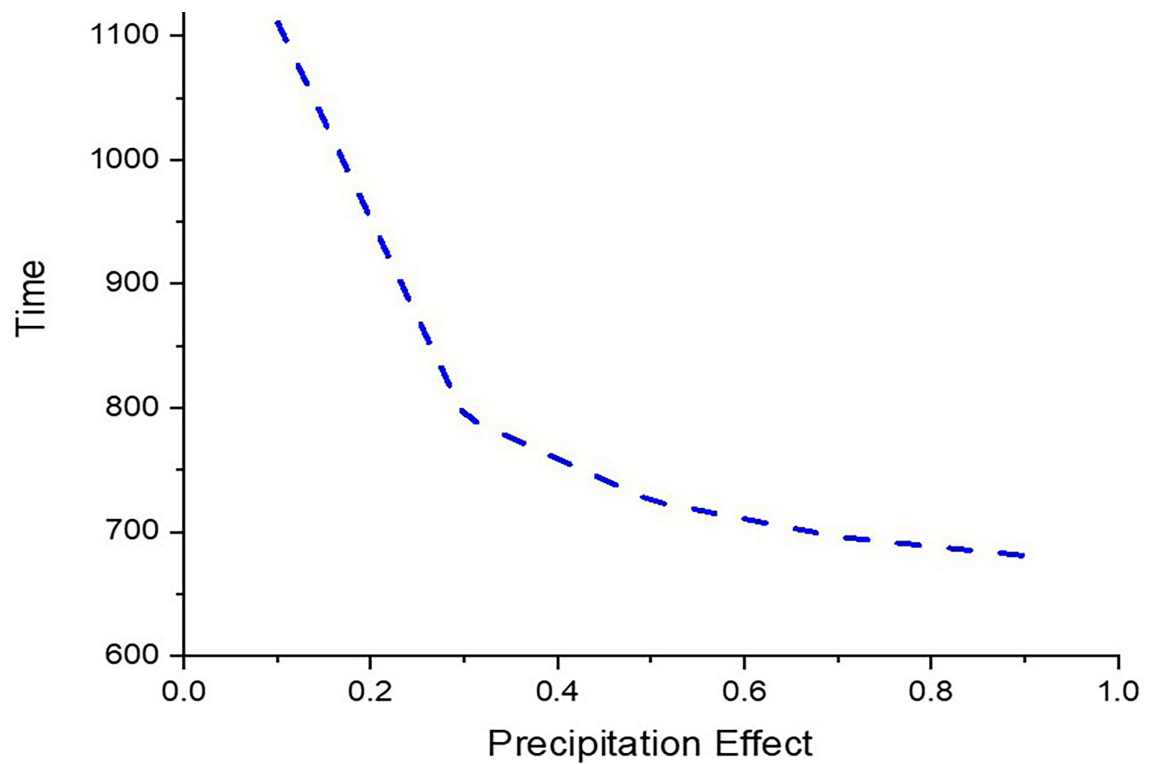


Figure 4.39. Real-time precipitation influence

Table 4.11

Ground water influence parameter variation result

Precipitation Effect	Time(Minutes)
0.1	1111
0.3	793
0.5	725
0.7	696
0.9	681

The result shows that with more severe effects of the rain on the terrain, the time for project completion increases exponentially. Nevertheless, this cannot be controlled since the terrain and weather are a natural occurrence. So, this influence is just a reference to understand how much a project can be delayed if the terrain is not very well suited to be worked under severe climatic conditions. In addition to that, an increase of 30% of the effect (precipitation effect equal to 0.7) increases the normal time with no precipitation in around two weeks. A 10% increase (from 1 to 0.9 in the value of precipitation effect) has little effect on the time it takes to complete the project (both are around 681 days).

4.4.6 Risk analysis of equipment use

Under normal optimisation conditions, it is defined that for each area, the construction utilised two bulldozers and two excavators. The real-time interface in AnyLogic for risk analysis on equipment utilisation is shown in Figure 4.40 with bulldozer and excavator array, which are collections in AnyLogic. However, what if the manager says that one is enough? We want to analyse the risk of not meeting the deadline using a different number of machines by developing RiskOnEquipmentUse experiment on the model. Ten replications are used to understand the number of times that a project fails under those conditions. In that sense, we will arbitrarily assume a deadline of 700 days under the scenario where the same equipment has to take care of each one of the areas. These results can, of course, be extrapolated to any scenario where multiple areas are worked

bulldozersArray

excavatorsArray

times

RiskOnEquipmentUse - Parameter Variation Experiment

Name: ☐ Ignore

Top-level agent:

Maximum available memory: Mb

Parameters

Parameters:

☒ Varied in range
 ☐ Freeform

Number of runs:

Parameter	Type	Value		
		Min	Max	Step
bulldoz...pacity	Range	1	2	1
excavat...apacity	Range	1	2	1
compactorSpeed	Fixed	10		
areasPerCluster	Fixed	33		
manage...luence	Fixed	1.0		
manage...riment	Fixed	false		
accessE...riment	Fixed	false		
timeToUnblock	Fixed	60		
timeToBlock	Fixed	53.6666		
precipit...eriment	Fixed	false		
precipi...nEffect	Fixed	1.0		

After simulation run:


```

bulldozersArray.add(root.bulldozersCapacity);
excavatorsArray.add(root.excavatorCapacity);
times.add(root.getTimeStampDays());
          
```

Figure 4.40. Real-time risk on equipment analysis interface

at the same time, but for this risk analysis, it is enough. The plots in Figures 4.41 to 4.44 and Table 4.12 show the combinations that were tested and the obtained results.

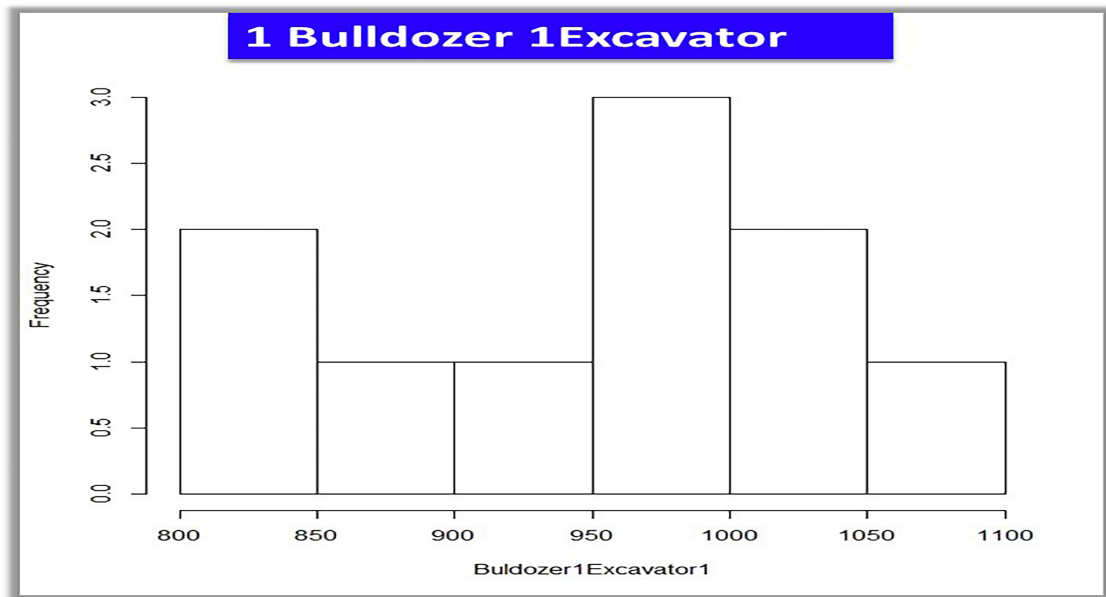


Figure 4.41. Risk analysis on 1 bulldozer and 1 excavator

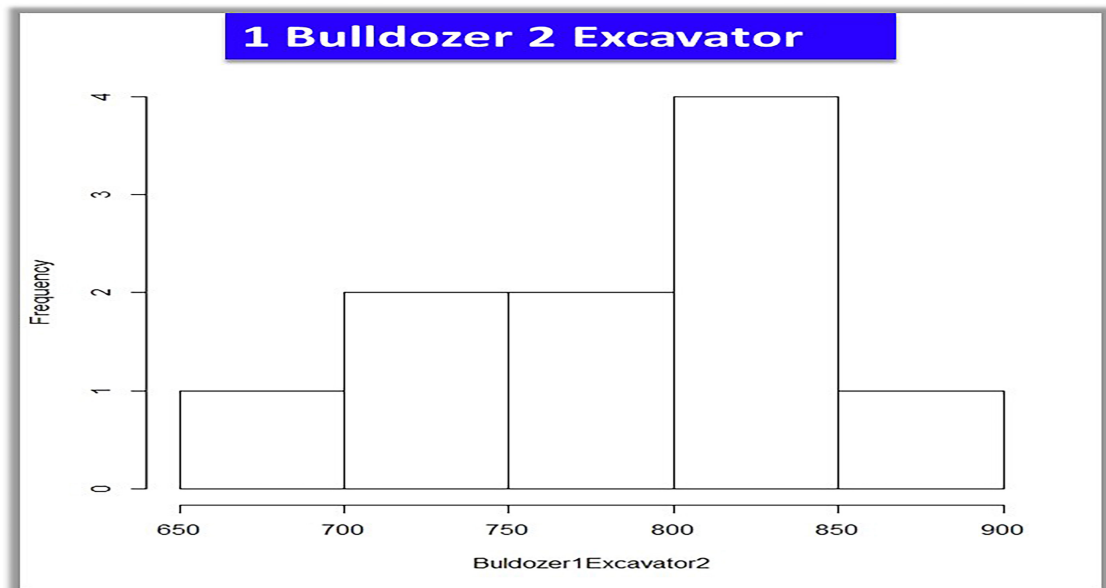


Figure 4.42. Risk analysis on 1 bulldozer and 2 excavator

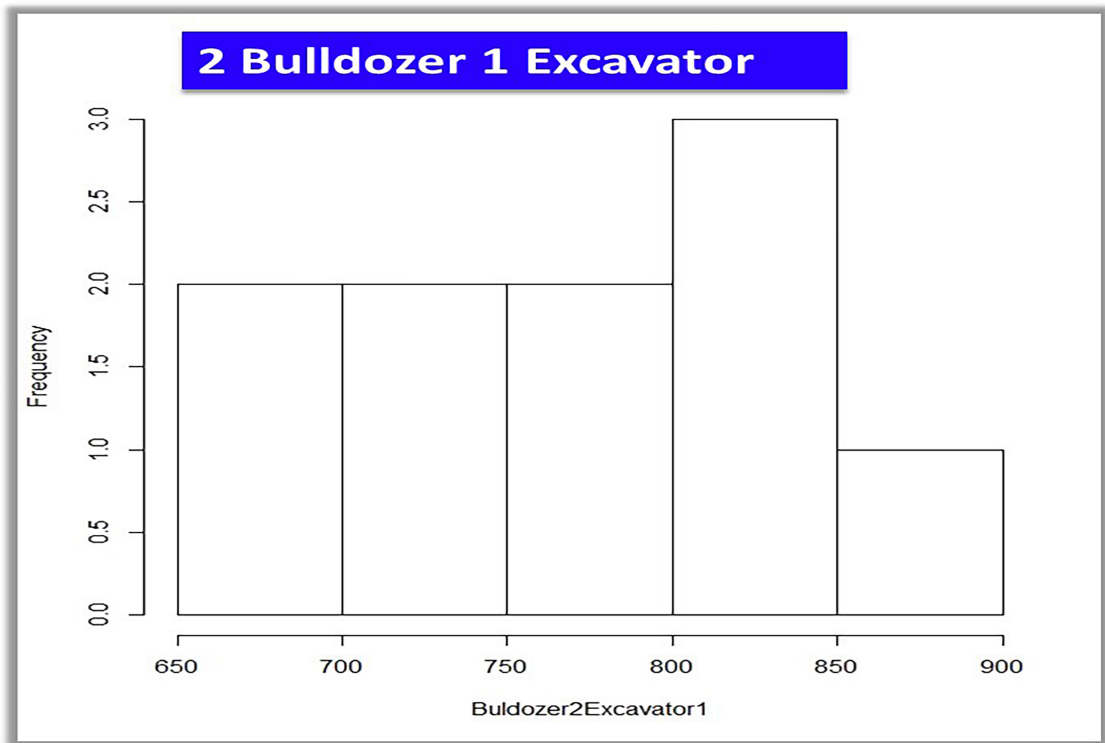


Figure 4.43. Risk analysis on 2 bulldozer and 1 excavator

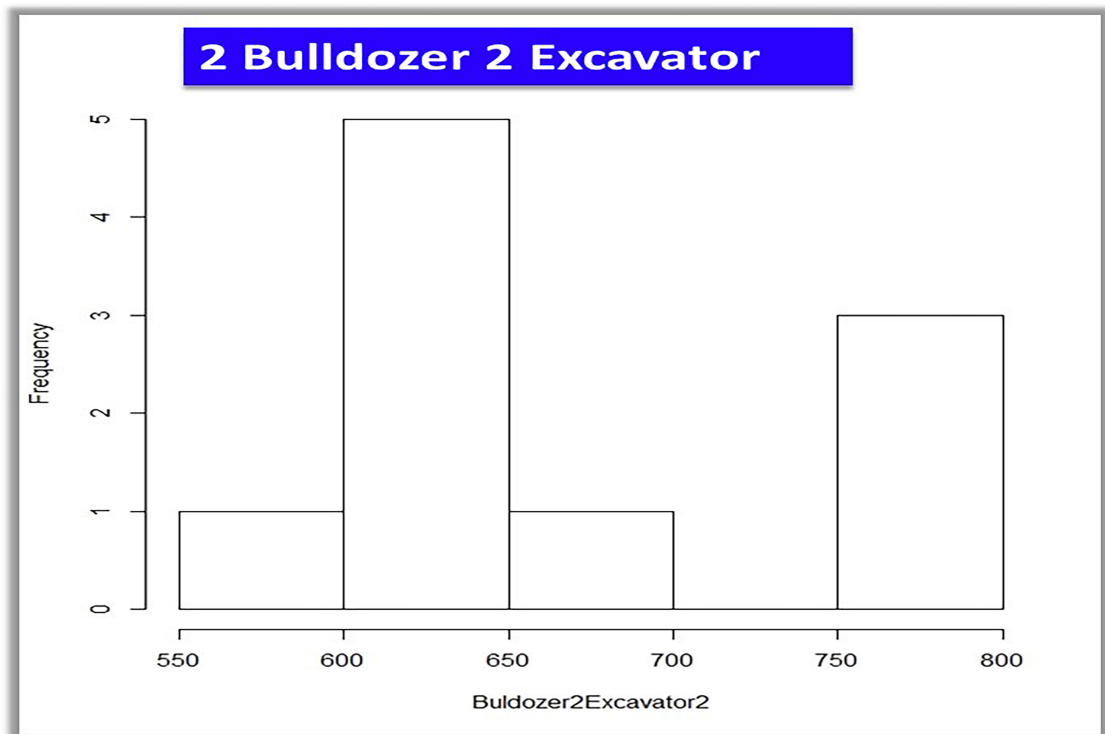


Figure 4.44. Risk analysis on 2 bulldozer and 2 excavator

Table 4.12

Risk analysis of equipment use summary result

		Probability of being late (%)		Average number of delay (days)
1	Buldozer	1	100	252
	Excavator			
1	Buldozer	2	90	84.5
	Excavator			
2	Buldozer	1	80	78.8
	Excavator			
2	Buldozer	2	30	-33(the project will be generally deliver before schedule)
	Excavator			

The influences and variabilities have been combined into the planning process to enhance risks analysis, in that case, provides answers to the posed Questions *Q10*, *Q11*, *Q12* and *Q13* asking:

Question *Q10: How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?*

Question *Q11: How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?*

Question *Q12: What is the technique to present the model solution for application by the construction project team to improve the planning decision?*

Question *Q13: To what extent can the integrated planning solution aid the capability of construction project management?*

4.4.7 System optimization

It is observed from the simulation runs that if only 1 team of machines working in each one of the areas is utilised, the duration to finish everything is around 680 days, but

if we use 17 teams of 2 bulldozers and 2 excavators (34 excavators and 34 bulldozers, the project is completed in only 300 days). It is known that in general, when projects are developed, it is always convenient to stay as close as possible to the deadline, not finishing too early, but not being late to optimise the costs. The AnyLogic interface after the optimisation is shown in Figure 4.45.



Figure 4.45. After optimization interface

The optimisation experiment runs generated the following optimal configuration:

Numberofbulldozers : 2

NumberofExcavators : 2

AreasPerCluster : 11, equivalentto3teams

Thejobwascompletedin449days.

*Totalnumberofmachines : $3 * 2 * 2 = 12$.*

Dynamic simulations can be performed by varying the parameters to obtain new results. Given the current parameters, decision-making support results in Figures 4.46 to 4.51 that aid the project team in resources utilisation and project accomplishment before the due date.

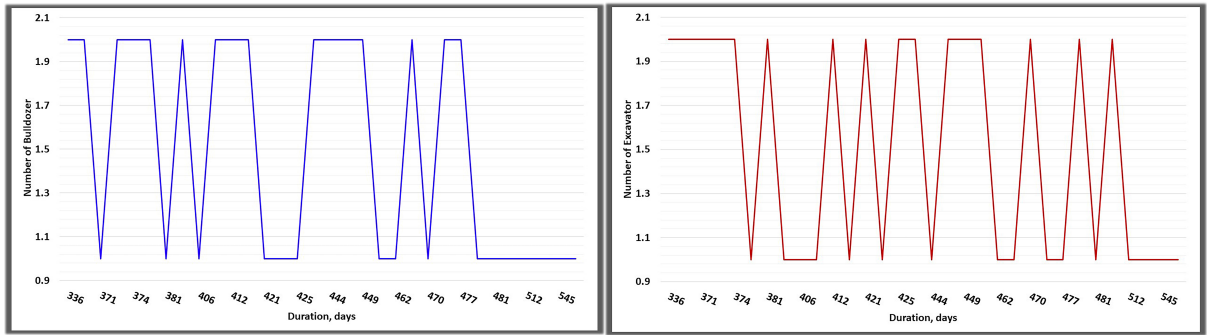


Figure 4.46. Optimum number of bulldozers Figure 4.47. Optimum number of excavators

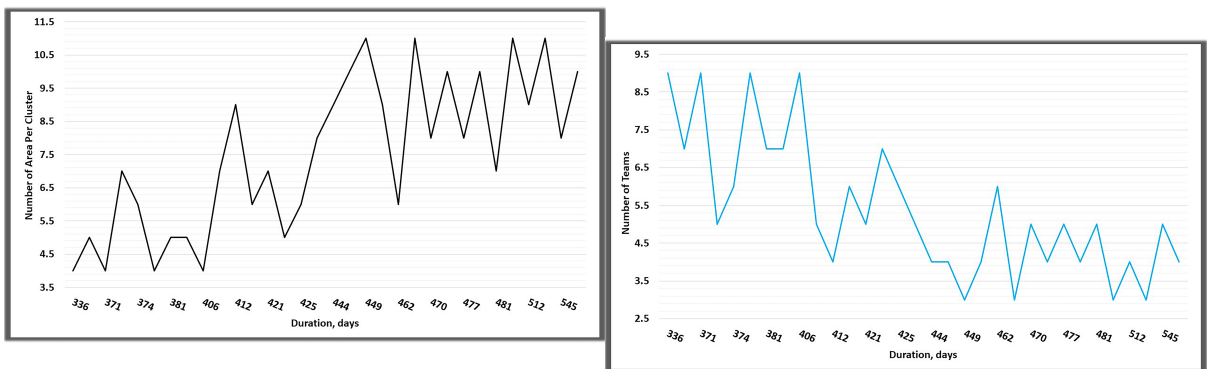


Figure 4.48. Optimum number of area per work cluster

Figure 4.49. Number of teams

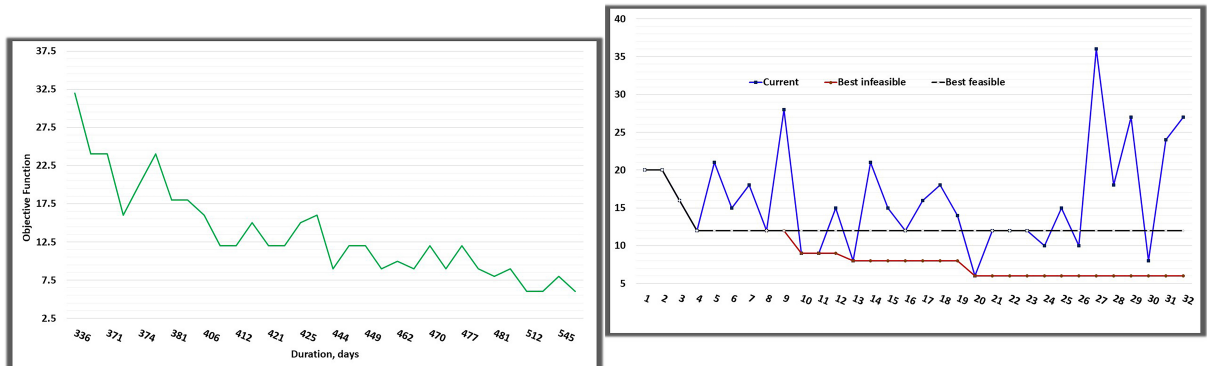


Figure 4.50. Objective function

Figure 4.51. Best feasible and best infeasible search

The results in the figures, the optimal parameters and variables of interest are number of

bulldozers, number of excavators, number of areas per work cluster, number of utilised work teams, the result of the objective function and results of the scatter search (current, best feasible and best infeasible). The results of the scatter search shows that the goal-feasible solution commenced from the objective function of 20 to 12 at the fourth iterations with the best solution found to be 12 whereby the search trajectory included infeasible solutions relative to the best feasible solution.

The development of an effective and optimum plan is when the interacting parameters can be minimised or maximised to enhance efficient schedule; subsequently, the research utilised the optimizer to accomplish that goal. Accordingly, the system optimisation provides answers to the posed Questions Question *Q10: How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?*

Question *Q11: How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?*

Question *Q12: What is the technique to present the model solution for application by the construction project team to improve the planning decision?*

Question *Q13: To what extent can the integrated planning solution aid the capability of construction project management?*

Q14:How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?

4.4.8 Gantt findings: schedule outcome of optimised plan

The optimum plan from the simulation modeling and optimisation in the different experiments generated the times to accomplish each activity, in Appendix 2. The

schedule is implemented after evaluating the different forms of the process model as a unit. The capability of the research analysis only generated the activity duration. It developed a platform to create the Gantt Chart using the durations exported to Microsoft Project for Gantt Charts. The charts are shown in Figures 4.52 to 4.54.

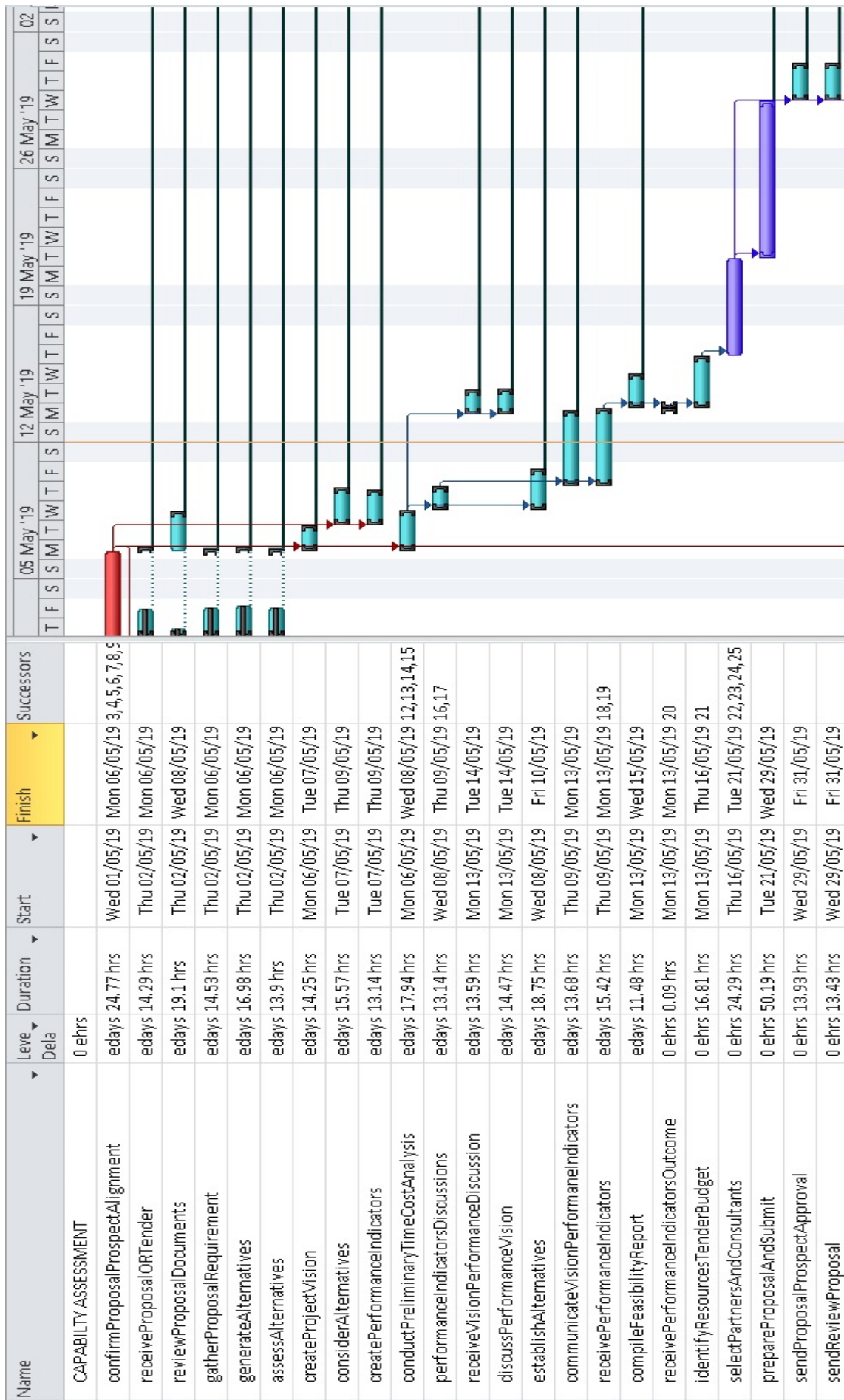


Figure 4.52. Gantt Chart of the optimised plan

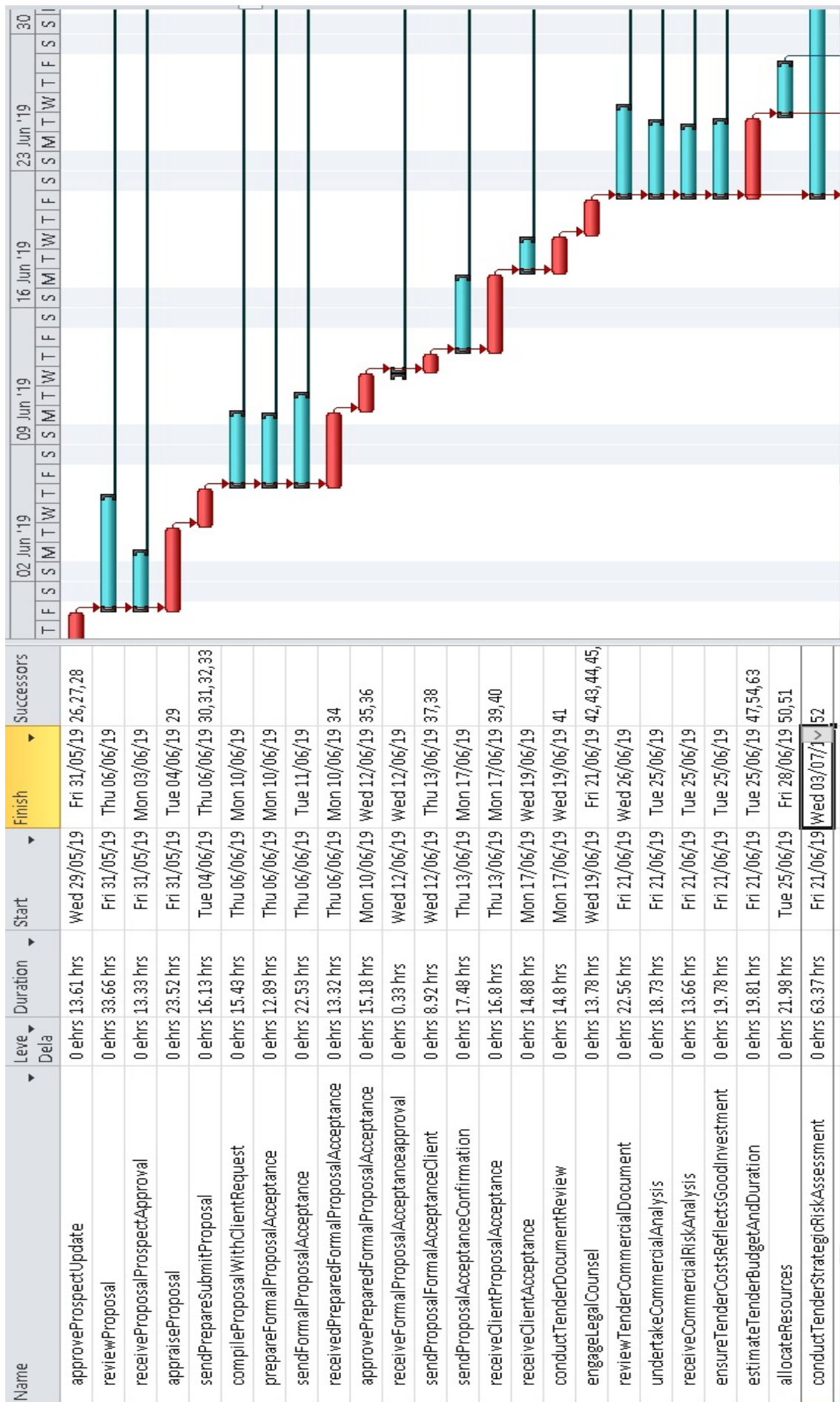


Figure 4.53. Gantt Chart of the optimised plan

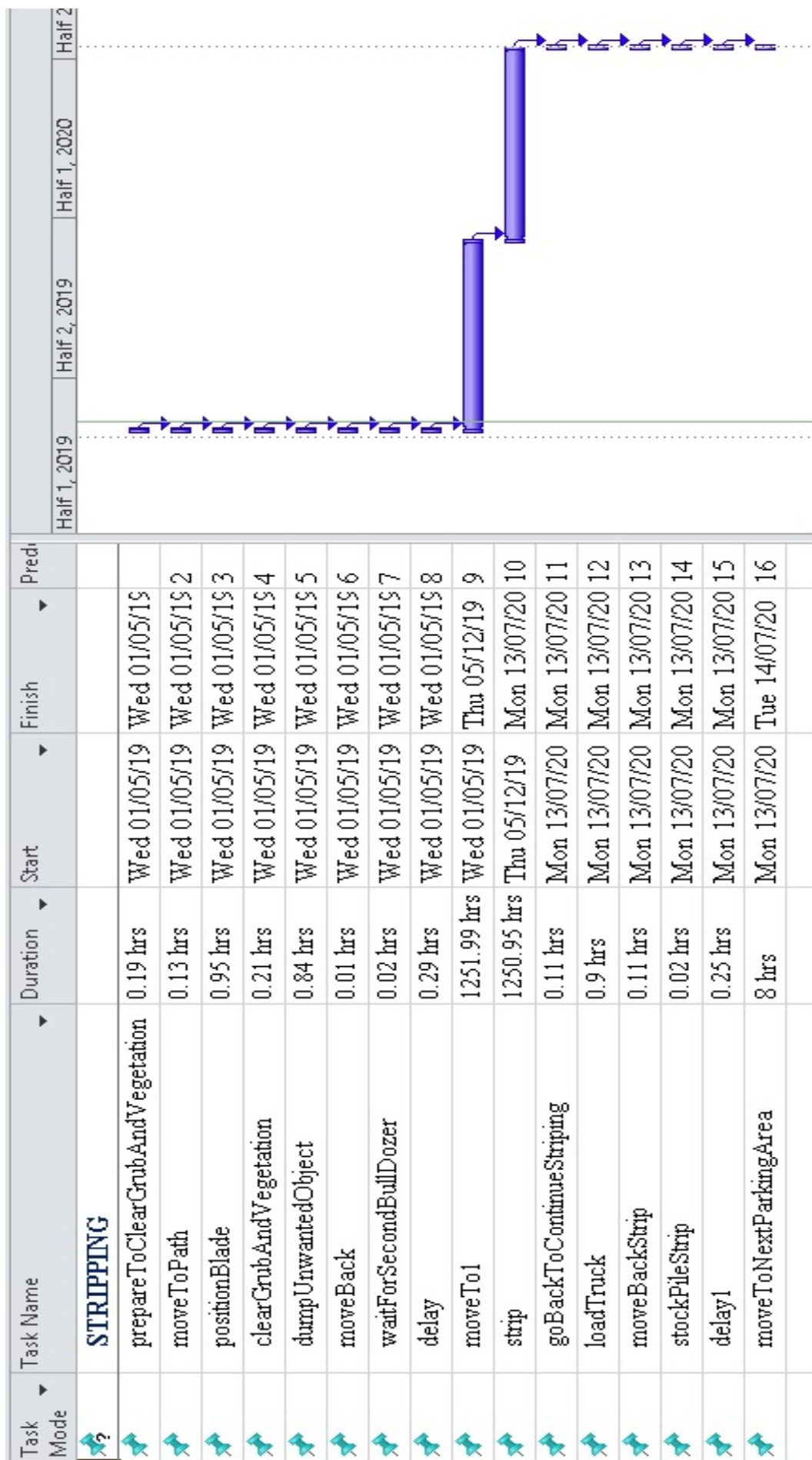


Figure 4.54. Gantt Chart of the optimised plan

4.5 Summary

In this chapter, the research described how the model is mapped with real-world case and data. The integrated and multi-hybrid model was examined to ascertain its propensity for execution by the strength of AnyLogic main simulation interface. While the next in the order was the test of validity for the hybrid model using simulations, at the other end, was the research aptitude to administer specific and comprehensive hybrid-model experiments that relied on parameter variation and sensitivity analysis.

Despite the simulation experiments, the validity of the experiments was verified through the application of statistical analysis: F test, t-test and outlier analysis between real-world data and the model data. The enthusiasm of every construction activities given a certain quantity of allocated resources is the approach to utilise the resources even in the dynamic and uncertain environment of the construction contract. On that account, the exploitation of the primary resources vis à vis the work cluster activities were assigned to a scatter search-optimiser (OptQuest).

The optimiser, which is a black box executor addressed the problems of the dynamic construction system, system flexibility, planning and scheduling integration. At the same time, proffered solutions to guarantee the set goals: feasible and best solution for the objective function. Correspondingly, a Gantt-system implementation to export the activity durations into either Primavera, Microsoft project or Excel were created using Gantt javascript and function calls. This chapter confirmed the realisation of the research goals taking into account the evidence of answers to the research questions, more specifically the *Objective B and Objective C* because in

Objective B: To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule.

Moreover, in

Objective *C: To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule..*

A summary of the research findings, together with their illustration, is employed to demonstrate the answers to the research questions. The next Chapter 5 presents the detailed discussion of the idea, results and findings of the current study.

Chapter 5

Discussion

5.1 Introduction

The research was designed to propose a new multi-hybrid framework for planning and scheduling in the construction enterprise. The validity of the proposed framework was evaluated to explore its capability for integrating the dynamic characteristics of construction systems (Buvik & Rolfsen 2015, Fellows & Liu 2015b, Todorović, Petrović, Mihić, Obradović, & Bushuyev 2015, S. Zhang et al. 2015). Given the results described in Chapter 4, the development and evaluation of the framework (Morgenthal et al. 2019, Panwar & Jha 2019, Todorović et al. 2015, S. Zhang et al. 2015) is one feature, and another concern is the enhancement for decision-making (Bakht & El-Diraby 2015, Monghasemi, Nikoo, Fasaee, & Adamowski 2015, Morgenthal et al. 2019) in the construction enterprise. The chapter discusses the attained research objectives and how the hybrid framework underpin decision making in complex and real-world construction projects both for the client and main contractors. The chapter culminates with the scenarios of application of the hybrid model to the construction industry.

In this chapter, the research presents the discussion on the research case, appraisal of the existing method for planning and scheduling, formulated simulation, and simulation modeling validity. In the same vein, this chapter presents discussions concerning the findings on the research questions and research objectives. It is the research questions that generated the findings. Accordingly, the chapter presents both sides of the research problem. This includes the consideration of the research results and associated implications, while cautiously presenting the statement of the result. As a guide to this discussion section, the research illustrated the applicable themes in the layout and content shown in Figure 5.1.

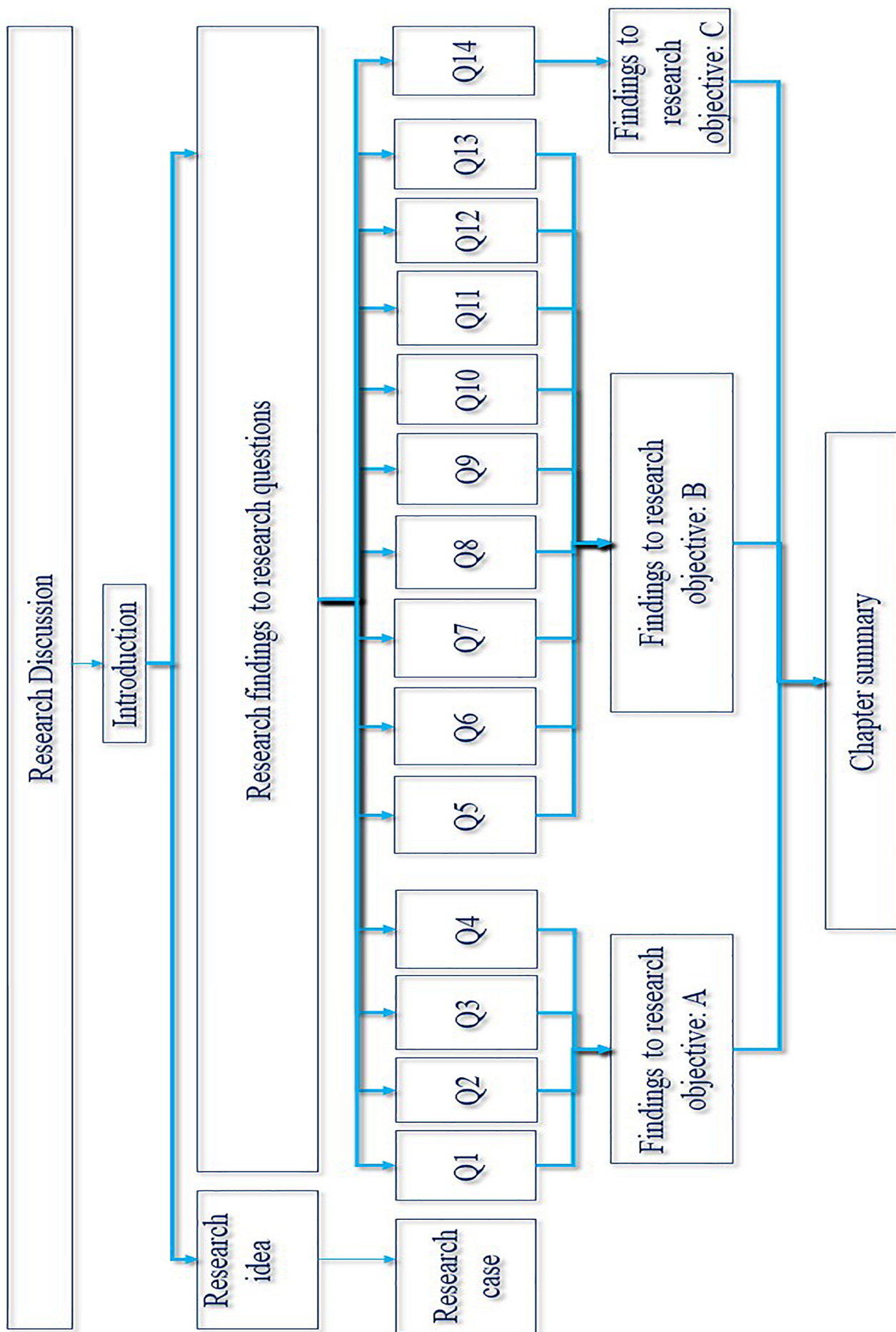


Figure 5.1. Chapter 5 layout and content

5.2 Research case

The study engaged real case data (J. Liu, Zhao, & Yan 2016, Vahdatikhaki, Hammad, & Siddiqui 2015) derived from the construction contract. Specifically, in the tender phase and construction phase to assess the inherent dynamic and complex environment. There are a significant number of research efforts to advance decision support for planning and scheduling (Hazır 2015). These occur in different facets of construction contracts, particularly in tendering and bidding phase, pre-construction and construction phase (Cagliano, Grimaldi, & Rafele 2015). Irrespective of the different phases, there are different levels of abstractions that explicitly characterise the phases. In the project life cycle, (Herroelen & Leus 2005, S. H. Lee et al. 2006) described the levels of abstractions required to tackle the entire construction planning and scheduling problem as strategic, tactical and operational details. In those research endeavours, a predominant exploration and evaluations of the construction systems are confined to the sub-components of the phases and the levels of abstraction.

Likewise, though the construction system and the associated decision-making package requires real-data that represents the real-world system, most current evaluation systems are limited in strength concerning the complexity and dynamic of the construction system (Alzraiee et al. 2015). In general terms, construction enterprise is capital intensive, and experimenting with the construction process on site for decision-making support is likely to be the unacceptable premium in different situations. In some cases, such an experiment can lack good process-design leading to the insufficient result, ostracising the experiment and boosting the globally acclaimed overruns (Arashpour, Wakefield, Lee, et al. 2016). It is a widespread acceptance that human decision-making is outstanding. Despite the human prowess, in complex and dynamic systems such as construction contracts, an aided tool is expected to augment immediate and quality decisions (P. Zhang, Li, Jiang, Fang, & Anumba 2019, N. Zhao & An 2016).

This research focused on those issues to develop a framework of the hybrid model from the scenarios of the case study company (CSC), precisely an infrastructure project with the utilisation of heavy equipment that determines the timely completion of the projects. During the construction processes, a wide range of influences nurtured complexities and uncertainties. The complications did not necessarily emanate from the construction management. However, they evolved from the complex knowns and unknowns variables that must be resolved to advance the project to completion. The integrated hybrid framework of Agent-based model (ABS), discrete-event model (DES), discrete-rate model (DRS) and system dynamics (SD) model, which is inadequate in construction planning and scheduling literature, was developed from the research *objectives* derived from the mechanisms of the case construction-system:

- (A) To understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading to time overrun.
- (B) To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule.
- (C) To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.

This study set out with the aim of assessing the importance of utilising real data from the construction contract of the case study company (CSC) explained in Section 3.8.2. One engaging finding is that the research design is formulated on a blend of cases that provided an original approach to elucidate construction planning and scheduling problems. This promoted the bridging of the gap between theory and practice. The

assertion is ratified and substantiated during the research work.

5.3 Appraisal of existing methods

Appraisal of existing methods The construction contract has defined deliverables to maximise resources and contract value while progressing through different stages. Each contract has defined time frame of completion. The effects on the previous phase can cascade to the subsequent phases if the effects are not adequately mitigated. Despite its scale and complexity and uncertain features, the accomplishment to achieve the set goals is paramount to the case study company (CSC). The case study company is a contracting company and have established processes to enhance achieving the project goals with a different decision point at each stage. The CSC company acquires construction contracts through bidding.

At the bidding stage, different technical and cross-functional teams are organised to explore opportunities of the potential contract, collaborate with consortium or alliances to prepare bids and plan extensively at the bidding stage (Al Nahyan, Sohal, Hawas, & Fildes 2019, Aziz & Aboelmagd 2019). The idea is on the premise that practical and tactical planning at the initial stage enhances the subsequent phase. In the bidding stage, a diverse range of real-time planning by the managers and teams are extensively utilised to ensure the success of bidding and contract award (Smyth, Duryan, & Kusuma 2019, Son, Khwaja, & Milligan 2019). The teams, from case study evaluation, consist of the opportunity management team, proposal and tender team, construction project management team, assurance checks team, knowledge management team, and the client. The implication is the high level of collaboration and management influences among the team (Laurent & Leicht 2019). In the tender phase of the research implementation, each team received the message, executed received the message and replied the message considering that each message had instructions.

This research is set on the presupposition that each phase determines the subsequent phase, and has developed a framework that considers each phase as interwoven with one another (X. Zheng, Easa, Yang, Ji, & Jiang 2019). The meaning is the deliverables of the previous phase automatically becomes the deliverable of the subsequent phase (Kabirifar & Mojtahedi 2019). For instance, the CSC prepares baseline line schedule at the tender phase, which is a deliverable to the construction phase (operational phase). The baseline schedule is transformed from one level to another to the master scheduling applied to control construction progress as well as pseudo-static rescheduling. The discussions from the CSC collaborations showed that three issues are evident. The concerns are bidding, complexity management and the need for decision support tool. The means is expected to serve as a gate intensifier from one phase to another as well as the entire gates as the one-unit gate. The research believes that the stronger the system of decision-making supports the stronger the gates. The stronger the gates, accordingly, the stronger the next phase, as shown in Figure 5.2.

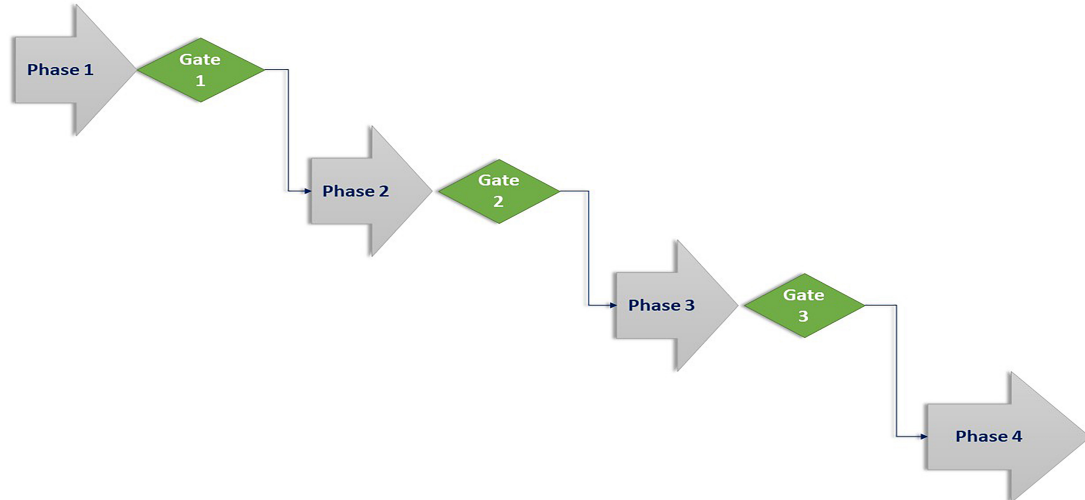


Figure 5.2. Construction contract phase and gate

The literature appraisal in this research and discussions on the existing technology and knowledge as well as in-depth case evaluation orchestrated the need for bridging the gap between real-world parameters of the construction system and theory. Then, a holistic approach is of great essence to handle overruns in planning and scheduling

of construction projects. It is accepted that real-time and dynamic planning and scheduling is practised in different sectors (R. Larsen & Pranzo 2019, Naticchia, Carbonari, Vaccarini, & Giorgi 2019, J. Zhang, Ding, Zou, Qin, & Fu 2019). The appraisal could not find any existing dynamic system that integrated the capability of multi-paradigm and framework to develop planning and scheduling solution, tested with different multi-levels of abstractions in the construction industry.

Even where dynamic frameworks (S. H. Lee et al. 2006) have been developed, there is no identified advanced and multi-hybrid framework in the literature (Fahmy et al. 2014) for the construction enterprise. Therefore, this research invented and introduced a set of frameworks in Sections 3.7.1.5 and 3.8.10 to explore and evaluate dynamic and complex construction system in planning and scheduling together with influencing factors. Comparison of the multi-hybrid framework with those of other studies (Alvanchi et al. 2011b, Mostafa et al. 2016, Nasirzadeh et al. 2018a, Peña-Mora et al. 2008, Rondini et al. 2017, J. Wang & Yuan 2016) confirms the novel of the framework and a landmark for future research in dynamic and practical construction planning and scheduling.

5.4 Formulated model

Even though the implementation of the CSC construction contract is in phases, each phase has unique entities or agents performing role to ensure the complete execution of the project (Hsieh & Lin 2015). The aggregate of each phase sub-entities forms the composition of the independent agents in the basic construction system. The entities have distinct characteristics, communications and methods. Irrespective of the construction operations itself, the collaboration and interactions of the entities are complex. For the entities alone, while a specific part is tangible and abstract, other parts are either mobile or static or both concerning time of the construction events.

An explicit and in-depth study of the features of the entities was a step-ladder to justify

the modeling approach. This research analysed the different agents participating in the construction-contract case. The observation was that neither the agent-based model (ABS) nor discrete-event model (DES) nor discrete-rate model (DRS) nor the system dynamics model (SD) is sufficient to model the system. Instead, an amalgamation of the paradigms to enhance the utilisation of their attributes. At the outset of the research, the Bayesian network was embarked on to generate a schedule with dynamic characteristics in the presence of the influences of different phases. The network at a different level of analysis provided a comprehensive analysis of the association between phases and influencing factors. On the contrary, it was not sufficient to delineate the unique agents' characteristics working either positively or negatively on the construction contract.

The multi-hybrid model invented in the research are twofold: 1) the formulation of a model for investigating time influencing factors at different construction phases and; 2) a coupled paradigm of ABS-DES-DRS-SD and optimisation: the multi-hybrid model for exploring and evaluating complex and dynamic construction-system. Given the formalism of the solutions, the research is unique compared to earlier studies. It is the first to develop and reveal models for advancing construction planning and scheduling. The solutions development from the real-world case is significant in adopting real construction data for mapping and extrapolating real-world planning and scheduling.

5.5 Hybrid model validity

The development of models is one form of the novelty; likewise, ascertaining that the models have repetitive and predictive features is pivotal to the mechanism of the model (Borshchev 2013b, Sumari et al. 2013). The solution in this research was validated by administering some experiments ranging from simulations, parameter variation, sensitivity analysis and optimisation laid out in Chapter 4. The system visualisation in real-time, based on the characteristics of the construction case and utilisation of

Java-oriented AnyLogic system, is a support to the developed system.

Each of the model parameter and element is compared with one another in experiments involving simulation runs with visual and statistical observation. During the simulation, each of the internal components of the models and entities of the simulation was examined for consistency to ensure that its behaviour is not conflicting with the formulated models. The sensitivity analysis ("what-if") experiments varied the model parameters to investigate the magnitude of the resulting changes on the model parameters. The optimal and goal-seeking experiments were executed using OptQuest in AnyLogic. The simulation output is compared and fit with historical data by varying the parameters used in the model, which showed strong association and minor outliers.

The hybrid model proposition in the research is an aid to the decision-making support system for the CSC. This can be replicated to another construction enterprise of the CSC type. The internal validation was further confirmed with external validation from the construction team, and the feedback received from the team is evidence of the research strength to close the gaps forming the objective of the research. The discussion on the model validity is detailed with the research objectives and the accompanying objectives.

5.5.1 Finding to research question Q1

There are earlier research studies that have noted the importance of determining the categories of planning and scheduling (Deblaere, Demeulemeester, & Herroelen 2011c, Faghihi, Nejat, Reinschmidt, & Kang 2015, Hans et al. 2007, Lamas & Demeulemeester 2015a, Lambrechts, Demeulemeester, & Herroelen 2011, Van de Vonder, Ballestin, Demeulemeester, & Herroelen 2007, Varakantham, Fu, & Lau 2016) for construction system. In that regard, this research explores, as an improvement, to identify current systems for static and dynamic planning. This question can be viewed as an essential component of the research question because there are many efforts in planning and

scheduling innovation. The effort to understand a way forward for improvements is expected to depend significantly on the features of the existing system and limitations on their ineptness to either eliminate or mitigate time overrun.

This research identified genetic algorithm (El-Abbasy et al. 2016a, 2017), evolutionary algorithm critical path method (H.-G. Lee et al. 2015), heuristics (Verma & Kaushal 2015), meta-heuristics (Nazari-Heris et al. 2017), mathematical optimization (C. Huang & Wong 2015), expert systems (L. Zhang & Wong 2015) as the construction planning and scheduling methods. In the same vein, other methods such as particle swarm optimisation (H. Liu et al. 2015), simulation (Francis 2016), multi-agent simulation (Hsieh & Lin 2015), commercial software, fuzzy (Pawan & Lorterapong 2015), ant colony optimisation (Myszkowski, Skowroński, Olech, & Oślizło 2015), building information modeling (Shou et al. 2015) are identified.

Irrespective of those methods, different studies have applied artificial intelligence (Wauters & Vanhoucke 2017), hybrid optimisation (Šetinc et al. 2015), hybrid evolutionary algorithm (Tran et al. 2015), graphical network, linear scheduling (Su & Lucko 2016), and artificial neural network (G. Heravi & Eslamdoost 2015) for construction planning studies. Interestingly, those systems are innovative, showing the dynamic nature planning and scheduling research in construction. It is dynamic on the notion that those identified systems span from the year 2010 to the year 2017 to examine the methods that are recent within the research time frame and literature review.

Surprisingly, the integration of agent-based system (Taillandier et al. 2015, X. Zheng & Wang 2015) (ABS)-discrete event system (Alvanchi et al. 2011b, S.-M. Chen et al. 2013, Gonzalez & Echaveguren 2012, Larsson et al. 2015, M. Lu 2003, Mawlana et al. 2015, Shawki et al. 2015) (DES)-discrete-rate system (Shan et al. 2015) (DRS)-system dynamics (Choi & Bae 2009, D. Das 2015, Khan et al. 2016, Mahdavi & Hastak 2014, Ozcan-Deniz & Zhu 2016) (SD)-scatter search optimisation (Peña-Mora et al. 2008) are

not among the method identified. The combination of those technologies is expected to evaluate the strategic, tactical and operational components of the construction system. One key and unique feature of the developed model is the capability of the different modeling methods to capture different distinct components of the construction systems as well as coupling an optimisation system capable of generating feasible and infeasible solutions.

Nevertheless, the finding of the system methods agrees with the systems for dealing with problems in the planning and scheduling of construction projects. The aftermath of this investigation is promising compared to those of other studies because a method of ABS-DES-DRS-SD-scatter search has not been identified. In this instance, pursuing research using that system is likely to improve the planning and scheduling in the construction project.

The finding is likely to be related to the innovative and dynamic nature of construction research, which is likely not to be unusual because of the large number of unique and diverse methods identified in the existing literature. Besides, it is likely to be engaging in identifying the ABS-DES-DRS-SD-scatter search optimisation but it is not to be scaled up to studies beyond the year, 2017. In general, therefore, it can be speculated that even though it is expected to be a hopeful method to construction planning and scheduling, the finding agrees with continuous efforts to creating innovative methods to solve time overrun.

One of the outcomes that emerge from this finding is that investing continuous efforts in construction planning and scheduling research develops systems that have the capacity and capability to solve planning and scheduling problems. The finding is expected to be encouraging towards creating solutions to enhance the execution of the construction system. It also encourages harnessing efforts to investigate the implementation of the findings.

5.5.2 Finding to research question Q2

Several literature studies and reports have shown that planning and scheduling incorporate variabilities (Deblaere, Demeulemeester, & Herroelen 2010, Deblaere et al. 2011c, Lambrechts et al. 2011, Wilkinson & Schofield 2010). The variabilities lead to complexities that result in the dynamic nature of construction projects. Dealing with the dynamic nature of projects require methods to capture the construction system characteristics. However, before the dynamic nature of the project, static methods can be applied to generate a fast plan and schedule for the project. In the literature survey, both static and dynamic planning and scheduling are utilised in construction projects (Alzraiee et al. 2015, Artigues et al. 2015, S. H. Lee et al. 2006). Although static scheduling is a necessary tool to generate instant insight into the plan and schedule, it does not capture variabilities that implicit to construction systems leading to time overrun (Giannoulis & Salonitis 2015).

The first question in this research was the need to identify the current static and dynamic planning scheduling methods for managing projects. Prior studies (Chua & Yeoh 2010, Davari & Demeulemeester 2017, 2018, Deblaere et al. 2011a, Lamas & Demeulemeester 2015b, X. Ning, Lam, & Lam 2010) have identified the need to be aware of the strength and weakness of the methods for static planning and scheduling, which is vital especially when dealing with different project phases. Likewise, a strong relationship exists between static planning and dynamic planning because the fundamentals of dynamic planning and scheduling are the static planning and scheduling (Herroelen 2013).

One of the exciting findings in the research is that the extensive planning and scheduling techniques identified as strategic, tactical and operational planning and scheduling if formulated efficiently, is likely to handle project variabilities and dynamics. In the findings, static, pseudo-dynamic and dynamic planning and scheduling are identified as the current system, with strategic, tactical and operational planning categorised into

the division of tackling known and unknown in planning and scheduling.

It is to some extent that the identified methods, strategic, operational and tactical methods can enhance capturing the different phases of the construction project system. However, the methods have not been utilised as an integrated unit for investigating planning and scheduling challenges. In comparison with the findings of (Alvanchi et al. 2011b, Herroelen 2003, S. H. Lee et al. 2006), the strategic-tactical-operational has not been integrated as an entity to solve planning problems. It has unique features for hierarchical planning that conforms with construction project execution from the tender phase to project handover.

However, previous findings (Alvanchi et al. 2011b, Mostafa et al. 2016, Nasirzadeh et al. 2018a, Peña-Mora et al. 2008, Rondini et al. 2017, J. Wang & Yuan 2016) have stated the application of the trio of strategic, tactical and operational planning and scheduling system. The studies have presented its capability to capture significant characteristics of the construction project. A possible explanation for this is likely to be the nature of the construction project system, its profit-oriented feature and challenges envisaged during the implementation of the planning method.

According to the review thus far, the finding provides further support on the current system for planning and scheduling that utilises strategic, tactical and operational planning since the construction system involves logical and hierarchical activities. It can, therefore, be a valuable basis for improvement for construction planning and scheduling. Although, this finding is subject to more investigations, likewise, it is of immediate importance in the method and approach for managing the dynamic nature of construction projects. The findings, despite the generated knowledge, require further examination. This method identified is an outstanding research effort that is implemented in this research and might form the basis for the subsequent research effort.

5.5.3 Findings to research questions Q3 and Q4

The dynamics in the development of new systems for the planning and scheduling in construction research, as identified in several literature studies is evidence of the possibility of challenges and hurdles encountered by different methods (Mostashari 2011). Amongst the research questions, the third research question is of the pursuit of recognising the limitations to the utilisation of the current solutions for planning and scheduling problems. The need for the explanation of those impediments is anticipated to assist the formulation of solutions to planning problems (Brucker, Qu, & Burke 2011).

Encompassed in the finding are some of the barriers that support the comprehensive application of the solutions to real construction projects. In particular are inflexibility, instability to variabilities, non-representation of the real-world, and non-collaboration of the components of the construction system (Lamas & Demeulemeester 2015a). It is because of disjointed objectives, the non-deterministic polynomial (NP-hard) problem causing combinatorial explosives in solutions, solution convergence, and incomplete combination of variables (Mostashari 2011). It is potentially the case, therefore, that those variabilities, when resolved, can promote the solution proficiency in solving planning and scheduling problem. The finding may facilitate an improved solution to planning problem if they are integrated into the solution likewise, continuously analysed.

Therefore, the utilisation of agent-based system (ABS)-discrete event system (DES)-discrete-rate system (DRS)-system dynamics (SD)-scatter search optimisation, is expected to be one of the possible methods to tackle the problem. The agent-based system (ABS)-discrete event system (DES)-discrete-rate system (DRS)-system dynamics (SD)-scatter search optimisation is the central method employed in this research. Nevertheless, at the initial research formulation, a dynamic Bayesian network (DBN) was employed for the examination of the interaction between construction time management and construction influencing factor. The selection of

ABS-DES-DRS-SD-scatter search optimisation is based on the premise that each of those methods has unique features utilised in construction research and has been applied in different research and studies. The methods' hybrid is expected to agglomerate the essential features of each method to proffer solutions to the planning and scheduling problems in construction research, thereby enhance solutions to time overrun. The inference sustains the research question seeking to gain an intuition of the best approaches to real-world planning and scheduling problems. The main goal that raised the Questions *Q1, Q2, Q3 and Q4* is Objective *A*: the necessity to *understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading to time overrun*. The review enhanced the identification of the central themes that governed the entire research.

5.5.4 Finding to research question Q5

A healthy relationship exists between construction time management and construction influencing factors in a construction project (Doloi 2012). A good number of studies have identified and reported the influencing factors (Memon, Rahman, & Azis 2012, Memon, Roslan, & Zainun 2014, Solís-Carcano et al. 2015, Vanhoucke 2010). Those factors are supported by the influences identified from the CSC construction system. In the literature, some of the relationships have been studied to determine the impact, however in a statistical and static mode. The studies ranked the degree of importance of the factors. In this research, the exploration of the CTM and CTF relationship has been investigated in the dynamic mode using a dynamic Bayesian network (DBN) modeling (Codetta-Raiteri et al. 2012, Rafiq et al. 2015, X. Wu et al. 2015). The CTM-CTF relationship shown in the model, illustrated in previous sections, is a combination of construction time management that requires the continuous attention of the construction project team. In the model, the CTM and CTF interactions dimensions identify the two functions: 'success (S)' and 'failure (F)' emerging from CTM and CTF interactions, respectively (P. Williams, Ashill, Naumann, & Jackson 2015). With this

combination and contribution of any of the CTF and CTM variables, "S-S", and "F-F" are possible at different construction stages.

While success-success (S-S) CTM-CTF relationship impacts positively on time management, (F-F) result in adverse effects on time management. For instance, the relationship between CTM and CTF can be (S-S) due to client/owner factors, but F-F because of supplier and design factors. In success-success (S-S), the construction management team, with its effective CTM accepts the influencing factors as an opportunity to develop a better approach to achieve CTM success. The outcome is likely to be the manifestation in a positive relationship on time management, though the relationship can be non-linear (De Meyer et al. 2002, Kerzner 2013, Pich et al. 2002).

Instead of analysing the entire multidimensional array, the researcher utilised blocks of CTM-CTF relationship and the resulting impacts on single project value: the schedule. The approach was adopted to reduce the complexities of the modeling networks. Notwithstanding the adverse effects of CTF, CTM strategies resolved to ensure the success in the schedule. Therefore, even with CTF, good CTM strategies could ensure success in construction projects.

The framework has identified some features of CTM and CTF, namely their negative relationship and possibility of their positive relationships if adequately managed. The study developed visual, analytical and qualitative construct of the relationship framework for CTF-CTM. It provided insight to the construction team, and stakeholders to (1) describe and examine the qualitative relationships between CTM and CTF and, (2) identify the patterns and the resulting impact of the relationships. The findings can equip construction management teams and researchers with an instrument for further studies in construction management advancement and development. In that context, it solved the research question in pursuit of the decision support system to explore the relationships between construction time management and influencing

factors.

The research is designed to identify the CTF that influence CTM performance. As well as develop a CTF categorisation and explore the different relationships between CTM and CTF using a relationship framework. The identification of the CTF followed a comprehensive search and review of the literature. The CTF is discussed in previous studies (Amusan et al. 2018, Enshassi et al. 2010, Roslan, Zainun, & Memon 2015, Shehu et al. 2014, G. J. Sweis 2013a, P. Williams et al. 2015, Wong & Vimonsatit 2012); however, this study has evaluated the impact of CTM-CTF in dynamic mode. The study augments the theory of CTM and CTF in construction management. To build the CTF categorisation, the CTF is divided into main category and sub-category. This facilitated the identification of the CTF at different construction phases.

The main category is a categorisation based on the construction project life cycle, including the design phase, tender phase, pre-construction phase, procurement phase, construction phase, post-construction phase and operational phase. The sub-category relies on client-related CTF, contractor and subcontractor related CTF, design related CTF, and tender related CTF. The sub-system category is dependent on consultant related CTF, construction project related CTF, material and labour and equipment related CTF factors, external related CTF, and supplier related CTF. By categorising the CTF, the present study provides insight on the extent of verifications and investigations in these phases for CTF. The CTF identification presented further knowledge of the CTF and the effect on CTM. The study has shown that there is a relationship between CTM and CTF. The conceptual relationship framework is presented by the support of the multidimensional array and evaluated with dynamic Bayesian network, which produced eight propositions.

CTF is generated within the process of both strategic decision-making and tactical operations that depict the real world CTM. The interaction of the accompanying variables positions the CTM to complexities and ambiguities. The main strength of

the findings is the knowledge it has created that can enhance the effectiveness in CTM practice and research. The study showing the dependency of CTM success on CTF makes two contributions. Particularly on the theoretical dimension, it identifies CTF and highlights what CTF stake with CTM that result in different time management outcomes. The theoretical concept assumes a coherent interrelationship where the CTF and a combination of the CTF scenarios can be anticipated to underpin the emergent patterns for CTM strategies.

Moreover, the model facilitates a complete integration of a wide variety of CTF towards the insight on the multi-influences and variables limiting CTM success. The findings in this study are not exempted from limitations. The developed framework is dependent on intuitive knowledge, perceptions, limited data, time constraints, which calls for further testing to ascertain the validity and application. In other words: such studies will be based on how CTF affect the outcome in CTM. Current knowledge in construction projects explains that the construction project is dynamic with uncertainties, devising further strategies to understand and manage these interactions should be valuable.

5.5.5 Finding to research question Q6

In reviewing the literature in agreement with the CSC business system, the construction contract is divided into different phases, including tender/bidding, design, procurement, pre-construction and construction, post-construction and operation (PMI 2013). Each of the phases has accompanying characteristics and requirements. Having the uniqueness of each phase in mind, a research question was posited that since those phases have unique characteristics, it is likely to be of significant benefit to explore the multi-component of each phase with multi-method and integrate the phases.

It is revealed in the literature survey and CSC system that the phases are hierarchical with interface linking one phase to another (Hans et al. 2007, S. H. Lee et al. 2006, Vogel, Almada-Lobo, & Almeder 2017). However, the challenge was the approach to

integrate the multi-methods (Borshchev 2013b). Remarkably, the identification of the capability of AnyLogic platform suggested the possibility. The multi-hybrid method selection in this research is novel because of the goal to integrate the different nature and characteristics of the phases. While the close comparison between this research and previous studies (Alzraiee et al. 2015, S. Brailsford et al. 2018, Goh & Ali 2016, S. H. Lee et al. 2006, Nasirzadeh et al. 2018a, Peña-Mora et al. 2008, Sarakhsi et al. 2016), none of those studies has applied the hybrid of ABS-DES-DRS-SD-scatter search optimisation to solve planning and scheduling problem in the construction enterprise.

The discrepancy can be attributed to the implementation of the hybrid method. However, even at that comparability, it could be that there are other approaches suitable for the same purpose. Therefore, the suggestion is that even though this research has uniquely employed the multi-method to resolve the planning problem, other methods are likely to exist towards the same goal. As the method is very encouraging, it should a future research direction to enable the method to combine other phases of the construction project that are not integral to the present research.

5.5.6 Finding to research question Q7

One of the pivotal parts of multi-method modeling is the development of the implementation framework. The most critical components of the methods is the communication between the models. The present research was designed to determine the framework required to solve planning and scheduling problems. Because of the multi-method system applied in the research to merge different conditions of the construction project phases, the establishment of a framework became significantly necessary. As a result, a multi-hybrid modeling framework was developed.

In research studies of (Alvanchi et al. 2011b, Alzraiee et al. 2015, Fahmy et al. 2014, Goh & Ali 2016, S. H. Lee et al. 2006, Nasirzadeh et al. 2018a, Peña-Mora et al. 2008), the frameworks are utilised to create communication channel for different hierarchical levels

between the models. Likewise, in this research, the planning and scheduling problems involve strategic, operational and tactical variables that are pivotal to generating feasible and quality solutions. Each model has intrinsic partitions that are linked to form the hybrid compartment. The communication between the models to form a hybrid model is on the basis that strategic, operational and tactical variables of the relevant phases are inter-related and are dependent on the construction project system where the variables exist.

In the research, which is not the same as the frameworks is the development of models with agent or entities, and within the entities are other agents. In contrast to the mentioned studies for hybrid simulation modeling, while some of the communications are one-way, the other communications are two-way among the models in the framework. Previous frameworks are based on any of the two models to form a hybrid; in this research, four different models are combined to form the hybrid model, resulting in multi-hybrid-model.

The possible explanation of the findings is that planning and scheduling case is complex, dynamic, multi-facet, large-scale and realistic, and multi-modelling framework has the planning case nature as its features. In the framework, MAS is an agent utilised to investigate the tender phase. Within the tender phase are embedded, the different autonomous agents collaborating to accomplish the tasks. The DES forms the core of the multi-model because it is the part that evaluates precedence and relationships among tasks and resources allocation.

With the DES as the core, the DRS configurations are incorporated to investigate those process-centric activities that are insufficient in DES. The communication between DES and DRS is a two-way communication, and in the same vein, the communication between ABS and DES is one way. The one-way communication is because after the tender/bidding phase is the commencement of pre-construction and construction activities. The influences are examined with a combination of ABS and SD having a

one-way relationship or collaboration with the DES processing the construction activity. The one-way relationship is because the influences affect the construction activities, and unlikely the other way. There is a horizontal and vertical relationship between the models, and ABS is a unifying model since each model is considered as an agent. In that sense, ABS is the container object with DES, DRS and SD embedded into it, as shown in Figure 3.27.

The Framework that facilitated the simulation and optimisation for modeling the tender and construction phases is very complex, in terms of building the model. The level of the complexity is due to the number of methods integrated to form the multi-hybrid model. So, far in the existing studies, there is no evidence to show that the approach the research utilised in building the model is similar in terms of the complexity, although the existing methods have unique and varied integration frameworks.

However, this finding is likely not to be extrapolated to other project phases not considered in the present study. However, it has only represented the tender and construction phases implemented in this research. It is consequently likely that the framework and connection of the models are ideal for modeling the different phase of the construction projects because of the real-world representation of the construction project phases in practice in the research. The implication is that this study raises the possibility of modeling the entire construction system to improve decision-making to mitigate and reduce time overrun in the construction enterprise. The framework achieved the expected outcome as it was proficient to capture the multi-components of the construction system investigated in this research; nevertheless, further investigation is required for complete confirmation of the framework capability to other components that are not implemented in this research.

5.5.7 Findings to research questions Q8

The development of a framework is an arm of the research solutions. Moreover, the integration of the models: the multi-hybrid model to create a simulation is one of the challenging facets. In the literature, several frameworks are developed, but not implemented into real simulations (Alvanchi et al. 2011b, Alzraiee et al. 2015, Goh & Ali 2016, S. H. Lee et al. 2006, Peña-Mora et al. 2008). The framework in this research was implemented, as shown in Section 4.4.1. Concerning the research question 8, it was found that the integration of the model means amalgamating the various model components, and in that case, required unrelated multi-input data. The multi-hybrid model integration assured the flexibility to incorporate pluralist data (Bell et al. 2018, Borshchev 2013b, Creswell & Creswell 2017).

In the initial concept of the research, the idea was to limit the amount of the input data because of the possibility of inflexibility in the model accepting multi-input data. Contrary to that expectation, this study, with the support of AnyLogic tool, integrated different type data from qualitative, quantitative and observation data. Correspondingly, the simulations for the tender phase, construction phase and influences are integrated with their intrinsic data. In the number of studies where multi-method (two-models) are implemented, different data are utilised to develop the input parameters and variables (Alvanchi et al. 2011b, Alzraiee et al. 2015, Goh & Ali 2016, S. H. Lee et al. 2006, Peña-Mora et al. 2008). Those studies confirmed the multiple input data utilised for the multi-hybrid model. The aptitude of the research to utilise multi-data enhanced the integration of the model that resulted in the multi-hybrid modeling and simulation.

This research integrated four different models, with more than four different input data. The capability of the multi-hybrid simulation to integrate pluralistic data is contrary to previous data, which utilised the limited number of data, sometimes two models with two different data. It is essential to complement the capability of AnyLogic that

facilitated the multi-data utilisation with the features to use some scripts to define data input and data export. The gathering of the raw data is one point, interpreting and preparing the diverse data to achieve the method and the goal of the object or entity that utilised the data is also a considered part. The multi-method and multiple inputs mean different implementation in the AnyLogic software.

The creation of variables and parameter to map the communication method or function call required a consistent approach to represent the specific construction system or sub-system that required the data. This finding provided further support on multi-method data requirement, in that the data require mapping, interpretation, conversion, aggregation and consistent definition of the method between the data input to the system and expect data output from the system (Alzraiee et al. 2015, Borshchev 2013b, W. Song et al. 2018, Taillandier et al. 2015). However, the consistency of input data utilised in the implementation of the simulation is specific to the AnyLogic software and, this research is not likely to provide a generalisability for the data utilisation in other tool.

5.5.8 Findings to research questions Q8, Q9, Q10, Q11, Q12, Q13

Model validation and verification (Bharathy & Silverman 2010, Borshchev 2013b, Gore & Diallo 2013, Mostashari 2011) is amongst the challenges of multi-method simulation modeling. Research question Q9 was designed to identify the integration of construction planning and scheduling challenges and the approach utilised to address the challenges. The integration is implemented in the validation and verification experiments part of the research. The research considered a real case study; therefore, required the validation verifications to affirm the integrity and operationalisation of the developed modeling and simulation concerning the real case. Furthermore, the multi-method included influences and variabilities during the tender phase and construction phase in

terms of management influences, access egress, groundwater table and risks analysis on equipment use.

The significance and uniqueness of the multi-hybrid method is the capability to integrate variabilities and influences, and the reviewed literature has revealed limited efforts in that aspect. The idea is the development of a system or solution with extensive testing on construction planning and scheduling challenge to mitigate time overrun in the area of project characteristics and influences that formed the key point of research questions Q9, Q10, Q11. The approach is different from the existing research identified in the literature (Azar 2012, D. K. Das 2015, Han et al. 2013, Khan et al. 2016, Peña-Mora et al. 2008). While the validation experiments are employed to ascertain the model of the research cases represents the real tender/bidding and construction phases, the model verification techniques are employed to ratify and endorse the developed planning system as well as the output schedule in relation to the objectives of the model framework and development.

The outcome of the plan generated a schedule that was implemented using the Java class method, to validate the research question *Q13* on the approach to integrate planning and scheduling. The multi-method evaluated planning and scheduling in construction enterprise, and represented different components at strategic, tactical and operational levels of abstraction. The implication is the need to validate different parts of the system; however, the core of the model is DES supported by DRS. In that case, the validation is based on the DES system, whereas the verifications of the different systems in the ABS and SD models ascertain the expected validity. This is because of the visualisation of the simulation in AnyLogic that portrayed the system behaviour in the real case. For a multi-method system, complications exist in putting efforts in the validation of the entire system. Therefore, while avoiding the limitations, the verification experiments of each system: simulation, influences and risks on equipment analysis enhanced the entire system validations. The main goal that raised the Questions *Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, and Q13*

is Objective *B*: the necessity to *B. To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule.*

5.5.9 Findings to research questions Q14

The construction project system implemented in this research is complex and dynamic. In that regard, literature studies have revealed the resilience of simulation in solving complex and dynamic problems (Banks 1998, Borshchev 2013b, Sumari et al. 2013, Swinerd & McNaught 2012, Terstegen, Petz, Schlick, & Duckwitz 2016, Turner et al. 2016, ZHANG & YAN 2013, N. Zhao & An 2016). This research employed the benefit of simulation as a means of solving the considered system in terms of planning and scheduling. Even though it is known in the literature and existing studies as a method for solving complex and dynamic problems, nevertheless, it is not proficient in optimising the system. The research goals are limited to emulating the real-world case with simulation. Likewise, the generation of optimum conditions and values of the parameters is subject to the construction project objectives (efficient resources utilisation and time overrun minimisation).

The optimisation has been applied by different studies to find the points of parameters optimum in terms of minimisation and maximisation constraints. Correspondingly, in this research, optimisation of the tender/bidding phase and construction phase formed a central part of the research. The final question posed in the research is the possibility to integrate the simulation model with an optimisation system to facilitate optimum plan and schedule. In this research, optimum plan and schedule are generated by applying population-based, general purpose and metaheuristics optimizer, OptQuest, which is based on scatter search. In the literature, scatter search optimisation (Aziz, Hafez, & Abuel-Magd 2014, Baradaran, Ghomi, Mobini, & Hashemin 2010, Geng et al. 2016, Józefczyk & Siepak 2013, Laguna 1997) is one of the best-known optimisations with

the features of population-based metaheuristics. The capability and selection of the scatter search system are consistent with the acclaimed scatter search quality of the solution to the objective function, raised from the construction project system.

In the existing studies, scatter search is utilised to locate the available points that minimise the deviation between the possible point and infeasible point (Geng et al. 2016, Józefczyk & Siepak 2013, Laguna 1997). Similar to the research, the optimizer generated feasible and infeasible parameters that minimises the deviation of the model duration from the real case durations, as shown in Figures 4.46 to 4.51. In contrast to the existing literature, there is no identified evidence of the real implementation of multi-hybrid simulation with scatter search optimisation in the construction enterprise. However, the fascinating aspect of the optimisation system is its capability to generate an optimum plan of activities. The solution is in both the feasible and infeasible regions to enhance and improve the decision-making of the construction management team.

In that regard, it is conceivable to hypothesise that the integration of multi-hybrid method with optimisation is likely to allow generating optimum plan and schedule with the concerns of the present research. The findings can aid construction research to understand that there are aptitude and the possibility of improving the construction project system using the duo of multi-hybrid simulation and general purpose-based optimisation. The utilisation of scatter search optimizer in AnyLogic enhanced the consideration of the components of the entire construction system. The implication is that the phases of a construction project contract can be investigated through the developed research method. In the discussion of the integration and outcome of scatter search optimisation, the principal goal that raised the Questions *Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, and Q13* is Objective *C*: the necessity to *C. To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule*. The result is an optimum plan with an optimum schedule.

5.6 Summary

This chapter has discussed, through the findings of the research, the results link to the literature and research questions. While presenting the discussions, the main research results are re-stated with the outcomes, support and comparison with previous findings and the explanations of the findings. Although the prudent interpretations of the findings are presented, the recommendations of general suppositions are presented with the significance of the findings and continuous improvement of research findings. The next Chapter 6 concludes the main areas covered in the research, the limitations to the research scope and suggestions for future improvement.

Chapter 6

Conclusion

6.1 Introduction

Until this point, the thesis has explained, discussed, evaluated and illustrated its key components, including the introduction, literature appraisal, research methodology, research and findings and discussions. This chapter concludes the research by conducting backward feed exploration of the main ideas of each chapter; it provides the provision of final comment on the ideas in terms of recommendations for future improvements and direction towards further development of the findings. In that context, the thesis conclusion unveils a user guide: conclusion, main and overall contribution, and recommendations for application in the construction industry. In the same vein, it summarises the research limitations and further research improvements for the application of the multi-hybrid model and solutions in construction planning and scheduling. This project was undertaken to develop, design and evaluate a framework and multi-method paradigm for enhancing decision-making support and advancing construction planning and scheduling. This chapter includes research synopsis (section 1), significant contribution and assessment (section 2), recommendation for application in construction industry (section 3), research limitations (section 4), and future research work recommendation (section 5), with the content layout in Figure 6.1

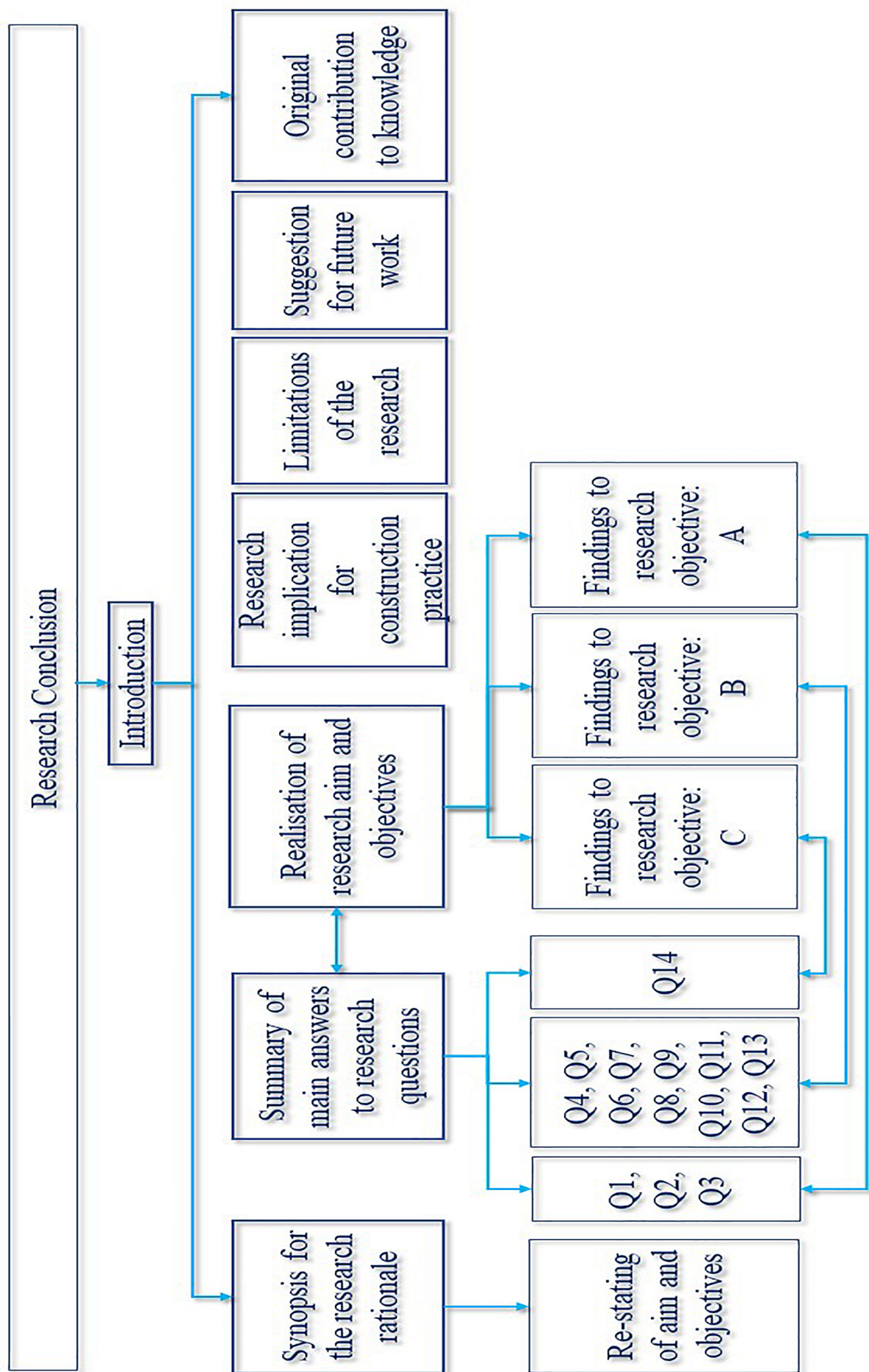


Figure 6.1. Chapter 6 layout and content

6.2 Synopsis for the research rationale

The aim of the present research is to develop and test a multi-method framework, concerning the implementation of integrated planning and scheduling system for a construction project, taking into account the associated system characteristics, components and influencing factors. The main objectives of the research in relation to the aim are:

- (A.) *To understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading to time overrun. ;*
- (B.) *To develop and assess a framework and model which reflects real-time planning and scheduling in tender and bidding and construction phases leading to an effective plan and schedule and;*
- (C.) *To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.*

Whereas the objective A evaluated planning and scheduling systems and categories, the objective B investigated the analysis and implementation of the research design to the planning and scheduling problem. Objective C assessed the capability of the optimisation system to generate an optimum plan and schedule, thereby integrating planning and scheduling.

Fourteen research questions are posited to generate the associated findings to achieve the objectives. The research has consistently presented the characteristics of construction

projects, namely scale, complexity, dynamic, uncertainty, and defined goals. On the other hand, the research presented the construction project as a system having inputs, influences from the environment, system interactions and outputs. Following the theory line of construction system planning and scheduling, the system inputs are expected to flow through the system with the expected outputs and requirements as defined in the system. However, in practice, the internal and external environment events on the systems hinder the idea. This is the evidence of real-world construction system causing system offsets and disturbances: deviations, disruptions and overruns.

Moreover, the execution of construction contracts is a phased process from tendering/bidding stage to contract execution. The outcomes – either positive or negative - of the prior phase is likely to have a significant impact on the succeeding phase. The concern of the present research in such cases is the requirement for a predictive and reactive controller on the system to achieve the defined system output by minimising or tackling the disturbances to ensure optimal solutions. With the coming on stream of the research needs, the contents were produced for research direction and guide. The study explores the construction planning and scheduling system and problems in a complex and dynamic environment and proposed a new methodology for enhancing system decision-making support through the application of the hybrid model and optimisation in the construction enterprise.

The aim, objectives and the questions answered in the research were discussed in construction project environment set out in [Chapter 1](#). In [Chapter 2](#), a comprehensive appraisal of the literature on construction scheduling in the dynamic and complex environment was pursued to outline the existing knowledge, likely knowledge need and the research gap including scheduling methods, timelines as well as the pros and cons. The discernment from the literature is one side of the research idea; nevertheless, bridging gap between theory and practice and identified problems is the other viewpoint. Accordingly, in [Chapter 3](#), the research utilised a postpositivism-pragmatism methodology of multiple case-in-one cases to explore the

solutions to the construction planning and scheduling problem using real-world data and observations.

In this regard, the CSC (main contracting company) was contacted to facilitate the objective of the research to draw real-data. The data was gathered from site data, contract data, contract processes, observations and interviews from the integrated functional and technical construction team of the CSC multi-million\$ project in New Zealand. The project is a construction project with massive construction. The curiosity to explore and evaluate the influences on tasks durations, which are the root causes of overruns in different phases of the project, was explored in the initial phase with dynamic Bayesian network analysis in [Chapter 3, Section 3.7](#). Despite the framework and model presented in that chapter, the findings required in-depth investigation because of the inability to capture the required entities and agents holistically in the construction contract. Buttressed with the limitations of the initial framework and model, in [Chapter 3, Section 3.8](#), a framework and model for integrating the construction contract from tendering/bidding phase to construction that relied on a construction project was the main aspects of that chapter.

The framework and model integrated construction planning and scheduling in multi-hybrid modeling and simulation. The framework and hybrid model (ABS-DES-DRS-SD) development are a function of the initial observation and data collected from the collaboration between the researcher and CSC. A framework or model is not functional if it is incompetent in portraying the real-world and proffering solution to the problem with its development. In the same vein, that element of the research is presented in [Chapter 3, Subsection 3.7.3 and 3.8.10](#) with framework descriptions, business process modeling, model descriptions and integrated-interface to accomplish the implementation in AnyLogic. The subsequent validation and experiments were executed in AnyLogic software using those gathered data and observations.

This part of the research conducted model experiments to verify and confirm the validity

of the proposed framework and model. The experiments were parameter variation experiment, risk analysis experiment and optimisation experiment using OptQuest. The experiments tested the performance of the model, which represented the real-world case and can be applied to construction projects. The results of the entire research generated expected results because it achieved the defined objectives with discussions centred on the statement of results. The next section presents a summary of the main answers to research questions.

6.3 Summary of main answers to research questions

From the outset of the research, the researcher explored different possibilities of evaluating the planning and scheduling in the construction system. As a result, utilised dynamic Bayesian network (DBN) (Dagum, Galper, & Horvitz 1992, Dagum, Galper, Horvitz, & Seiver 1995) in the initial problem formulation on the construction project time management (CTM) relationship with construction project time influencing factors (CTF) resulting from impacting (IM) on time. Furthermore, the research applied the agent-based simulation (ABS) (Copeland et al. 1945), discrete-event simulation (DES) (Gordon 1975), discrete rate simulation (DRS) (Damiron & Nastasi 2008), system dynamics (SD) (Forrester 1958, Sterman 1992) and OptQuest optimizer (Laguna 1997) to develop comprehensive framework and models as a decision-support package to augment planning and scheduling in the construction project contract.

The further evaluation using process models was because of the need for an in-depth investigation that integrated more components of the construction system. The exploitation of integrated model was employed because of model-development interest, preferably by the researcher careful analysis of the construction system. The system consists of a hierarchical and phase-based system (Herroelen & Leus 2005) with interacting components depicting dynamic and complex characteristics. The main research contribution is assessed in relation to the research questions in Chapter 1

including:

Table 6.1

Research questions Q1, Q2, Q3

	Research Questions for objective A: To understand the static and dynamic planning and optimisation approaches and identify the barriers in their implementation, leading to time overrun.
Question Q1	What is the current approach for static and dynamic planning in construction projects, and what form of the plan is produced?
Question Q2	How can the approach be categorised to identify its constraints to solving dynamic planning and scheduling problem?
Question Q3	What are the barriers to the utilisation of the current solutions for planning problems?

Construction planning and scheduling is among the techniques applied to manage and control project for due date accomplishment, resources allocation and objectives realisation. The key characteristics of the construction project is its dynamic and non-deterministic nature triggered by complexity, scale, change and uncertainty. There are wide range of studies on static scheduling, known to be deterministic, predictive and unreactive to disruption events. Similarly, the construction contract is influenced by many operational and contextual variables that are interrelated without a translucent boundary on their interactions, as it progresses from one phase to another.

The nature of the construction project leads to a range of scheduling problems requiring efficient scheduling technologies and solutions. An initial discussion with the CSC revealed this reality: projects deviated from defined goals to overruns due to complexities and changes. A discussion with the project team, again, presented that to ensure quality plan and schedule, an opportunity for the reactive system in addition to its predictive features are likely to be effective decision-support if such systems are available. In relation to literature review concepts, Section 4.2 ascertained the answers to the research questions in Table 6.1. The different planning and scheduling systems were identified with their categorisation that revealed the uniqueness of the approach utilised in this research in comparison to those planning and scheduling methods.

In connection to the answers to those questions is the accomplishment of the *objective A*. The goal is to understand the static and dynamic planning and optimisation

approaches and identify the barriers in their implementation, leading to time overrun. This goal was achieved and contributed to the integration of scatter search optimisation with multi-hybrid simulations to generate ABS-DES-DRS-SD-Scatter search. The next set of research questions, shown in Table 6.2 were central to the implementation of the new planning and scheduling system developed in the research. Ten numbers of the Table 6.2

Research questions Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13

Research Questions for objective B: To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule.	
Question Q4	What are the expected strategies if pursued, positively influence the real-world planning system and improve system solutions?
Question Q5	What are the relationships between construction time management and influencing factors in construction projects necessary to gain insight about reducing time overrun in construction projects?
Question Q6	What aspect of the planning and scheduling problems and attributes need multi-method to assess the multi-component of the construction system?
Question Q7	What mechanism can best integrate multi-decision support for planning and scheduling of construction projects?
Question Q8	To what extent can the model assure the flexibility to accept multiple inputs?
Question Q9	What are barriers that may be associated with the model integration, and how are they addressed?
Question Q10	How can the result of management influences be an efficient option for improving the project planning in tender/bidding phase?
Question Q11	How can the proposed integrated planning and scheduling model be implemented to account for project characteristics and influences?
Question Q12	What is the technique to present the model solution for application by the construction project team to improve the planning decision?
Question Q13	To what extent can the integrated planning solution aid the capability of construction project management?

research questions, in Table 6.2, are the attestation of their significance in the research. In accordance with the research questions, nevertheless, the backbone of the research, regardless of the interest of real-word case, came-up from the comprehensive review on the existing literature and body of knowledge in construction field. Whereas, research question **Q5** was specifically conducted from initial idea of the research to investigate CTM-CTF-IM relationship, the rest of the research questions **Q4, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13** are generated because of the need for a comprehensive study that integrated significant amount of the tender/bidding and construction phase components. Therefore, first the answer established for **Q5** is summarised.

The relationship of the construction time influencing-factors (CTF) with construction time management (CTM) was established of having a critical impact in determining the productiveness of the whole construction project life cycle from the resulting impact (IM). The impact of the relationship of the CTF-CTM variables was confirmed by the investigation facilitated by a dynamic Bayesian network (DBN). The investigation supported the study to derive eight propositions and a new framework on how CTF determines CTM performance. The result findings, which are lacking in the current body of literature, established the relationship and the valuable insight of CTF influence. It established that the construction project team could apply the relationship framework to improve time management performance at different project phases. The answer is established in Section [3.7.1.2](#), [3.7.1.3](#), [3.7.1.4](#),[3.7.1.5](#), [3.7.3](#), and [3.7.4](#).

In consonance with the rest of the research questions [Q4](#), [Q6](#), [Q7](#), [Q8](#), [Q9](#), [Q10](#), [Q11](#), [Q12](#), [Q13](#), the literature reviewed a number of research interests on dynamic planning with multi-method paradigms (Alvanchi et al. 2011b, Fahmy et al. 2014, Goh & Ali 2016, S. H. Lee et al. 2006, Nasirzadeh et al. 2018a). The limitations of those studies centred either on frameworks that were not tested or incomprehensive with the facets of construction contracts evaluated in this research. While some of the studies presented the solution of the dynamic and complex system with either ABS or SD or DES or SD-DES or SD-ABS or ABS-DES, the present research in the process of representing a sufficient amount of the system components employed ABS-DES-DRS-SD-Optimization: a unique and novel contribution of this research.

The significant research contribution is the development of a multi-hybrid model for the evaluation of complex and dynamic planning and scheduling in infrastructure construction. The development is based on javascript and AnyLogic interface. The ease of use of the software is not a problem to any insufficient knowledge of java because changing of parameter values is the requirement to derive statistical analysis for decision-making. It is, as well, user-friendly in updating and controlling of the plan

and schedule with efficient resources allocation. The proposed method utilised in the research work can aid bid and opportunity management team to evaluate time influences on the tender and request for the proposal without time overrun and applying the bidding phase planning deliverables to the construction phase. Equally, the deliverables from the bidding phase are utilised during construction phase management.

The solution implementation in AnyLogic simulation showed a good performance of the hybrid model. A set of experiments, in Section 4.4, were conducted to yield quality solutions tested and analysed using statistical analysis. Any number of experiments can be performed by varying the parameters to generate a set of solutions. Interestingly, the prowess of simulation experiments is as a result of varying the parameters to align with a specific and different set of conditions, as the modeler desires. The research developed the experiment platform, and a significant number of experiments can be performed for the different enormous number of conditions. The case study project is of large scale, complex and dynamic with influences, which the developed model can analyse including generating schedules from the time it takes to finish each activity, predictive schedules, schedule update and risk analysis.

Similarly, with the developed parameters from the experiments, different objective functions can be defined to evaluate and achieve the optimal goals using scatter search optimizer. Before the experiments and optimisations, the model was validated through validation experiments. The proposed solution was externally validated, irrespective of the internal validation, which garnered positive feedbacks from CSC. The answers to the research questions in Table 6.2 could not have developed without an objective. The requirement to attain those answers is the *objective B*: To develop and assess a framework and model which reflects real-time planning and scheduling in tender/bidding and construction phases leading to an effective plan and schedule.

This research in relation the answers to research questions developed dynamic Bayesian network (DBN) simulation model and framework. Besides the DBN, the

research developed an original planning and scheduling method and framework called agent-based simulation (ABS)-discrete rate simulation (DES)-discrete rate simulation (DRS)-system dynamics (SD)-scatter search (SS) optimisation, presented in Section [3.8.10](#), [3.8.12](#), [3.8.13](#), [3.8.11](#), [3.8.17](#), [3.8.18](#), [3.9](#). The establishment of research questions [Q4](#), [Q6](#), [Q7](#), [Q8](#), [Q9](#), [Q10](#), [Q11](#), [Q12](#), [Q13](#) facilitated the entire system optimisation and the integration of planning with scheduling that established answer the research question in Table 6.3.

Table 6.3

Research questions Q14

	Research Questions for objective C: To enhance the understanding of how the integration of the developed model with optimisation leads to the achievement of best alternatives for the project plan and schedule.
Question Q14	How efficient is the integration of the model with the optimisation system generates an optimal plan and schedule?

In this research, construction project scheduling is a product of construction project planning. For an effective construction system, an integration of planning with scheduling is likely to proffer solutions to the construction problem. This research has integrated planning with scheduling. The significant advancement of construction planning and scheduling of this research is the creation of solution from the inclusion of the wide range of components of the construction system depicting the behaviour of a real-world construction system for effective construction planning and scheduling.

On the other hand, the acceptance of solution evaluation and practical application by CSC buttressed the research significance. In the integration, first, the simulation models and frameworks were developed. Second, the different tender/bidding and construction phases were amalgamated. Third, the variabilities in the form of influences were associated with the model. Those activities established the simulation model for a planning system. Finally, the plan was optimised to create the optimum plan. To generate the schedule, a Gantt Java class was established. The Gantt Java class facilitated the integration, which generated activities duration.

The established activity duration is exported in excel format and can be developed into Gantt chart in any of the project planning and scheduling tool, for instance, Microsoft project and Primavera. The integration of planning and scheduling was motivated by the requirement of the *objective C*. The objective and the research questions was established in Section *3.8.10, 3.8.12, 3.8.13, 3.8.11, 3.8.17, 3.8.18, 3.9* because in those section, plan integrated with schedule after the optimisation. Having established the summary of the answers to the research questions and the accomplishment of research objectives, next Section 6.4.

6.4 Suggestion of research implication for the construction practice

Overall, this study strengthens the idea that there are different methods for construction project planning and scheduling, and there is a need to continue improving the methods to facilitate efficient mitigation of time overrun. In addition, the research aim is to *Develop and test a multi-method framework, concerning the implementation of integrated planning and scheduling system for a construction project, taking into account the associated system characteristics, components and influencing factors*. It has provided a deeper insight into a new procedure of implementation that can reinvigorate the lens to look at the planning and scheduling problem through to the solution.

The accomplishment of the research questions has presented the understanding of the methods, and the necessity to device methods capable of capturing the multicomponent of the construction planning and scheduling system. The achievement is concerning the dynamic and variability features that encompass the system. In that context, it generated further clarity and understanding of the approach for future investigations of the construction project planning and scheduling for research and development

organisations. The variability occurs in the different phases of the construction project.

In relation to the variabilities that forms the influence on the construction system, there is the demand always to have systems to evaluate how the construction time influencing factors (CTM) affects the construction project time management (CTM). This research developed a framework system with DBN to aid the construction planners to weigh and assess the resulting impact of the factors on the project duration, and the system is established relative to the research Questions [Q5](#).

The framework identified some features of CTM and CTF, namely their negative relationship and possibility of their positive relationships if adequately managed. The study developed visual, analytical, qualitative construct, and conceptual nature of the relationship framework for CTF-CTM. Therefore, the implementation of the framework provided insight to the construction team, and stakeholders to (1) describe and examine the qualitative relationships between CTM and CTF and, (2) identify the patterns and the resulting impact of the relationships. The findings can equip the construction management teams and researchers with an instrument for further studies in construction management advancement and development.

Another central summary theme is the established answers to the research questions [Q4](#), [Q6](#), [Q7](#), [Q8](#), [Q9](#), [Q10](#), [Q11](#), [Q12](#), [Q13](#). The research delineated and evaluated a new decision framework and method for the advancement of construction planning and scheduling, not only integrating complexities and dynamics of construction operation but encompassing the phases in construction contracts. The study quest for real-world data and operation mechanism utilised data collected from the case study company CSC. The collected data and the CSC formed the critical internal and external parameters utilised to test and confirm the validity of the proposed system.

As such CSC sense of acceptance of the solution and its excellent feedback of the developed solution is an assertion of the in-built benefits and acceptance. Although the

case study is a multi-case -in-one case, the research contributes to existing knowledge of construction knowledge by providing a recommendation for the usefulness of the solution to construction practice, specifically:

- (1) the in-depth guidance and principles of integrating complex and dynamic construction systems for the valuable solution;
- (2) an adept mechanism for construction teams to evaluate and optimise planning and scheduling that captures influences and real-time events;
- (3) developing an easy to apply simple model and framework without complicated mathematical complexity which can boost ease of applicability by the construction teams without the need of any developed analytical skills;
- (4) unlike other planning and scheduling tool, the developed model is a powerful tool that integrates the large-scale entities including influences in real construction system to generate a plan and schedule that can convert the present tools for planning and scheduling from major tools to supporting tools;
- (5) wide range of experiments, risk analysis and optimisation that can be performed concurrently in the solution ensures optimal and efficient performance of the output for a decision support package and;
- (6) multimethod simulation experiments present the opportunity for the construction team to understand the basic business analysis, trade-off analysis and process flow analysis with tactical, operational and strategic Key Performance Indicators (KPI) in the form of statistics to guarantee effective decisions;

The associated *objective B* has provided frameworks for real-time planning in the tender and construction phase. Furthermore, a new technique to generate schedule from optimising plan for the baseline schedule, proactive schedule and predictive schedule. This is affirmed with the research question *Q14*, whereby the developed model was integrated with optimisation to generate plan and schedule in *objective C*. This approach is valuable to construction planners and the construction team for generating plan and schedule that mitigates or surpasses time overrun.

6.5 Research limitations

After the research findings establishment and presentation to CSC company, the generalisability of the results is constrained by certain factors including:

- (1) Multi-case-in-one case that does not cut across other construction companies. Though the construction processes can be the same, the influences of other companies are likely to be different. However, the framework can integrate other scenarios since, within the analysis region, standards for construction operations are the same, but outside the present location can be unlikely the same (Bell et al. 2018, Love, Teo, Carey, Sing, & Ackermann 2015, Müller, Zhai, Wang, & Shao 2016, Ridder 2017);
- (2) At this stage, there are few complexities of the process design, which can limit inexperienced team member to apply the solution with ease. Those complexities in this research need more timeframe for further understanding and elaboration;
- (3) The tender phase of the solution studied only the CSC process. Since the construction market is enterprising, the CSC processes are specific to its operations and not likely the same process in other companies;

- (4) The evaluation is in AnyLogic software, which is not directly a project management software, there is a need to have an automated implementation of the Gantt chart directly from AnyLogic;
- (5) The implementation of the entire planning and scheduling system requires an independent system architecture for a complete construction solution requiring software development and;
- (6) The pluralistic features that the method is expected to have is one that can integrate the phases of the construction project and building information modeling without solution quality degradation and convergence problem.

6.6 Recommendation for future research work

There are several potential questions still unanswered in the research. Given the future direction, a natural progression of this study is to analyse:

- (1) An independent tool that will rely on drag and drop is required for development to ensure an autonomous process design for exploring and evaluating construction systems and problems with automated data;
- (2) In-depth analysis for a complete resources' interactions, allocations and utilisations;
- (3) An extension of the solution is required to integrate building formation modelling (BIM);

- (4) More planning and scheduling objectives are required including cost analysis, cash flow, earned value management and flexibility for embracing more objectives;
- (5) There is a requirement to extend the phases to capture the complete project phases common to construction enterprise with custom defined additional features;
- (6) The quality outcomes of the contract phase features are key to system evaluations, more evaluations are required for creating gatekeepers from one phase to another whereby with some set criteria, no phase will be allowed to progress without passing assurance checks by the gatekeeper;
- (7) Complex construction project is required to be sustainable, not only in terms of business but also safety impact. An interface for safety analysis can be a future consideration and;
- (8) Because constructions system is the sum of subsystems. Creating the opportunity to look at each component with the opportunity of an easy interface to analyse the system holistically.

The implication and outcome of the suggested efforts if implemented, could enhance the features shown in Figure 6.2 for the planning and scheduling method. The realisation of the features (Bonnie 2015, Fahmy et al. 2014, S. H. Lee et al. 2006) in the figure is likely to assure efficiency in mitigating time overrun and other associated objectives. In a broader sense, future research is required to explore the case with particularisation of in-depth analysis, further testing with other construction activities. It also requires creating independent platform unique for the construction system, and flexibility in the application with drag and drop objects. Furthermore, the future investigation is

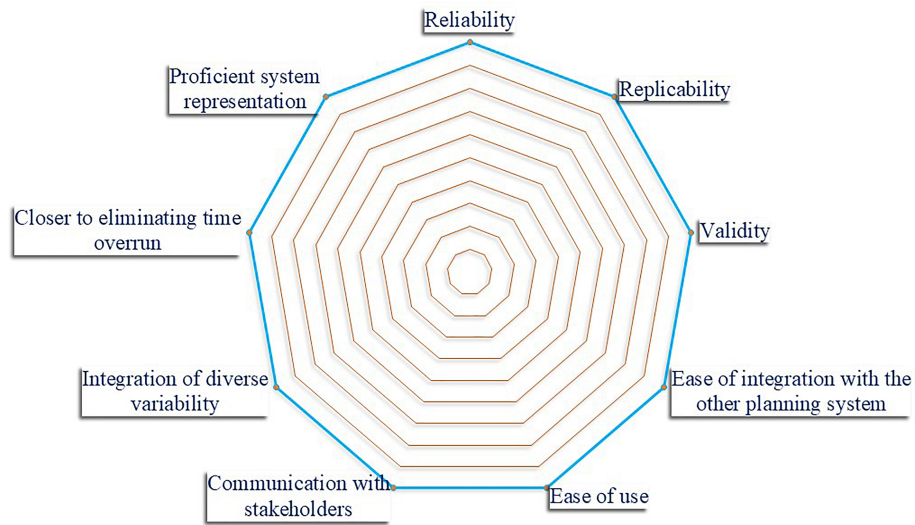


Figure 6.2. Scheduling method feature

expected to combine multi-objectives instead of time alone, an approach to reduce simulation time and flexibility for the different optimisation algorithm.

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Acronyms

<i>AAE</i>	Average Absolute Error
<i>ARE</i>	Absolute Relative Error
<i>SD</i>	Standard deviation
<i>AS₁</i>	Work clusters activity state
<i>bc</i>	Bulldozer capacity
<i>compactorShouldMove</i>	Compactor movement implementation
<i>compactorSpeed</i>	Compactor speed
<i>CTM_{observt}</i>	Influence on CTM
<i>currentArea</i>	Current earthworks area
<i>currentPathNode</i>	Equipment resources current driving path
<i>ec</i>	Excavator capacity
<i>Ftest</i>	F test analysis
<i>finalArea</i>	Final area of earthworks
<i>IM_{cost}</i>	Cost impact from CTF on CTM
<i>IM_{function}</i>	Function impact from CTF on CTM
<i>IM_{profit}</i>	Profit impact from CTF on CTM
<i>IM_{safety}</i>	Safety impact from CTF on CTM
<i>IM_{schedule}</i>	Schedule impact from CTF on CTM
<i>initialArea</i>	Area before the next area
<i>N₁</i>	Real data
<i>N₂</i>	Model data
<i>numSmallUnwantedObjects</i>	Number of unwanted object put into the system for stripping
<i>P()$\mid$Pa()</i>	Probability notation
<i>Pa</i>	Parent probability
<i>q</i>	Stresses
<i>S₁</i>	Initial state distribution
<i>S_D</i>	Final state distribution
<i>ttest</i>	t-student distribution
<i>unwantedObjectsDiscarded</i>	Number of discarded object put into the system for stripping
<i>wasteLocation</i>	Dumping for an area dump
<i>X, Y</i>	Chainage spatial coordinates
<i>CSC</i>	Case study company

A_{jt}	Work clusters (clearing activity Interarrival time for earthworks)
$AS_{cleargrub,jt}$	Work clusters (clearing activity arrival time for earthworks)
$AS_{cleargrub,j}$	Work clusters (clearing activity for earthworks)
$cAS_{cleargrub,j}$	Work clusters (clearing activity completion time for earthworks)
$dAS_{cleargrub,jt}$	Work clusters (clearing activity delay time for earthworks)
$ES_{earthworks}$	Earthwork system
$pAS_{cleargrub,jt}$	Work clusters (clearing activity processing time for earthworks)
$S_{cleargrub}$	Work clusters (clearing system for earthworks)
$S_{compact}$	Work clusters (compact system for earthworks)
S_{cut}	Work clusters (cut system for earthworks)
S_{fill}	Work clusters (fill system for earthworks)
$S_{soilstrip}$	Work clusters (stripping system for earthworks)
$S_{undercut}$	Work clusters (undercut system for earthworks)
aA, aB, aC, aD, aE	Each location area agent
ABS	Agent-based simulation
aF, aG, aH, aI, aJ, aK, aL	Each location area agent
aM, aN1, aN2, aN3, aN4	Each location area agent
aN5, aN6, aN7	Each location area agent
apcs	Area per cluster
areaNode	Area of earthworks
BIM	Building information modeling
BN	Bayesian network
BPMN	Business process modeling network
bUM	Business unit manager
CM	Construction manager
Co_{CTM}	Construction phase CTM
CPM	Critical path method
CPT	Conditional probability tables
CTF	Construction time influencing factors
CTF-CTM-IM	Construction factors influence on construction time from impact
CTFn	CTF at different stages
CTM	Construction time management
CTM_{interv}	Intervention after CTF on CTM
CTM_t	CTM at a specific time
CTM-CTF	CTM and CTF nodes relationship
currentSegment	Segment of area of earthworks
DBN	Dynamic Bayesian network
De_{CTM}	Design phase CTM
depthAC14	Depth of AC14 fill

depthAC20	Depth of AC20 fill
depthBackFill	Depth of backfill
depthBase	Depth of base
depthGenCut	Depth of area to cut
depthGenFill	Depth of area fo general fill
depthSubBase	Depth of sub base
depthTopsoilStrip	Depth of area to topsoil strip
depthWearingCourse	Depth of wearing course fill
depthWearingCourse	Depth of wearing course
DES	Discrete event simulation
DRS	Discrete rate simulation
DSP	Decision support package
EVM	Earned-value management
F-F	Failure outcomes
fillSegment	Segment of fill area for eartworks
F	Function call or method
GA	Genetic algorithm
GDP	Gross domestic product
GL	Ground level
HSE	Health, Safety and Environment
IM	Impact
int	Integer
IP	Infrastructure Project
JPD	Joint probability distribution
kgToCut	Mass of cut
kgToFill	Mass of fill
LOB	Line-of-balance
managementInfluence	Management influence
NP	Non-deterministic polynomial
numSegmentsToFill	Number of area to fill
OECD	The Organisation for Economic Co-operation and Development
OR_{CTM}	Operational phase CTM
parkingNode	Parking area for equipment
pathNodes	Equipment resources driving path
PC_{CTM}	Procurement phase CTM
PERT	Program evaluation and review technique
PoC_{CTM}	Post construction phase CTM
PrC_{CTM}	Preconstruction phase CTM
precipitationInf	Precipitation influence
R&D	Research and development
RFI	Request for information
SD	System dynamics
SO	Stakeholders' objectives

S-S	Success outcomes
stripVolumePerPath	Volume stripped per path
Te_{CTM}	Tender phase CTM
timeSpentStripingPath	Time spent for stripping path
timeToBlock	Time on access egress
timeToStripPath	Time to strip path
timeToUnblock	Time required to solve access egress
TQ	Technical query
V	Variable
volAC14	Volume of AC14
volAC20	Volume of AC20
volBackFill	Volume of backfill
volBase	Volume of base
volGenCut	Volume of cut
volGenFill	Volume of fill
volTopsoilStrip	Volume of topsoil strip
volWearingCourse	Volume of wearing course
wasteNode	Waste area for dump
WBS	Work breakdown structure
workCluster	All agents' area
wtS	Work teams

Appendices

Appendix 1: Process-based model building data for construction

Table 6.4

Areas A, B, and C chainage

Area A chainage (678.59m ²)		Area B chainage (543.60 m ²)		Area C chainage (214.45 m ²)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
20	82.8	20	87.1	20	101.3
19.4	72.7	20.3	82.5	20.3	97
36.6	71.1	100.4	82.8	75.7	97.6
53.9	70.8	110.8	82.2	76	101
65.3	70.2	110.5	89.9	20	101.3
65	77.6	85.3	89.6		
70.2	78.8	67.7	89		
75.1	78.8	55.1	88		
81.3	77.9	20	87.1		
84.7	77				
90.2	79.4				
111.1	81				
111.1	82.5				
99.7	82.5				
86.5	82.5				
20	82.8				

Table 6.5

Areas D, E, and F chainage

Area D chainage (592.44 m ²)		Area E chainage (951.51 m ²)		Area F chainage (456.76 m ²)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
20	115.1	19.7	122.8	145.3	80.3
19.7	111.4	20.6	114.5	145.3	79.1
47.1	110.2	62.8	116.7	190.2	77
62.8	109.3	83.1	116.4	192.1	74.2
78.5	108.4	110.8	117.9	197.9	73.6
85.3	107.7	109.9	130.2	201.3	76
109.9	107.7	54.2	126.2	285.1	69
109.9	116.4	19.7	122.8	317.1	68.3
77.6	116.1			359.9	65.9
60.3	115.7			377.3	65.9
20	115.1			375.7	69.6
				359.9	69.6
				305.1	69.9
				286.9	70.5
				257.4	72.7
				210.3	77.3
				180.4	78.8
				145.3	80.3

Table 6.6

Areas G, H, and I chainage

Area G chainage (1879.7 m2)		Area H chainage (1605.69 m2)		Area I chainage (404.13 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
144.1	86.2	144.4	89.3	290.9	82.8
144.1	80.3	144.4	85	290.9	79.1
175.2	79.1	193	85	360.5	76.7
211.8	76.3	270.6	80.3	369.6	76.7
271.8	71.4	290.3	80	364	83.4
304.2	69.6	290.3	82.2	360.5	83.4
359.9	69.6	359.6	81.6	290.9	82.8
375.7	69.6	363.1	81.6		
368.8	76.3	359.6	85		
359.9	76.3	359.6	85		
328.8	77.6	354	91.1		
290.3	78.8	144.4	89.3		
389.7	80.3				
270.3	80.3				
245.7	82.5				
209.9	84.3				
194.6	85				
191.5	85.9				
144.1	86.2				

Table 6.7

Areas J, K, and L chainage

Area J chainage (1440.56 m2)		Area K chainage (694.93 m2)		Area L chainage (m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
145	116.1	145	118.8	144.4	132.4
144.5	108.1	145	115.1	144.4	119.4
337.7	108.1	193.3	115.4	187.2	120.1
328.8	115.4	329.1	114.8	242	120.4
145	116.1	326	117.3	299.5	118.2
		244.7	119.8	327.9	117.6
		145	118.8	315.5	130.2
				284.8	134.5
				276.1	139.8
				231.5	141.6
				210.6	138.2
				149.3	134.5
				149.3	132.4
				144.4	132.4

Table 6.8

Areas M, N1, and N2 chainage

Area M chainage (m2)		Area N1 chainage (1021.03 m2)		Area N2 chainage (m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
144.7	145	206.8	60.9	212	68
144.7	131.8	204.6	59.6	206.1	59
149	131.8	178.6	74.6	191.7	68.4
149	134.2	172.2	72.6	173.7	78.3
210.3	137.6	153.3	80.6	162.9	82.8
232.1	140.7	118.7	84.1	144	89.6
274.9	139.1	110.4	84.6	125.6	94.5
285.4	134.8	104.6	90.2	110.3	96.8
308.2	132.1	103.7	93.4	95.9	98.6
315.2	130.2	102.7	98.2	75.6	99.9
315.2	133.9	95	99	49.5	97.7
296.8	141.3	71.6	99	41	108.5
282.6	147.1	67.9	93.5	59.9	108
280.4	150.2	64.9	98.2	100.4	107.1
277.4	153.6	58.8	97.9	129.6	102.6
261.4	156.7	55.3	97.9	147.2	99.9
250.6	157.9	52.7	98.2	166.1	93.6
240.7	160.1	51.1	100.1	179.6	86.4
235.5	154.5	66.8	100.9	192.6	83.3
210.6	147.8	90.7	100.3	212	68
174.5	142.2	109.6	99.5		
168.1	141.9	125.3	97.1		
157.6	144.7	140.5	93.1		
153	145.6	154.7	88.3		
150.2	146.2	173.8	82.2		
148.1	147.1	184.7	74.5		
144.7	145	206.8	60.9		

Table 6.9

Areas N3, N4, and N5 chainage

Area N3 chainage (733.08 m2)		Area N4 chainage (1434.03 m2)		N5 chainage (1957.69 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
220.6	66.2	215.6	104.4	182.5	138.9
211.5	68.4	41.9	107.6	185.7	135.2
193.5	81.5	32.9	114.8	15.4	133.6
168.8	94.1	207	113.9	8.8	141.6
140	102.6	215.6	104.4	154.3	140.5
122	105.3			182.8	199.4
145.8	104.4			182.5	138.9
215.2	105.3				
226	105.8				
229.6	111.2				
239.5	99				
242.2	92.3				
237.2	81.5				
233.2	74.7				
229.6	72.9				
234.5	81.5				
236.8	86.4				
237.2	92.3				
233.2	94.5				
227.3	98.1				
196.7	101.7				
139.5	103.1				
165.6	97.7				
176	94.5				
190.4	87.3				
200.7	78.8				
220.6	66.2				

Table 6.10

Areas N6, N7, and N8 chainage

Area N6 chainage (2183.48 m2)		Area N7 chainage (689.06 m2)		N8 chainage (1510.17 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
171.6	153	231.4	70.7	337.6	234.7
182.3	138.6	230	73.8	337.1	217.9
8.5	140.8	238.6	85.1	257.1	233.9
0.3	150.6	240.8	93.2	187.3	235.8
43.9	153.3	238.6	99.5	184.9	234.4
69.2	152.5	227.8	111.6	163.4	235
103.8	152.2	105.3	248.9	155.4	236.8
136.2	152.2	244.4	101.3	147.7	240
171.6	153	246.7	96.8	141.6	245.1
		246.7	92.7	136.5	248.8
		244.4	88.2	143.4	249.1
		231.4	70.7	157.8	240.3
				230.2	239.2
				242.9	239
				252.5	240.8
				275.7	239
				289	239
				303.6	236.3
				337.6	234.7

Table 6.11

Areas N9, N10, and N11 chainage

Area N9 chainage (3038.01 m2)		Area N10 chainage (3913.61 m2)		N11 chainage (788.01 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
338.2	217.7	312.4	179.9	232.8	208.9
337.1	203.2	314.8	171.6	222.1	200.4
295.1	213.3	303.1	158.9	218	192.1
207.6	215.5	288.7	155.9	212.4	183.8
193	215.2	253.3	153.3	213.1	183.6
175.5	208.3	235.8	151.4	212.3	170.6
170.9	213.3	223	164.7	204.4	176.7
178.6	219.3	221.1	174.8	184.7	198.2
188.4	224.1	221.9	187.3	182.8	199.6
184.9	225.1	225.9	195.3	184.9	197.4
158.6	226.2	235.8	202.5	197.2	205.4
144.8	242.4	293.2	200.6	212.3	208.4
152.7	238.4	306.8	193.5	220.3	208.1
159.1	235.8	310.3	186	232.8	208.9
186.3	235.2	312.4	179.9		
254.9	233.4				
285.5	228.3				
338.2	217.7				

Table 6.12

Areas N12, N13, and N14 chainage

Area N12 chainage (3752.86 m2)		Area N13 chainage (946.09 m2)		N14 chainage (414.3 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
327.9	174.1	335.7	203.2	335.7	141.8
322.3	159.3	335.7	141.8	335.7	135.8
314	148.2	297.4	141.8	268.7	135.8
297.4	141.8	314	148.2	264.6	141.8
265.5	139.9	322.3	159.3	335.7	141.8
253.5	152.4	327.9	174.1		
293.2	154.2	325.5	188.4		
304.3	159.3	320.5	200.4		
308.9	164.9	306.6	211		
311.7	170.4	335.7	203.2		
313.1	179.6				
309.8	150.5				
303.8	194.9				
294.1	198.1				
248.4	202.3				
235.5	201.8				
227.2	195.3				
220.7	185.2				
221.6	173.2				
222.1	164.9				
235	151.9				
253.5	152.4				
226.7	148.7				
203.6	177.3				
212.9	169.5				
213.8	184.7				
217	191.6				
224	202.7				
231.3	208.7				
216.6	208.7				
205.5	207.3				
194.9	204.6				
182.9	199.9				
176.4	207.3				
193	214.3				
206.4	217				
296.5	213.8				
306.6	211				
320.5	200.4				
325.5	188.4				
327.9	174.1				

Table 6.13

Areas N15, N16, and N17 chainage

Area N15 chainage (2334.78 m2)		Area N16 chainage (1967.07 m2)		N17 chainage (2497.09 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
336.6	114.1	336.6	104.8	325.7	9.6
336.6	104.8	336.6	40.2	328.6	7.2
297.8	104.8	275.7	104.8	325.2	4
288.6	114.1	336.6	104.8	320.6	1.9
				310.8	5.6
				269.8	33
				261.3	36.5
				226.4	56.9
				237.9	68.7
				252.3	75.6
				258.9	76.1
				265.3	73.2
				271.2	67.6
				325.7	9.6

Table 6.14

Areas N18, N19, and N20 chainage

Area N18 chainage (734.47 m2)		Area N19 chainage (215.52 m2)		N20 chainage (306.63 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
294.6	6	286.8	3.7	300.4	80.4
280.3	6	285.4	1	296.4	78.5
254.4	23.1	256.3	20.3	246.1	134.1
225.8	47.6	224.4	46.2	233.6	151.9
229	56.3	224.9	49.4	300.4	80.4
251.7	41.1	252.1	26.8		
293.2	3.7	286.8	3.7		
294.6	6				

Table 6.15

Areas O1, O2, and O3 chainage

Area O1 chainage (2745.31 m2)		Area O2 chainage (349.38 m2)		O3 chainage (4040.78 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
205.5	103.9	40.6	31.4	219.3	116.8
205.5	97	57.3	2.3	220.7	108.5
196.3	96.5	49.9	2.3	181.5	99.7
185.2	93.3	26.8	22.6	160.2	93.7
173.6	91.4	40.6	31.4	149.2	88.2
161.2	86.4			141.3	83.1
147.8	76.2			128.8	76.2
114.5	49.9			97.9	57.3
83.1	18.9			85	55.9
80.3	10.2			62.8	42.5
80.3	1.8			54.5	37.4
65.1	2.8			52.2	33.2
57.3	15.2			52.6	23.6
50.8	28.2			55.4	14.3
51.7	33.7			63.3	2.3
87.7	56.8			40.6	2.8
97.4	58.2			9.7	33.2
130.2	77.1			16.2	34.2
140.4	82.2			23.6	34.2
161.6	92.8			115	90.5
205.5	103.9			151.5	106.2
				183.8	115.9
				219.3	116.8

Table 6.16

Areas O4, O5, and O6 chainage

Area O4 chainage (7710.33 m2)		Area O5 chainage (1963.98 m2)		O6 chainage (2028.58 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
248	118.2	248.9	125.6	240.1	150.1
179.6	113.1	248.9	119.1	240.1	142.7
142.7	101.6	204.6	117.3	21.7	141.3
112.7	87.3	0	114.5	22.6	145.5
23.1	33.7	0	122.8	0	144.1
15.7	35.1	248.9	120	0	151
0	48			240.6	149.2
0	113.6				
248	118.7				

Table 6.17

Areas O7, O8, and O9 chainage

Area O7 chainage (3355.26 m2)		Area O8 chainage (4564.13 m2)		O9 chainage (4841.26 m2)	
Coordinates		Coordinates		Coordinates	
x, m	y,m	x, m	y,m	x, m	y,m
339.4	144.1	338.5	148.2	241	148.2
338.5	135.3	338.5	144.1	0	152.4
258.6	148.2	274.3	151.9	0	212.9
190.2	151.9	221.6	156.5	97	169.9
149.6	156.1	191.6	159.3	121.9	162.5
116.4	164.4	151.5	166.2	151.9	156.5
93.7	171.8	142.7	168.1	241	148.2
49.4	191.6	96	181.5		
0	212.4	51.7	203.2		
0	227.2	0	226.7		
40.6	208.3	0	247.5		
79	190.7	39.3	236.9		
113.6	176.9	63.7	224.9		
146.8	166.7	132.5	185.2		
195.8	159.8	159.8	175.5		
276.6	152.4	186.1	172.2		
339.4	144.1	183.8	166.7		
		338.5	148.2		

Table 6.18

Evaporation data

Amount (mm)													Period(Hrs)
2	0.4	1.5	2.3	1.8	3.4	3.6	2.5	0.9	1.3	1.5	3.5	3.8	24
2.2	0.8	1.2	1.2	2	3.7	2.8	3.4	1.3	1.3	0	2.4	2.8	24
2.3	0.3	1.7	2.1	3.3	3.6	2.6	3.2	0.8	1.2	1	1.8	3.1	24
2	1.1	1.4	1.9	1.6	4.5	3.4	2.7	0.7	0.1	1.5	2.2	4.4	24
2.4	0.3	1	1.5	2.8	3.4	2.9	1.6	0.7	0.3	1.4	0.6	5.1	24
2.3	1.3	0.5	1.6	2.7	2.7	4.2	1.8	0.9	0.9	0.9	1.9	4.1	24
2.1	0	0.3	1.1	3.6	3.3	4.4	1.5	0.4	0.4	1.4	2.6	3.8	24
2.2	0.6	0.6	2.1	3.5	4.8	3.2	2.4	0.8	1.1	1.2	3.1	2.3	24
1.1	0.5	1.4	2.1	5.7	3.1	2.1	1.2	0.7	1.5	2.1	3.9	4.2	24
1.1	0.6	1.8	2.4	1.9	3.5	1.1	1	1.4	1.6	2.3	3.2	3.8	24
1.8	0.6	1.8	1.5	2.6	4.7	2.4	2.4	0.3	1.3	1.8	3.1	3.5	24
2.1	0.6	1.6	1.4	2.2	3.8	0.5	0.9	1	1	1.9	1.9	1.9	24
2	0.3	0.8	1.8	2.4	2.6	4.2	1.7	0.8	0.4	0.6	2.5	4.4	24
0	0.9	1.6	2.2	2.6	2.9	4.3	0.1	0.5	0.6	1.4	2.8	5	24
2	0.9	1.2	2.2	2.2	2.4	3.9	1.1	0.8	0.6	1.9	2.6	2.2	24
2	0.4	0.3	2.2	2.4	3.5	3.4	2.3	0.2	0.8	0.2	2.1	2.2	24
1.4	0.7	1.4	2.7	1.6	3.1	2.7	2.1	0.3	0.4	1.6	3.3	3.4	24
0.1	0.8	1.4	2.1	3.3	3.3	4.1	1.9	0.6	0.5	1.9	2.9	5.2	24
1.1	1.3	0.3	2.4	2	5.1	3.8	1.5	0.8	1.8	1.8	1.4	4.4	24
1.7	0.9	1.3	2.4	3	3.4	3.4	1.5	0.8	0	0.9	2.5	5	24
1.2	1	1.5	1.8	4.6	4.1	3.3	1.5	1.3	0.6	2.2	2.6	3.6	24
1.6	0.2	1.7	1.2	4.6	4.8	4	2	1	0.8	2	4.2	3.3	24
0.2	0.4	1	0.5	3	4.8	2.6	2	0.8	0.7	2.2	4.9	3	24
1.6	0.7	0	1.1	1.5	5.2	3.4	1.3	0.3	0.7	2.1	3.7	2.9	24
0.7	0	1.4	2.4	3.7	5.5	3.1	2	1.3	0.9	1.3	4.5	3.2	24
0.9	0.7	0.6	2.8	3.7	5.8	3.6	1.1	1.1	1.4	0.7	0.1	3	24
1.3	0.9	1.1	2.1	3.1	6	4.4	1.1	1	1	1.2	3.8	2.6	24
1.2	0.5	0.3	2.3	4.5	4.7	2.8	1.7	0	1.2	1.4	4	3.9	24
0.5	0.1	0.9	1.7	4.9	3.5	3.7	1.7	0	1.7	1.7	4.1	1.1	24
0.7	0.5	1.1	3.4	4.5	4	4.3	1.3	1.1	1.6	1.5	3.8	3	24
1.1	1	1.6	3.6	2.4	4.7	3.2	0.4	1	0.9	1.4	4	1.4	24
1.6	0.6	1.8	3.1	3.5	5.3	3.7	0.4	0.6	0.4	2.8	3.5	1.6	24
0.8	0.4	2	2.8	2.2	4	2.8	1.8	0.4	1.2	2.8	3.1	2.7	24
1.3	0.7	1	1.9	5	4.3	2.7	2	0.5	1.4	2.4	2.4	3.5	24
1	0.8	1.6	3.2	3.5	0.6	3.3	1.7	0.5	1.2	2.6	2.1	2.8	24
0.7	0.9	1	2.8	5.4	2.6	2.4	1.4	0.2	1.2	0.8	2.1	4.6	24
0.9	1	0.5	1.4	5.1	2.9	1.9	1.2	0.4	0.7	2.4	1.6	4.9	24
0.6	0	1.8	2.6	4.3	2.5	3	1	0.8	0.8	0.5	3.1	5.7	24
0.4	0.4	1.9	2.7	4.5	4.7	4.6	1.4	0.4	1.2	1.3	1.7	4.7	24
0.9	0.8	1.5	1.7	4.1	3.1	3.1	0.8	0.8	0.9	0.2	2	3.5	24
0.7	0.6	1.1	3.4	1.3	3.9	3.6	0.7	0.5	0	1.1	1	4.3	24
0.6	0.8	1.8	2.9	2.2	2.2	3.3	1.2	0.4	1.2	0.6	2.8	3.9	24
1.2	0.6	1.8	2	2.2	1.4	1.6	0.4	0.4	3.1	2.1	2.3	4.8	24
1	0.8	2.4	1.4	3.2	1.9	3.5	1.4	1.8	2.3	1	4	4.4	24

Table 6.19

Rainfall data

Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min
0.04	7.1	0.006	0.05	10.8	0.005	0.27	8.8	0.031	0.88	10.6	0.083	0.11	3.5	0.031
0	262.5	0.000	0	16.5	0.000	0.06	3.9	0.015	0.18	6.5	0.028	0.64	28.7	0.022
0.09	14.6	0.006	0.07	5.9	0.012	3.5	5.8	0.603	0.64	10.8	0.059	0	20	0.000
0.4	28.9	0.014	0	22.3	0.000	0.23	3.3	0.070	0.09	9.2	0.010	0.31	10.4	0.030
0.8	40.5	0.020	0.14	5.2	0.027	1.47	5.8	0.253	0	11.3	0.000	0.81	12	0.068
0.29	8.2	0.035	0.43	23.5	0.018	3.52	3.7	0.951	0.15	29.3	0.005	0.55	15.2	0.036
0.36	15.8	0.023	0	186	0.000	3.34	6.3	0.530	0.08	4.1	0.020	0.1	16.8	0.006
0.59	12.6	0.047	0.06	5	0.012	0.07	19.9	0.004	0.21	31.5	0.007	0	72.6	0.000
0.19	7.9	0.024	0	24.9	0.000	0	63.1	0.000	0	77.4	0.000	0.13	2	0.065
0.35	9.8	0.036	0.15	29.6	0.005	0.32	4.2	0.076	0.17	19.6	0.009	0.3	7.5	0.040
0	14	0.000	0.18	9.4	0.019	0.04	8.2	0.005	0	15.1	0.000	0.59	6.8	0.087
0.19	6.7	0.028	0	426.8	0.000	0	126.7	0.000	0.13	16.2	0.008	0.16	12.8	0.013
0.36	8.6	0.042	0.04	4.3	0.009	0.17	3	0.057	0	75.8	0.000	0.4	10.4	0.038
1.96	11.9	0.165	0.12	24.8	0.005	0	26.9	0.000	0.09	2.9	0.031	0.77	11.2	0.069
0.77	8.3	0.093	0	728.9	0.000	0.41	7.5	0.055	0	8.1	0.000	0	6.4	0.000
0.13	7.4	0.018	0.12	6.2	0.019	0.75	6	0.125	0.07	18.2	0.004	0.07	1.8	0.039
0.58	7.6	0.076	0	42.5	0.000	2.29	12.3	0.186	0.23	11.8	0.019	0.06	5.6	0.011
0.44	10.4	0.042	0.07	10.8	0.006	0.16	11.6	0.014	0	29.9	0.000	0.2	10.8	0.019
0.23	9.6	0.024	0.71	1.7	0.418	0.06	19.8	0.003	0.25	2.9	0.086	0.1	5.1	0.020
0	10.3	0.000	0.83	8.1	0.102	0	5379.2	0.000	0.1	5.1	0.020	0.21	21.3	0.010
0.1	16	0.006	0.08	6.2	0.013	0.08	4.1	0.020	0.34	8.2	0.041	0	63.2	0.000
0.39	4.9	0.080	0.16	4.7	0.034	0.08	10.4	0.008	0.28	5.3	0.053	0.24	6.6	0.036
0.11	17.3	0.006	0	121.5	0.000	0	65.4	0.000	0.07	5.5	0.013	0	26.7	0.000
0.19	6.4	0.030	0.1	4.1	0.024	0.34	10.5	0.032	0	161.6	0.000	0.09	10.2	0.009
0	172.9	0.000	0.17	29.1	0.006	0	1083.7	0.000	0.2	38.3	0.005	0	163.9	0.000

Table 6.20

Rainfall data

Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min	Amount (mm)	Period (min)	mm/ min
0.86	9.3	0.092	0.16	10	0.016	0.79	3.3	0.239	0.22	6.9	0.032	0.11	5	0.022
0.59	4.5	0.131	0.31	10.5	0.030	0.38	10.5	0.036	0	85.1	0.000	0.28	6	0.047
0	206.4	0.000	0.09	8.2	0.011	0.73	8.3	0.088	0.13	4.5	0.029	0.15	18.7	0.008
0.04	2.3	0.017	0.12	4.6	0.026	0.65	18.7	0.035	0	22.8	0.000	0.28	6.4	0.044
0	48.8	0.000	0.3	14.2	0.021	0.16	9.9	0.016	0.06	7.5	0.008	0	12144.9	0.000
0.46	10.4	0.044	0.26	15.6	0.017	0.11	7.6	0.014	0	30.8	0.000	0.07	9.3	0.008
0.41	13.9	0.029	0.34	11.1	0.031	0	15.5	0.000	0.24	4.7	0.051	0	10.8	0.000
0.29	4	0.073	0.16	4.7	0.034	0.37	4.6	0.080	0.44	5	0.088	0.09	10.1	0.009
2.1	10.5	0.200	0.57	22.9	0.025	0.31	6.7	0.046	0.09	2.9	0.031	0	148.9	0.000
0.15	5.2	0.029	0.41	5	0.082	1.47	11.3	0.130	0.35	5.5	0.064	0.04	3.5	0.011
0.94	6	0.157	0.34	15.3	0.022	0.18	18.4	0.010	0.05	3.9	0.013	0	1396.9	0.000
0.16	8.8	0.018	0	9.2	0.000	0.18	9	0.020	0.21	4.6	0.046	0.09	2.4	0.038
0.29	1.5	0.193	0.31	6.1	0.051	0	40.8	0.000	0	20.8	0.000	0	23.4	0.000
0.27	6.6	0.041	0.12	6.7	0.018	0.31	14	0.022	0.53	3.5	0.151	1.2	3.9	0.308
1.61	12.2	0.132	0.1	9.9	0.010	3.53	12.3	0.287	0.54	8.6	0.063	0.31	4	0.078
0.21	5.3	0.040	0.46	4	0.115	0.55	5.8	0.095	0.21	2.5	0.084	0.66	3.7	0.178
0	21.3	0.000	0.15	6.9	0.022	0.47	1.8	0.261	0	10.2	0.000	1.43	26.9	0.053
0.14	8.8	0.016	0.18	2.1	0.086	0.53	3.5	0.151	0.24	7.3	0.033	0.37	19.1	0.019
0.2	3.8	0.053	0.24	8.7	0.028	0.22	3.5	0.063	0	13.3	0.000	0.09	2.5	0.036
0.5	4.1	0.122	0.05	2.9	0.017	0.25	3.3	0.076	0.13	2.7	0.048	-133.85	2205.2	-0.061
0.54	7.5	0.072	0.2	6.3	0.032	0.08	9.7	0.008	0	19.3	0.000	0	212.5	0.000
0	28.1	0.000	0	4.3	0.000	0.04	11.2	0.004	0.12	19.7	0.006	0.64	3	0.213
0.18	4.8	0.038	0.23	6.6	0.035	0	1083.3	0.000	0.15	5.5	0.027	0	45.5	0.000
0.06	11.2	0.005	0.28	9.2	0.030	0.2	12.6	0.016	0.07	8.1	0.009	0.07	7.5	0.009
0	3630.7	0.000	0.91	5.1	0.178	0	1742.6	0.000	0	719.2	0.000	0	348.3	0.000

Table 6.21

Depth and volume distribution data

	Depth (m)	Volume (m3)
GEN FILL	(0)-(0.75)-(3)	0-1000
GEN CUT	(0)-(0.6)-(3)	0-1000
TOPSOIL STRIP	(0)-(0.03)-(3)	0-1000
SUB BASE	(0)-(0.39)-(3)	0-1000
BASE	(0)-(0.20)-(3)	0-1000
AC14	(0)-(0.06)-(3)	0-1000
AC20	(0)-(0.085)-(3)	0-1000
WEARING COURSE	(0)-(0.06)-(3)	0-1000
BACKFILL	(0)-(0.06)-(3)	0-1000

Table 6.22

Productivity data

Activity	Productivity
Cut production rate	96-440m3/d
Fill production rate	264m3/d
Top soil strip	120-264
Subbase	187m3/d
Base	187m3/d
Place AC14 Layer	184m3/d
Place AC20 layer	243 m3/d
Place Wearing Course	183 m3/d
Backfill	440 m3/d

Table 6.23

Parameter distribution data

Parameter	value units		
Number of unwanted objects that have to be manually removed. This is equivalent to the number of times a labourer will pick up unwanted objects and place them in the bin	10	unwanted objects/m ²	Distribution (1-100)
Labourer Speed	5	km/h	Distribution (1-50)
Average distance from unwanted object to bin	5	meters	Distribution (1-50)
Time required to Dump unwanted object	10	seconds	Distribution (1-300)
Time required to pick unwanted objects	1	minute	Distribution (1-10)
Number of bulldozers	2	bulldozers	Distribution (1-4)
Number of labourers	4	labourers	Distribution (1-10)
bulldozer speed	30	km/h	Distribution (1-100)
Time To clear Grub and Vegetation (Equivalent to the time it takes for a bulldozer to workcollecting unwanted objects before moving to the waste zone)	10	minutes	Distribution (1-50)
Time it takes to position the blade	1	minute	Distribution (1-10)

Appendix 2: Time to complete each tasks

Table 6.24a

Activity duration

CLIENT		PARTNERSHIP	
Task	Duration (hr)	Task	Duration (hr)
prospectAdvert	14.1	liaiseWithGMSAndInternalLC	36.9
receiveProspect	20.1	determinePartneringAgreement	20.7
receiveProspect2	0.0	completeVentureApprovalForms	15.8
examineProspectOpportunity	11.6	seekVentureApproval	17.9
reviewProspectExaminationReport	13.4	waitVentureApproval	21.5
considerPursuingProspec	58.3	receiveVentureForms	15.5
communicateProspect	13.9	approveVentureForms	13.7
reviewProspect	15.2	receiveVentureApproval	
WaitForProspectMeeting	14.9	executeVentureApproval	13.5
attendProspectDiscussion	29.2	waitForTTAForm	74.3
discussProspect	14.2	integrateInternalLegalContact	18.0
prepareProspectInterestResponse	14.9	alignPartneringIssues	23.2
waitExecutiveAuthorityApproval	14.7	completeQuestionnaire	11.6
approvePreparedInterest	14.7	negotiateTTATerms	15.6
communicateApprovedInterest	14.1	waitForTTAApproval	41.5
receiveBonafideInterest	14.4	receiveTTAForm	13.4
companyInterest	14.4	reviewTTAForm	14.6
		approveTTAForm	13.6
		waitForProposalTender	168.8
		receiveTTAApproval	9.5

Table 6.24b

Activity duration continued

OPPORTUNITY EVALUATION		CAPABILITY ASSESSMENT	
Task	Duration (hr)	Task	Duration (hr)
explainProspectStrategicBenefits	14.3	waitKnowledgeBaseMeeting	16.4
conductStrategicRiskassessment	63.4	conductSiteVisit	14.9
uploadBriefingOutcomes	12.4	receiveKnowledgeBaseMeeting	14.2
submitBriefingOutcomes	15.0	generatePreliminaryReport	14.0
receiveBriefingOutcomes	14.2	receiveKnowledgeBaseMeeting1	48.9
appraiseInitialCapability	11.7	reviewSiteInformationReport	11.9
reviewBriefingOutcomes	20.9	establishProjectKnowledge	14.6
assignInitialResources	14.6	sendknowledgeBaseMeeting	14.1
evaluateRejection	12.9	waitKnowledgeBaseMeetingResponse	12.2
improveProspectUnderstanding	12.3	discussKnowledgeBase	18.8
ascertainInitialCapability	14.5	receiveKnowledgeBaseApproval	9.2
proposalWaiting	0.0	waitVentureApprovalForms	119.0
strengthenClientRelationship	11.8	checkIfKnowledgeBaseIsOK	25.3

Table 6.24c

Activity duration continued

CONTRACT NOTIFICATION AND AGREEMENT		SCOPE CLARIFICATION	
Task	Duration (hr)	Task	Duration (hr)
receiveClientAwardNotification	14.6	scopeEvaluation	15.4
readyForMeeting	18.5	sendScopeClarification	13.3
negotiateContractToFinalise	18.6	prepareQuestions	9.4
prepareForNegotiation	15.0	receiveScopeClarification	15.7
completeContractAward	14.8	scheduleScopeClarificationMeeting	13.7
negotiatingContractTm	4.6	receiveScopeClarificationMeetingTM	11.2
negotiatingContract	2.2	clarifyScope	19.9
awardContract	19.8	clarifiedScopeTQandRFI	137.5
waitForAcceptancePreparation	15.0	receiveScopeAnsweredTQAndRFI	13.4
prepareContractAcceptance	15.0	receiveScopeClarifiedTQandRFI	8.1
signAcceptanceLetter	14.9	reviewScopeClarifiedTQandRFI	20.6
acknowledgeAcceptance	14.2	updateScopeSpecification	26.2
communicateTenderCompletion	13.4	receiveCompanyTQandRFIAcceptance	13.4
endTenderTasks	12.5	receiveTQandRFIAnswerAcceptance	13.1
obtainFinalAwardResponse	16.5		
reviewWonContract	18.4		

Table 6.24d

Activity duration continued

PRECONSTRUCTION ACTIVITIES	
Task	Duration (hr)
waitProjectTeamInauguration	0.3
constituteProjectConstructionTeam	374.1
receiveConstructionTeam	14.8
receiveProjectTeam	14.4
arrangeHandOverMeeting	16.5
receiveHandoverMeetingNotice	15.6
receiveHandoverMeetingNotification	15.7
receiveHandoverNotice	15.2
attendHandoverMeetingCM	13.8
attendingHandover	14.9
attendHandoverMeeting	16.1
conductHandover	18.1
confirmHandoverOfDocuments	7.9
completeHandover	7.3
recieveHandOverDocuments	5.8
endOfHandover	2.8
communicateProjectVisionPerformanceIndicators	14.0
receiveForPerformanceIndicatorrrPM	13.8
reviewDocuments	14.5
conductStartUpWorkshop	14.8
conveneMeetingToUpdateSchedule	12.7
discussSchedule1	15.3
receiveScheduleUpdate	14.4
discussSchedulePP	15.3
discussScheduleCMT	2.3
waitForAdjustedSchedule	13.7
adjustSchedule	14.2
communicateAdjustedSchedule	1.1
approveSchedule	30.2
waitForOtherPlan	29.7
notifyMeetingForOtherPlans	23.8
postAwardSchedule	121.6
approveOtherPlan	40.2
meetForOtherPlans	18.2
generateOtherPlanPP	31.0
generateOtherPlanCMT	31.0
generateOtherPlan	12.8
communicateFinalisedPlan	15.1
sendClientCompanyApprovedPlan	16.3
waithForClientResponse	20.4
approveProjectPlan	20.4
communicateApprovedPlan	15.0
preparationOnTrafficSwitch	14.7
reviewDetailedTrafficPlan	146.1
waitTrafficPlanApproval	65.1
alignTrafficPlan	27.6
waitClientTrafficPlanApproval	37.5
reviewTrafficPlan	19.8
approveTrafficPlan	17.7

Table 6.24e

Activity duration continued

STRIPPING		CUT/UNDERCUT	
Task	Duration (hr)	Task	Duration (hr)
prepareToClearGrubAndVegetation	33.0	inSituSoilTestForUndercut	32.6
moveToPath	0.2	moveToCutArea	0.1
positionBlade	0.1	dig	2408.4
clearGrubAndVegetation	1.0	potentialBlocked	11.5
dumpUnwantedObject	0.2	moveTo2	242.3
moveBack	0.8	dig2	2408.4
waitForSecondBullDozer	0.0	truckLoadCut	3291.3
delay	0.0	truckLoadCut1	3304.0
moveTo1	0.3	rotateTowardsTruck	647.6
strip	1252.0	waitForTruck	13.2
goBackToContinueStriping	1250.9	rotateBack	647.6
loadTruck	0.1	moveTo3	240.3
moveBackStrip	0.9	delay2	0.0
stockPileStrip	0.1	moveToNextCuttingArea	0.2
delay1	0.0		
moveToNextParkingArea	0.3		

Table 6.24f

Activity duration continued

FILLING/COMPACTING		SITE VISIT PREPARATION	
Task	Duration (hr)	Task	Duration (hr)
goGetFillMaterial	1273.3	Task Name	Duration in HRS
pickUpFillMaterial	1653.7	requestSiteInformationVisit	12.0
goToAreaToFill	1273.0	recieveCompanySiteInformationVisitRequest	13.7
fluidDropoff	1653.7	receiveSiteInformationVisitRequest	14.4
backToPark	0.6	developValueProposition	13.8
moveToAreaToCompress	0.7	approveSiteInformationVisit	16.0
compact	59.1	receiveClientSiteInformationVisitApproval	10.0
backToParking	0.7	receiveFormalProposalAcceptance	875.4
auxDelay3	0.0	approvedSiteInformationVisist	948.0
moveToNextParkiArea	0.1		
moveToTheNextArea	0.1		