Exploring Project Management through System Dynamics Modelling: Revisiting the Importance of the Rework Cycle

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ABSTRACT

This paper explores the contributions of system dynamics modelling to traditional project management practice. We establish why it is an important approach to assist with management decision-making. Key aspects of this systemic technique are highlighted, and the methodology that guides this research is described. We have revisited many published models, and identified key explanatory structures (*e.g.*, rework cycle) that are fundamental to project delivery decisions. Furthermore, we consider how the rework cycle can be applied to the extended project life-cycle and the Project Management Institute's process groups. It is recognised that this discipline is evolving. Therefore, future research directions for system dynamics modelling within the project management discipline are outlined.

Keywords: Project Management; Rework cycle; System Dynamics; Systems Thinking

INTRODUCTION

Project management (PM) is continuously evolving as a discipline (Davies, 2017; Morris, 2013). It is emerging as an important profession (Schon, 1983) which attempts to tackle identified societal challenges. From the 1950s, various systematic techniques (*e.g.*, PERT) have been developed to assist with project delivery through control and planning (Miller, 1962). These systematic approaches are the foundations of traditional project management and the professional bodies (Morris, 2013; Morris and Geraldi, 2011). Traditional project management is linked with delivery, tactical and operational (short term) decision-making, efficiency, ‘doing the project right’, project management success (cost, time, schedule) (Cooke-Davies, 2007) or the iron triangle (Atkinson, 1999).

Significantly, many management related disciplines (Rosenhead and Mingers, 2001) have recognised a dichotomy of problem situations. For instance, problems versus messes (operational research/ Systems) (Ackoff, 1979); high ground versus swampy lowland (systems/management) (Schon, 1983); tame versus wicked problems (design) (Rittel and Webber, 1973). The project management discipline has acknowledged increased complexity and uncertainty (Elia *et al.*, 2020; Morris, 2013; Winter *et al.*, 2006). Jackson (2019) believes that systems thinking can deal with complexity. The system dynamics approach (Forrester, 1961) is strongly linked with systems thinking (Richardson *et al.*, 1994). System Dynamics (SD) can explore various scenarios and offer structural explanations to generated dynamic behaviour. These systemic insights can guide management decisions-making. Furthermore, we assert that traditional systematic approaches are appropriate for the former problem situation, and SD is more suitable to the latter dichotomy category. It is significant that, in parallel, that SD has been applied to traditional project management practice (*i.e.*, delivery) (Poziomek *et al.*, 1977; Roberts, 1964, 1974). In 1978, system dynamics was prominent in the project management field when a simulation model resolved a $447 million USD Ingalls shipbuilder claim against the US Navy (Cooper, 1980).

The Ingalls project had started with a contract in 1970 to build a 30-ship fleet of destroyers. It was known as DD963, or the DD project. However, by the mid-1970s the cost overrun had exceeded USD $500 million, due to design changes. In this case, the SD approach was used to quantify the effects on the DD project (Sterman, 2000). The developed model facilitated the PM domain to analyse non-linear behaviour over time.

The DD project issue was resolved through the use of the rework cycle SD model, and this systemic technique became more popular and was applied to assess software development, infrastructure construction, and solving claims (Abdel-Hamid and Madnick, 1987; Rodrigues and Bowers, 1996; Rodrigues and Williams, 1998; Xu *et al.*, 1998). However, our literature review suggests, from 2000s and onwards, that the application of SD to traditional PM has levelled off (or even in decline).

Interestingly, recently applications of SD has been used for claim analysis (Nasirzadeh *et al.*, 2019), decision-making processes (Lopes *et al.*, 2015; Sadabadi and Kama, 2014), policy design (Ogano and Pretorius, 2017), and human resources analysis (e.g. a project based on Brooks' law) (Garcia-Alvarez *et al.*, 2016). Moreover, this systemic approach has been employed to understand the dynamics of the projects, such as agent-based models (Jo *et al.*, 2015; Wu *et al.*, 2019) or hybrid simulation models (Barbosa and Azevedo, 2018; Jalal and Shoar, 2017; Nasirzadeh *et al.*, 2019; Zhong *et al.*, 2018). Our reviews indicates that the application of SD does take into account the complexity and uncertainty of long-term project impact (i.e. links with project back-ending (operations) and beyond).

The project life-cycle has been extended to capture front-ending, delivery and back-ending (APM, 2019; Artto *et al.*, 2016; Cooke-Davies *et al.*, 2009; Williams *et al.*, 2019) in order to assist with tackling identified problems associated with unsuccessful projects (Morris, 2013). Moreover, Winter *et al.* (2006) offered some future research directions (*e.g.*, social process, project complexity, value creation) for the PM discipline. This has facilitated advances in PM which are associated with project front-ending, strategy decision-making, 'choosing the right project', effectiveness, project success (*i.e.*, value, benefits) (Cooke-Davies, 2007; Miller and Lessard, 2000; Williams *et al.*, 2019, 2009). These significant advances have implications for SD modelling within the PM discipline. Moreover, we contend that most SD models have been produced within the boundary of traditional PM practice (*i.e.*, project delivery).

The manifestation of the extended-life cycle indicates there is a need to rethink the modelling boundaries of system dynamics to assist with these new emerging aspects of management decision-making (*e.g.*, strategy, long range planning and back-ending impact). It is recognised that new complexities, uncertainties and non-linarites will emerge in these new challenges for the discipline. However, there is a need to identify key systems structures (*e.g.*, rework cycle) associated with traditional project management which required to be integrated into these new modelling challenges for the SD technique.

Revisiting the importance of the rework cycle system dynamic model used to simulate the DD project. This modelling can be considered to be a type of *post-mortem* which is undertaken in the project back-ending stage of the extended life cycle. There is a need to develop confidence in the SD approach before considering its application in project front-ending decision-making. Hence, this paper addresses the following three research questions: i) what are the benefits of connecting the rework cycle SD model with PMI process group? ii) what are the advantages and limitations of using SD modelling for project management? and iii) what directions might inform future SD modelling simulation in project management? This paper aims to highlight the importance of the rework cycle in monitoring and controlling of executing a project. For that, the paper presents the key elements to build the simulation model for PM by the rework cycle. A comparison between simulation results and PMI process group is presented. Thus, the paper contributes to the existing literature to simulate PMI process group by a depiction of the rework cycle structure.

Additionally, this paper addresses three specific objectives: i) Define the benefits to connect the rework cycle SD model with the PMI process groups, ii) Establish the advantages and limitations of using SD modelling for PM, and iii) Determine directions of SD modelling simulation in PM.

The remainder of the paper is structured as follows. The next section presents a description of the research problem and an overview of SD modelling. This section shows how a systemic view can be useful for PM enquiry. It is followed by an outline of the methodology used for this research associated to the systematic literature review. Next section is findings which has a descriptive analysis. Later, the discussion section is structured into three main topics: a) linking the rework cycle SD model to the PMI process group, b) advantages and limitations of using SD modelling for PM, and c) directions for system dynamics modelling simulation in project management. Finally, the paper concludes and offer future research directions.

DESCRIPTION OF RESEARCH PROBLEM

Project Management has evolved in order to address both internal and external discipline challenges. Numerous studies highlight project failure with respect project management success (short term objectives) (*i.e.*, cost, time, quality) and project success (long term objectives) (value, benefits) (Miller and Lessard, 2000; Morris, 2013; Morris and Hough, 1987). The analysis of failure causes associated with traditional project management (*i.e.*, project deliver) (theory 1 (Winter *et al.*, 2006)) led to the inception of the Management of Projects (MoP) (Morris, 1994) (theory 3 (Winter *et al.*, 2006)). MoP has three distinctive levels, namely, technical core (linked to traditional project management), strategic envelope and institutional context (Morris, 2013). These internal discipline challenges initiated an evolution that encouraged a more holistic approach (linked with systems thinking) to achieving project and project success (Cooke-Davies, 2007). Moreover, MoP activity attempts to tackle identified failure causes in order achieve consistent project success. Winter *et al*. (2006) identified research directions (*i.e.*, from product creation to value creation), which could enhance the MoP paradigm. The MoP and work of Morris has influenced the APM body of knowledge, extended life-cycle which aligns with project front-ending, project delivery, and project back-ending (Artto *et al.*, 2016; Miller and Lessard, 2000; Morris, 2013; Williams *et al.*, 2019, 2009), which suggests increased complexity, uncertainty, unknown unknowns, and non-linarites. The research of Morris and co-workers has fundamentally re-conceptualised the boundaries of the theory and practice of PM (*i.e.*, beyond the boundaries of traditional project management). This has significant implications for the PM profession.

The professions aim to tackle societal challenges (Schon, 1983). Climate change (IPCC, 2021) is the most critical societal challenge and provides the external context for new evolutions for the PM discipline. Importantly, the project management discipline could be conceptualised as an open system that is influenced by its environment. This environmental change facilitates both theoretical and practical gaps within the discipline that need to be addressed. Moreover, the leads to new modelling directions for SD, which are influenced by MoP and climate change. Furthermore, there is a need to identified key SD structures associated with traditional project management practice, which should contribute to future modelling directions. Unexpectedly, we have discovered potential structural enhancements which could inform and offer further explanatory insights to traditional project practice.

Behaviour Dynamics Hypothesis

Figure 1 represents a behaviour dynamic hypothesis of the rework cycle for a project. The balancing loop is denoted as B1 which establish the relationship between work to be done and work done correctly. The balancing loop (B1) is the hypothesis that means, if work to be done increases, then work done correctly increases above what it would have been.

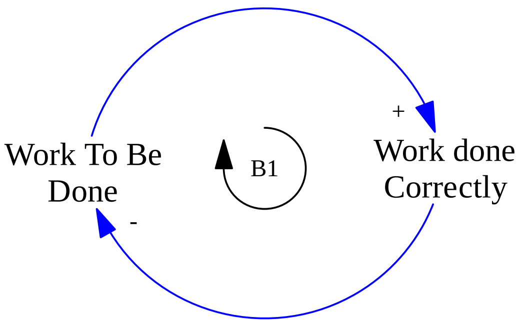


Figure 1. Project management work hypothesis.

Exploring PM through SD modelling reinforces project decision-making at long-term. The most used structure to simulate within SD modelling is the rework cycle. However, the rework cycle has limitation such as changing staff, activities, and delays per phase. To enhance the simulation model, this paper proposes a rework cycle per phase or process group. As a result, consecutives or series of rework cycles offer a better understanding of project behaviour.

SYSTEMS MOVEMENT, SYSTEMS THINKING AND SYSTEM DYNAMICS

There is a need to highlight the connectivity between the Systems Movement, Systems Thinking and System Dynamics. We believe that the systems perspective may contribute to the project management discipline in tackling climate change (IPCC, 2021). The system dynamics modelling technique was developed by Jay Forrester in the 1950s to simulate system behaviour over time that includes nonlinear dynamics, complex system, feedback loops, and delays (Ansari, 2019; Forrester, 1961; Jackson, 2019; Sterman, 2000). System dynamics was developed and applied in practice, but was disconnected from systems thinking. However, the connectivity between system dynamics and systems thinking was established in the 1990s (Richardson *et al.*, 1994). Barry Richmond contrasted systems thinking and system dynamics definition developed by Forrester. Richmond considers systems thinking a broader idea than system dynamics, instead of considering systems thinking as Forrester did "a small subset of system dynamics" (Richmond, 1994, p. 136).

Importantly, Roberts (1964, 1974) and Poziomek *et al*. (1977) applied this technique to the project management domain. System Dynamics and Systems thinking are found to be established in project management (Bell *et al.*, 2019; Chitongo and Pretorius, 2018; Cooper, 1980; Elia *et al.*, 2020; Kapsali, 2011; Lyneis and Ford, 2007; van Oorschot, Eling, *et al.*, 2018; Pargar *et al.*, 2019; Wang *et al.*, 2017; Yeo, 1993). Moreover, systems thinking is a key idea of the Systems Movement (Checkland, 1981). Checkland asserts that the Systems Movement is a meta-discipline, and establishes General Systems Theory (von Bertalanffy, Boulding, Gerard, Miller, Rapoport) and Cybernetics (Wiener, McCulloch, Ashby, Powers, Pask, Beer) as part of the intellectual foundations. Moreover, open and closed systems theories (Kapsali, 2013) are an integral part of the movement. Significantly, Lane and Jackson (1995), and Schwaninger (2006) have connected system dynamics with the systems movement.

Checkland (1976) discusses the emergence of the systems movement, which "attempts in all areas of study to explore the consequences of holistic rather reductionist thinking"

(Checkland, 1976, p. 92). Furthermore, he produced a supporting map which delineates between the study of systems and the application of systems ideas in different disciplines (*e.g.*, Geography). The study of systems is divided into theoretical developments (*e.g.*, General Systems Theory and Systems thinking) and practical real-world problem solving (*e.g.*, Hard Systems Methodology, RAND systems analysis and soft systems methodology). Critically, the systems movement aims to tackle problems of organised complexity.

Jackson (2019) believes systems thinking can deal with complexity. Checkland (1981) contends systems thinking is associated with two pairs of ideas, namely: emergence and hierarchy; communication and control. The former ideas are associated with Biology, and the latter are connected with aspects of Engineering. Fundamentally, system dynamics is rooted in servomechanics (Forrester, 1961; Richardson, 1999). Therefore, we argue that system dynamics (servomechanics) is linked with communication and control, and therefore an integral part of the systems movement. Additionally, system dynamics can highlight the structural complexity of real-world problems (Jackson, 2019). Hence, the motivation of this review of system dynamics contributions to the project management discipline.

System dynamics modelling for system explanation

Thinking in wholes (or boundaries) assists with recognising boundaries of our modelling rationality. We believe our research has connectivity with the work of Herbert Simon and bounded rationality. The principle of bounded rationality is defined as "the capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behaviour in the real world or even for a reasonable approximation to such objective rationality" (Simon, 1957, p. 198). Furthermore, we acknowledge our literature review of system dynamics models is within the boundaries of traditional project management practice (theory 1(Winter *et al*. (2006)), and we attempt to identify important structures (systemicness with this identified boundary) that explains relevant dynamic behaviour. Moreover, these structures will be integrated into future system dynamic models of the extended boundaries of new project management practices (links with theory 3 (Winter *et al.*, 2006)).

System dynamics modelling process

Sterman (2000) established a five iterative steps for SD modelling process, as shown in Table 1: 1) problem articulation, 2) dynamics behaviour hypothesis, 3) formulation, 4) testing, and 5) formulation and evaluation.

Table 1. System dynamics modelling process (Sterman, 2000).

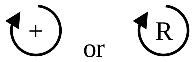
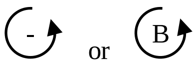
Step	System Dynamics modeling process	Method/Tools
1	Problem articulation	Identify key variables and reference mode
2	Dynamic behaviour hypothesis	Causal loop diagram
3	Formulation	Stock and flow diagram
4	Testing	Tests of dimensionality and consistency
5	Policy formulation and evaluation	Sensitivity analysis (SA) and Scenarios

First step, problem articulation or boundary selection, relates to theme selection, key variables, time horizon, and dynamic problem definition. Second step is the formulation of dynamic behaviour which can include initial hypothesis generation, endogenous focus, and tools for mapping such as causal loop diagrams (CLDs), and subsystem diagrams. Third step is concerning to the formulation of a simulation model by specifying the structure and estimating initial conditions such as stock-and-flow diagram (SFD). Fourth step, testing, develops model tests through sensitivity, and robustness under extreme conditions. The last step, policy formulation and evaluation, is where the process is iterative within the process by defying “what happen if …” scenarios, design policy, or analyse sensitivity.

Causal loop diagram

The CLD reinforces the dynamic behaviour hypothesis step which is used for qualitative analysis system behaviour. CLDs structure causal links among variables of a system. In other words, CLDs link cause to an effect by using arrows. The arrows are the causal links explaining in Table 2. In addition, Table 2 explains causal link polarity, positive (+) or negative (–), to establish the changes from dependent variable to independent variable, namely, causal positive link or casual negative link. When causal links constitute a closed loop, it is considered as positive loop (reinforcing) or negative loop (negative), as shown in Table 2.

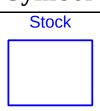
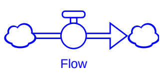
Table 2. Causal loop diagram notation (Sterman, 2000).

Name	Notation	Description
Causal positive link		If X increases, then Y increases above what it would have been.
Causal negative link		If X increases, then Y decreases below what it would have been.
Positive (reinforcing) loop		Reinforcing loop identifier circulates clockwise direction as the loop to which it corresponds.
Negative (balancing) loop		Balancing loop identifier circulates counter-clockwise direction as the loop to which it correspond.

Stock and flow diagram

The SFD is a tool to formulate and represent the processes of PM through a simulation model. The SFD underpins the formulation step of the modelling process which is used as quantitative analysis. SFDs emphasise in physical structure by elements: stocks, flows, converters, and connectors, described in Table 3, which its interaction forms a SFD. Stocks are used to state the system by generating the information of the variables. Stocks are connected with flows, which regulate its input or output as a rate of change. This rate of change can be connected by using connectors.

Table 3. Stock and flow symbols (Xu and Zou, 2021, p. 19).

Name	Symbol	Description
Stock		The level of any variable in the system.
Flow		The rate of changes in stock, which can cause the increase or decrease of a stock.
Converter		It connects stock and a flow in a complex setting, used for intermediate calculations.
Connector		It denotes connection and control between system variables, showing the causality.

METHODOLOGY

A systematic literature review was conducted, accordingly to Tranfield et al. (2003), by three stages: i) planning, ii) conducting, and iii) reporting. Planning is the first stage which seeks the selection of the dataset divided into four steps, as described in Table 4. The dataset included articles from Web of Science and Scopus as search engines with a time span between 1980 and 2000.

Table 4. Systematic literature review planning.

Steps	Search strategy	No. of articles	Search engine
1	Articles using search keywords queries: "project management" and "system dynamics"; Time Span: 1980-2020.	110 210	Web of Science Scopus
2	Refine by categories: management (49), operations research management science (18), business (10).	58	Web of Science
	Filter by subject area: business, management and accounting (99), decision sciences (34), social sciences (29).	125	Scopus
3	Merge articles from Web of Science and Scopus.	129	
4	Articles that use the rework cycle model.	76	

This research conducted, second stage, the systematic steps described in Table 4. For the first step, articles with “project management” and “system dynamics” were retrieved from Web of Science and Scopus database searches. In the second step, articles were refined by categories (Web of Science) and subject area (Scopus). The third step is used to merge the two article datasets. The last step concluded with a dataset of 76 articles that uses the rework cycle model.

The descriptive analysis of the dataset (76 articles) includes distribution of publications per year from 1980 to 2020, fields where SD modelling and PM have been blended, percentage of project performance as triple constraint (cost, time, and quality), percentage of the extended project life cycle in the front-end, project execution, and back-end domains, and percentages of project management process group according to the Project Management Institute (PMI) (PMBOK, 2017). The last stage reports the findings obtained.

FINDINGS

This research examines 76 articles of PM and SD approach between 1980 and 2000, as shown in Figure 2. Although SD for PM started in the 1980s with the rework cycle (Cooper, 1980), the use of this approach for PM began in the 1990s. From the 2000s onwards, SD has been used to modelling PM.

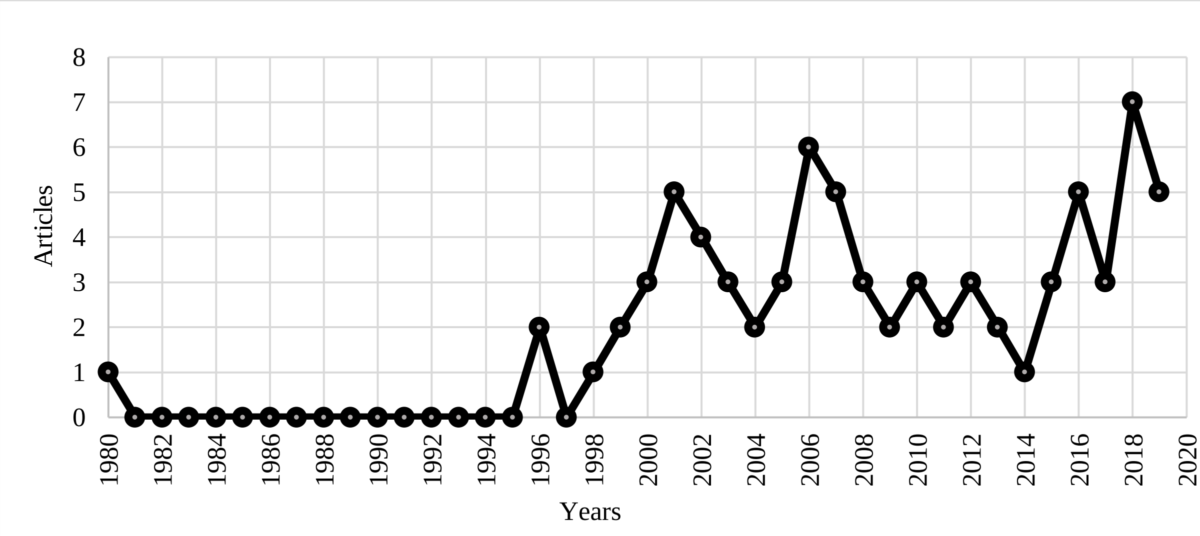


Figure 2. Distribution of publications per year.

Since 1996, SD has been used the rework cycle to modelling PM principally for infrastructure projects as shown in Figure 3. Figure 3 shows variables and percentages of fields for PM applying SD modelling from the dataset: 17 per cent to product development, 14 per cent to research and development (R&D), 9 per cent to software development, 7 per cent to aeronautical and aerospace, and 4 per cent to shipbuilding. Not only applied SD to PM has been used in different fields, but SD also has been applied in strategic management, energy, transport, and environment (Calderon-Tellez and Herrera, 2021; Cosenz and Noto, 2016; Ford, 1997; Herrera *et al.*, 2019; Torres *et al.*, 2017).

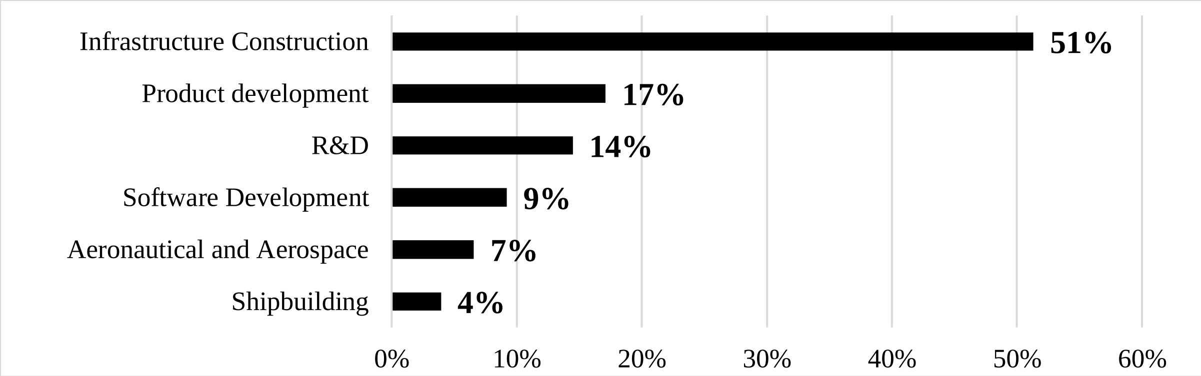


Figure 3. Fields where SD modelling and PM have been blended.

Traditional PM focuses on the triple constraint or project performance: time, cost, and quality (Atkinson, 1999). The research found that rework cycle been assessed by the triple constraint for infrastructure construction projects (Nasirzadeh *et al.*, 2008; Nasirzadeh and Nojedehi, 2013; Ozcan-Deniz and Zhu, 2016; Wu *et al.*, 2019; Zhong *et al.*, 2018). Figure 4 shows variables and percentages of the dataset in relation to triple constraint: 70% to cost, 97% to time, and 87% to quality.

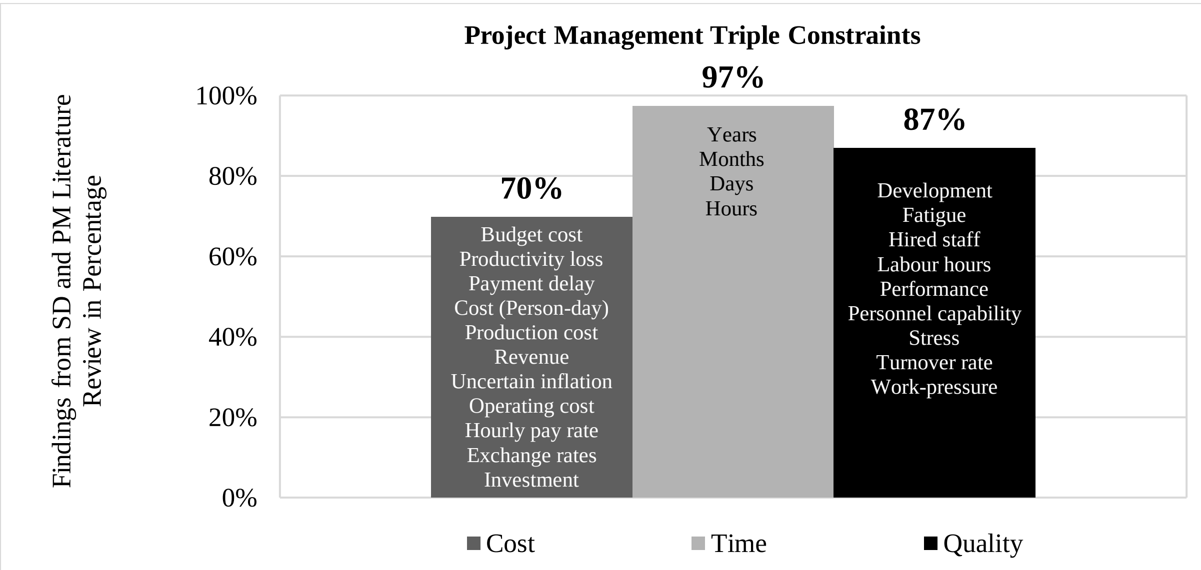


Figure 4. Percentage of project performance as triple constraint (cost, time, and quality).

The research identified that all SD models focused on project delivery. Figure 5 shows variables and percentages of the extended project life cycle: 12% included front-end of projects (Barbosa and Azevedo, 2018; Zhong *et al.*, 2018), and 11% included back-end of projects (Cui *et al.*, 2010; Yaghootkar and Gil, 2012).

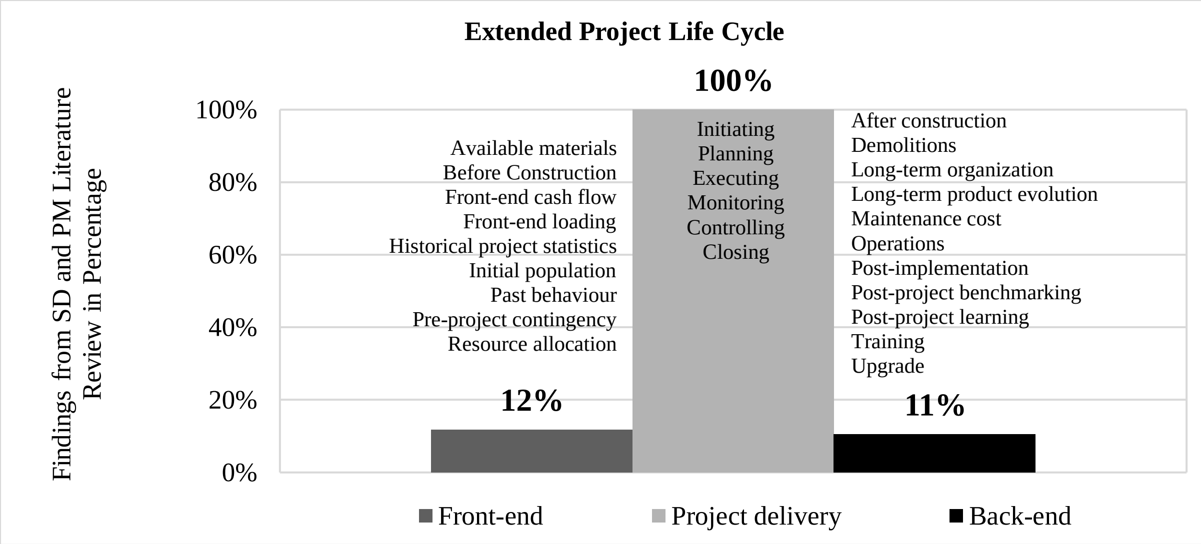


Figure 5. Percentage of the extended project life cycle in the front-end, project execution, and back-end domains.

Expanding project delivery, this research uses PMI process group: initiating, planning, executing, monitoring and controlling, and closing (PMBOK, 2017). Figure 6 highlighted variables and percentages from the database that uses the PMI process group: 100% on the execution, 99% on the monitoring and controlling, 89% on the closing, 76% on planning, and only 47% on the initiating.

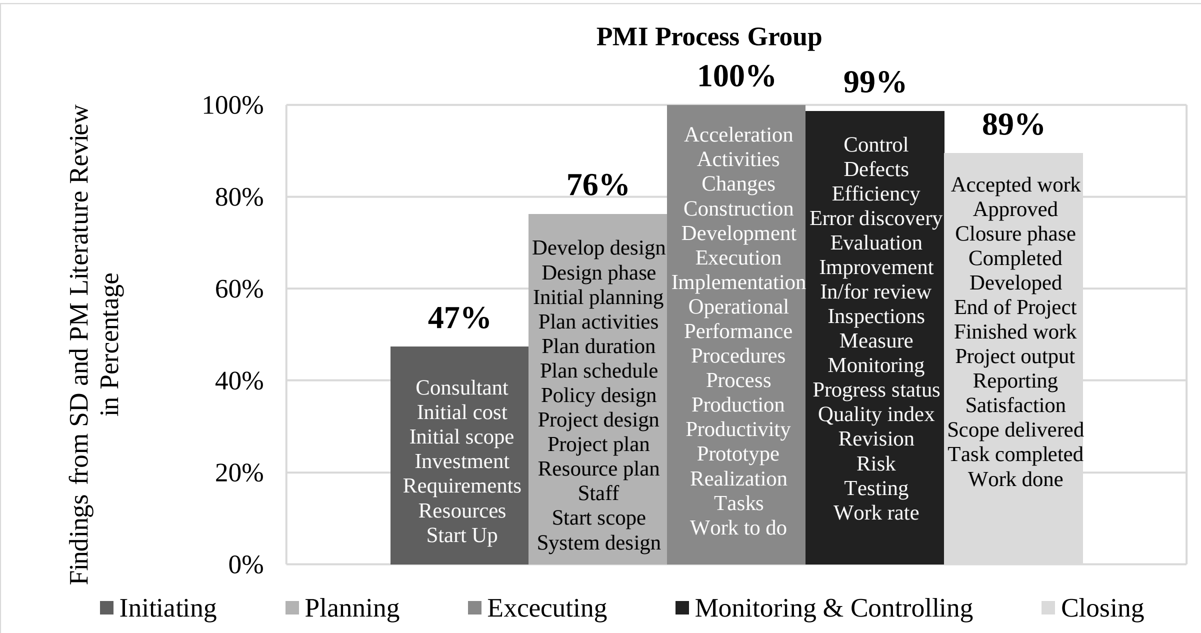


Figure 6. Percentages according to the project management process group (PMBOK, 2017).

DISCUSSION

The result of descriptive analysis shows that SD modelling for PM focus on project delivery. Inside its project delivery, the modelling is referring to executing, monitoring and controlling, and closing process group with a low focus on initiating and planning process group. Having said that, this research analysed three aspects: First, the link of the rework cycle SD model with PMI process group. Second, advantages and limitations using SD modelling for PM, and third the future directions for SD modelling simulation in PM.

Linking the rework cycle SD model to the PMI process group

The CLD rework cycle model is showed in Figure 7 which has two reinforcing (R) loops and 5 balancing (B) loops. Cooper *et al.* (2002) established principal variables for the rework cycle structure such as “work to be done”, “work actually done”, “rework discovery”, “productivity”, “people”, and “quality”. B1 established the relationship between work to be done and work done correctly. However, the activities to be done are specific for one process group limiting the number of works to another process group. B2 sought the relationship between work actually done, and work done correctly. Due to some work need to be add, B3, B4, and B5 is connected to the rework. Reinforcing loop (R1) represents the relationship between the work to be done, the productivity, and staff. However, if staff are different from one process group to another, this model is limited. Last loop is R2, this loop relates R1 and B3 loop; in other words, rework to productivity and staff. To sum up, the rework cycle model is limited by adding work and changing staff in a process group. To solve these limitations, linking rework cycles is proposed to include PMI process group for project time span.

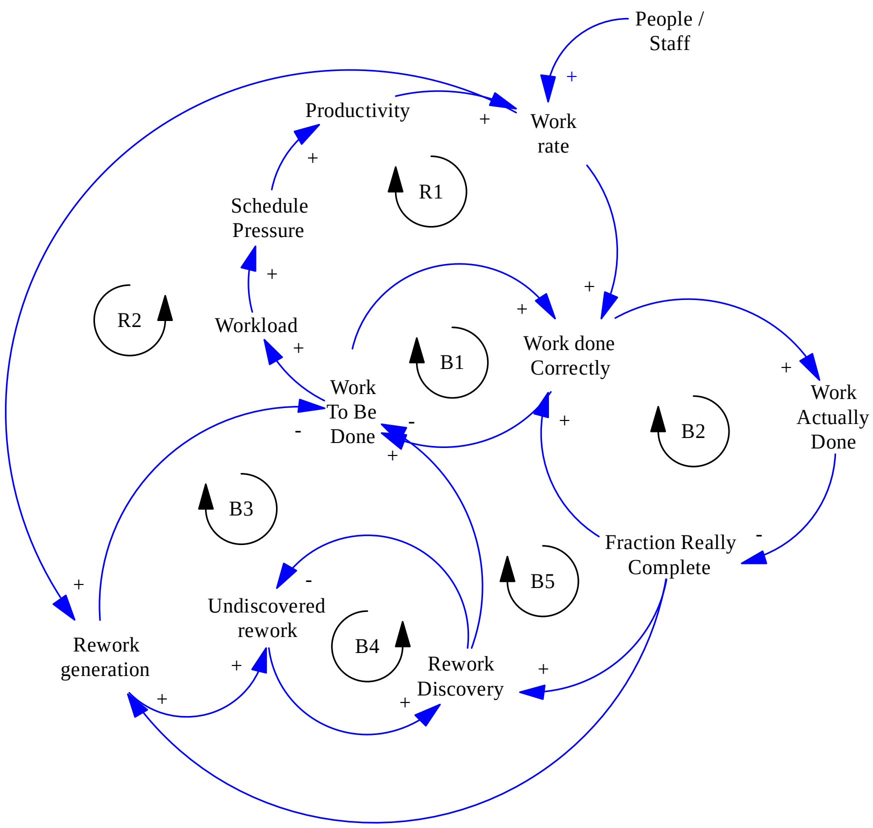


Figure 7. Causal loop diagram for the rework cycle model.

Linking rework cycles by using the process groups sets up the project effectively, as shown in Figure 8. Each process group was represented by a rework cycle. The idea of using a rework cycle for each process group was due to the use of different staff, activities, costs and duration within each process group. Using detailed data for each process group represented a better approach for the project forecast span simulation, where the interaction of the phases (in this case the process groups) simulates a better approximation of the project performance based on the triple constraint. Focusing on just carrying out the work (PMBOK, 2017), deployment (APM, 2019), or building (Morris and Geraldi, 2011) from the project life cycle is not sufficient to have a representation of when the project is duly completed.

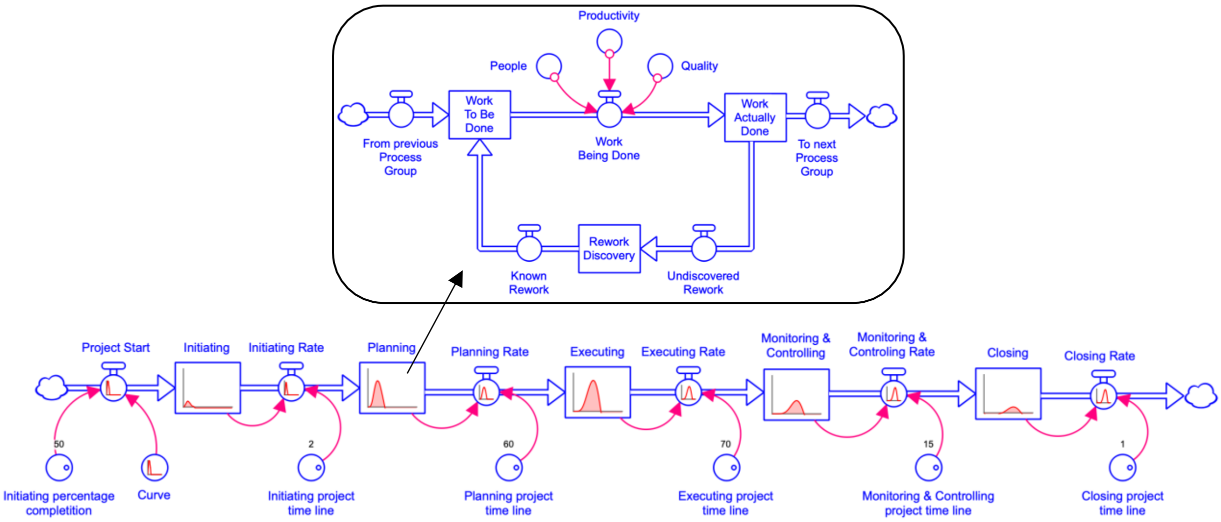


Figure 8. General SFD structure of linking multiple rework cycles.

PM simulation has been used to contribute towards and improve project performance modelling with one rework cycle SD model to simulate the entire project (Cooper *et al.*, 2002; Cui *et al.*, 2010; Godlewski *et al.*, 2012; Lyneis *et al.*, 2001; Lyneis and Ford, 2007; van Oorschot, Sengupta, *et al.*, 2018; Ozcan-Deniz and Zhu, 2016; Yan *et al.*, 2019). Figure 9 shows the interaction of linking the rework cycles to simulate the entire project. It should be noted that simulating only the executing process group supresses the effects of other process groups and this impact the project over time.

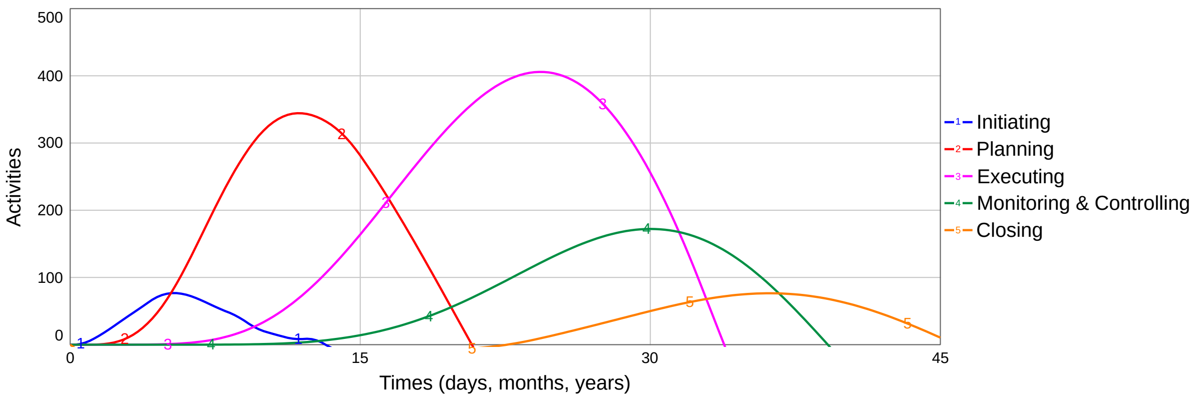


Figure 9. Simulation results by linking multiple rework cycles.

Advantages and limitations of using system dynamics modelling for project management

This research identifies advantages and limitations of using SD modelling for PM as shown in Table 5.

Table 5. Advantages and limitations of using system dynamics modelling for project management.

Advantages	**Limitations**
Understand project behaviour and complex project.	Lack of accuracy
Conceptualisation and formulation of project problem	Need to use tests for confidence in the model
Forecast and visualize behaviour at long term	SD modelling requires expertise
Capable of simulate "what happen if …" scenarios	Time-consuming for SD model generation

Directions for system dynamics modelling simulation in project management

Climate change (an external challenge) will affect the project discipline (links with open systems theory). Moreover, it may also impact SD modelling with the PM discipline. This research identifies four distinctive directions that may assist PM to achieve both project management success (*e.g.*, cost, time, and quality) and project success (*e.g.*, value and benefits).

First direction suggests the integration of PM with sustainability and Innovation (*e.g.*, interdisciplinary thought), which links respectively with project front-ending and back-ending. Moreover, to extend project back-ending, which integrates the systems impact concept (linked with sustainable project success).

Second direction advocates qualitative systems modelling (*e.g.*, CLDs as a soft methodology) for project decision-making. This is the development of simple (structural) dynamic hypothesis for future projects, which offer explanations (mental models (Senge, 2006)) for long range thinking and planning.

Third direction asserts the use of quantitative SD modelling (*e.g.*, SFDs as a hard systems methodology) for exploring sustainable project success. This enables long range environmental evaluation of aspects such as carbon dioxide (CO_2) emissions produced by projects.

Fourth direction suggests transdisciplinary thought which is guided by ideas associated with the Systems Movement. Developing project management SD models that utilises aspects of models from different disciplines (*e.g.*, Innovation and Sustainability), which may reduce the possibility of bounded rationality (Morecroft, 1983; Simon, 1990) in project decision-making.

CONCLUSIONS AND FUTURE WORK

The rework cycle SD model (Cooper, 1980), as fundamental structure, has been applied to assess PM by using CLD (*e.g.*, qualitative) and SFD (*e.g.*, quantitative). However, these structure focus on project delivery. Hence, this paper has aimed that linking rework cycles represents a better approach to forecast project behaviour over time. The simulation shows similarities to the PMI process group (PMBOK, 2017) which can reduce costs, monitor schedule overruns, and use for project decision-making.

Linking rework cycles identified key elements of PM simulation. The amount of rework cycles depends on the phases or process groups used to develop the project. If the staff, activities, or delays changes within a phase or process group, it is recommended to assign another rework cycle. As a result of linking rework cycles, the simulation will be a better approach to the reality. The hypothesis presented satisfied the statement if work to be done increases, then work done correctly increases above what it would have been.

Using SD modelling has advantages for PM. For instance, CLDs are used to understand project behaviour and conceptualisation of project problem. Meanwhile, SFDs are used to understand complex systems, formulate project problem, and simulate scenarios. Soft and hard variables are used in SD modelling for forecast and visualize project behaviour at long term.

This research offers four future project management directions using the SD technique and informed by Systems Movement thought: 1) Project Management modelling becoming more interdisciplinary and to integrated with innovation and sustainability; 2) Qualitative SD modelling (CLDs as a soft methodology) for front-ending project decision-making; 3) SD (quantitative) models (SFDs as hard systems methodology) for environmental long term impact evaluation of sustainable project success; 4) transdisciplinary thinking for quantitative SD modelling which is guided by the Systems Movement ideas (Checkland, 1976) and bounded rationality theory (Morecroft, 1983; Simon, 1990).

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