**Project Portfolio Implementation under Uncertainty and Interdependencies: A Simulation Study of Behavioral Responses**

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**Abstract:** Even though systems thinking has been highlighted in portfolio management theory, independent project control logic still dominates its implementation process. This paper constructs a system dynamics model for portfolio monitoring and control. Considering the on-going portfolio as a complex social system, the impacts of project interdependencies () on portfolio decision-making are investigated under a behavioral paradigm. Our findings indicate the remedial actions, affected by behavioral factors like planning fallacy and ‘Pet project’ effects, may generate escalation of commitment under specific levels of uncertainty and interdependencies. Thus, portfolio coordination decisions should be made from a strategic perspective with the consideration of complexities embedded in the system and behavioral responses from portfolio managers.

**Key Words:** System dynamics; behavioral OR; project portfolio; uncertainty.

**1 Introduction**

In the multi-project context, most organizations undertake Project portfolio management (*PPM*) to improve the project investment efficiency and realize value (PMI, 2017). As portfolios are intrinsically dynamic and exposed to the ever-changing environment, uncertainties regarding projects, inter-project issues and organizational changes induce disruptions and even failures on the achievement of goals for projects portfolios (Petit & Hobbs, 2010). While project control activities have been widely applied for decades, however, limited evidence shows how to resolve issues originated at the portfolio level continuously (Petit, 2012). Empirical research indicates that only half of the organizations using *PPM* regularly track the portfolio benefits (De Reyck et al., 2005; KPMG, 2017). Even if the benefits are evaluated, managers seem not to perform well in coordinating project portfolios (Sobtsenko & Tararyko, 2009) because they often lack a broad overview of the multiple projects and their managerial decisions (e.g. resource re-allocation and project re-prioritization) are made in an isolated way and fail to improve the portfolio performance (Blichfeldt,2008). As such, a strategic portfolio implementation model to facilitate systemic decision-making is in urgent need for portfolio success (Kopmann et al., 2015).

Portfolio implementation is more challenging than scaling-up the implementation of individual projects (Repenning, 2000). As internal and external factors (e.g. market development, technological turbulence, and resource deficiencies) prevail generating disruptions on projects (Petit, 2012; Voss & Kock, 2013), their portfolio-level impacts vary because the existence of complex project interdependencies (*PIs*). On the one hand, synergies that add benefits to the portfolio arise from the sharing of resources and knowledge between projects (Daniel & Daniel, 2018). On the other hand, projects compete for scarce resources to improve their investment in order to achieve the project’s objectives (Chao & Kavadias, 2008). These *PIs* form multiple feedback mechanisms so deviations in one project can be compensated or diffused, affecting the rest of the portfolio (Williams et al., 2003). Likewise, as project and portfolio managers are responsible for the implementation process, including reporting projects’ deviations and evaluating different remedial action proposals, the heuristics and behavioral biases can affect their decisions departing from a rational and optimal management of the project (Martinsuo, 2013).

Therefore, the projects’ dynamics, their complex interdependencies and the interplay between behavioral choices underpin the portfolio implementation system and, consequently, a separate analysis of each aspect may lose the strategic perspective to achieve the goals for the project portfolio (Lechler & Thomas, 2015). System Dynamics Modeling is a suitable method for its advantages in visualizing portfolio structure and behaviors, observing the consequences of external events and rehearsing the managerial actions taken to mitigate the deviations. It does not replace portfolio optimization models or project control techniques discussed in other Operational Research literature but it complements them by transparently formulating the complex portfolio implementation system from the strategic and behavioral perspectives (Rodrigues & Bowers, 1996a; Rodrigues, 2000). Moreover, research has already introduced System Dynamics to project management (e.g. Eden et al., 2000; Wang et al., 2017; Williams et al., 1995 ) but few models related to the management of project portfolios have been constructed (Repenning, 2000).

In the subsequent sections, a System Dynamics model (Sterman, 2000) is proposed to integrate the interactive effects of uncertainties and complexities and to identify the adequate responses of portfolio managers to these effects. With the goal to maximize the overall portfolio benefits (Serra and Kunc, 2014), this research looks beyond the ‘hard’ and isolated project operational data and focuses on a wide scope of complexities regarding project interdependencies and behavioral biases. It not only contributes to the *PPM* practice by providing a decision support system for strategic portfolio implementation but also offers a novel application of behavioral OR in project management by modelling behaviors in a multi-project context.

Section 2 illustrates the theoretical background, with discussions of the research framework and complexities in the portfolio implementation process. In Section 3, a System Dynamics model is constructed and the variables involved are explained. Section 4 presents the experimental results, describing the interactive effects of uncertainties and project interdependencies, the selection of remedial actions, and the influences of behavioral responses, followed by the discussions in Section 5 and conclusions in Section 6.

**2 Theoretical Background**

**2.1 Hierarchical Framework for Portfolio Implementation**

For a better understanding of the system, we firstly present a portfolio implementation framework (see Figure 1). Portfolio managers are responsible for transforming the portfolio strategy into multiple goals for different projects and allocate the resources accordingly so the value generated by each project can support the realization of the benefits at portfolio-level (Chiang & Nunez 2013). However, the existence of uncertainties and disruptions implies the need for monitoring& control processes (follow the bold lines).



 **Figure 1 Hierarchical framework of portfolio implementation (adapted from Loch & Kavadias (2002); Schultz et al. (1987) and Wang et al. (2017))**

For example, we take Project A to illustrate the relevant project-level activities and project-portfolio interactions.

***The project level*** concentrates on operational activities to meet the project goals (Wang et al., 2017). When uncertainties unfold and induce a deviation between the project performance (realized value) and its strategic goals (expected value), the deviation is monitored and reported to portfolio managers periodically, and decisions are made to define the degree of remedial actions (i.e. adjustment of investment) required to mitigate the deviation.

***The portfolio level*** identifies the synergetic effects among projects and makes/adjusts funding decisions to maximize the overall benefits. Portfolio managers often make outcome-based decisions using operational information (Aritua et al., 2009): they are informed about the project performance deviation (step 1), make decisions on how to re-allocate investments (step 2), and then take remedial actions to adjust the project performance (step 3). A critical issue at this level is the impact of project interdependencies since changes in one project can affect the performance of others.

This template is suitable for most organizations according to our discussions with experienced PMOs. Nevertheless, since we have the ambition to provide a general framework that can be easily adapted to different portfolio contexts; we ignore interventions that can alter the characteristics of the system. For example, we focused on the uncertainties at project level that can be solved by adjusting resources and not re-organizing the overall portfolio. Additionally, we set the remedial actions as different investment policies, e.g. more budget, yet in reality these actions can also involve the changes regarding staff, technology, materials, etc., which may cause side-effects, such as increases in productivity but also further disruptions (Howick, 2003). Another potential change in the characteristics is the impact of the organizations’ culture and rules on the flows of information between hierarchies. Finally, in some situations, the value generated by projects is also reinvested to the portfolio generating a change in the available resources (Petit, 2012; Jafarzadeh et al., 2015). These simplifications have two implications. On the one hand, they can help to concentrate on the main problems such as observing the portfolio behavior and defining the adequate managerial decisions. On the other hand, they reduce the complexity existing in real cases and their idiosyncratic issues.

The dynamism and complexities involved are discussed subsequently to clarify the research scope.

**2.2 Uncertainties and the Portfolio Implementation Process**

Uncertainties are emphasized in project portfolio studies to represent the changes and developments whose outcomes and probabilities are not known (Korhonen et al., 2014). The sources of portfolio uncertainties have been traced back to individual projects (Olsson, 2008; Petit & Hobbs, 2010), organizational complexity (Engwall & Jerbrant, 2003; Petit, 2012), and business environment (Voss & Kock, 2013; Petit, 2012). Please see Martinsuo et al. (2014) for a systematic review. Some research suggest managing or mitigating uncertainties through responsive actions that can continually monitor and capture the dynamic information (Pedersen& Nielsen, 2011). Petit (2012) applies a dynamic capabilities framework to portfolio implementation and suggests using sense-making to grasp the impacts of uncertainties and adjust the portfolio accordingly. Korhonen et al. (2014) argue that, by providing information about the uncertain situations, management control systems can help to appease uncertainties but the integration of individual project changes to the portfolio level has not been well-studied.

This research concentrates on how project uncertainties affect the portfolio behavior in the implementation system. Disruptions&Delays (*DD*), proposed by a collection of project litigation papers (Howick, 2003; Howick & Eden, 2001; Williams et al., 2003), is the concept employed to indicate the tactical impact of uncertainties on project implementation: cost and schedule overruns, missed opportunities and reduced performances (Howick & Eden, 2004; Wang et al., 2017). When faced with *DD*, increasing the available resources to remove delays is one of the key remedial actions in conventional project management practices (Lyneis & Ford, 2007).

The portfolio-level resolutions to cope with *DD* mainly focus on priority setting and resource re-allocation. Literature suggests that the portfolio decision-makers have the flexibility to ‘improve’ or ‘abandon’ projects (Loch & Kavadias, 2002). In most circumstances, requests for additional funds and scope change are frequently made from project managers to portfolio managers (Petit, 2012). Engwall & Jerbrant (2003) describe that, in practice, the investment is normally re-distributed from low-prioritized, or smoothly going, projects to high-prioritized projects or projects in urgent need of funds. However, few analytical tools can help to verify the reasonability and validity of these decisions.

**2.3 Project Interdependencies at the Portfolio Level**

*PIs* originate from technological leverage, knowledge sharing and market dependencies (Verma & Sinha, 2002). The importance of *PIs* in portfolio decision-making has been highlighted by a number of researchers, e.g. Aritua et al. (2009). Sanchez (2017) emphasizes that portfolios, as complex adaptive systems, cannot be fully known without understanding the interdependencies. From the strategic point of view, this research considers two typical typologies of *PIs*: Resource Competition (*RC*) and Synergetic Effects (*SE*) (Repenning, 2000). Normally *RC* can constrain the generation of value during the implementation of multiple projects while *SE* increases the value realized in portfolios.

***Resource Competition (RC).***Projects often share a common resource pool, e.g. specialized technical staff, in the portfolio (Loch & Kavadias, 2002). As the resources in an organization are often scarce, e.g. 73% of organizations report lacking enough resource capacity for supporting projects (Planview, 2017), the implementation of one project may take resources away from other projects if they share similar resources, e.g. resource dependency (Verma &Sinha, 2002). Empirical studies demonstrate that competition on priorities, resources and personnel are ‘continuous negations … on … the access to available resources’ (Engwall& Jerbrant, 2003).

***Synergetic Effects (SE).***The synergetic effects arise when the performance of one project relates to others (Repenning, 2000). When two projects complement each other, their implementation can lead to a positive synergy that adds additional benefits beyond the sum of the individual benefits. On the contrary, having two projects with significant functional overlap may lead to costs that surpass the combined benefit. This paper focuses on a positive synergy.

**2.4 Behavioral Factors in Portfolio Implementation**

The study of behavioral aspects in project management emerges from the discussion on project escalation issues, i.e. the tendency to continue investing in the failing projects (Pala et al., 2015; Pan & Pan, 2011). Several cognitive limitations have been proposed to explain its occurrence, such as self-justification theory, prospect theory and sunk-cost effects (Keil et al., 2000). Extending the research scope from projects to portfolios, heuristics and biases of portfolio managers can also occur when they decide upon remedial actions for multiple competing projects. Concerning the impact of heuristics and biases on portfolio level decisions before and during the implementation stage, this paper investigates the impacts of two common behavioral factors: planning fallacy and ‘Pet project’ effects (Beringer et al., 2013; Loch, 2000).

***Planning Fallacy (PF)*** demonstrates that managers forecast the outcomes based on delusional optimism, which may induce overestimation of benefits, and underestimation of costs, demand, risks, etc. (Kahneman& Tversky, 1979). Flyvbjerg (2008) argues that on average, the underestimation of costs in transportation infrastructure projects was found 44.7% for rail, 33.8% for bridges and tunnels, and 20.4% for roads, and one of the main psychological explanations for this inaccuracy is planning fallacy. As the total budget serves as a key variable to determine the portfolio implementation behavior, the direct impact of *PF* on its estimation, i.e. a shortage of the overall available budget, is one of the key elements of our study.

 ***‘Pet project’ Effects (PE)***refers to the fact that portfolio managers hold on to their personally preferred projects regardless of the execution performances (Beringer et al., 2013). Blichfeldt and Eskerod (2008) suggest that *PE* influences the resource allocation system and has detrimental impacts on portfolios. As priorities are often set to individual projects based on their estimations, there may be a need for changing priorities during the implementation of a project portfolio (Childs& Triantis, 1999). Nevertheless, due to personal interests or social-political issues, the advocacy of project managers for their ‘pet projects’ can restrict the adjustments on investment and priorities or reduce the adjustments so they become insufficient (Beringer et al., 2013).

**3 System Dynamics Model Development**

Following the theoretical framework, a stylized model of a two-project portfolio is constructed on the basis of well-established System Dynamics models related with project management such as Ford et al. (2007), Son & Rojas (2011) and Wang et al. (2017). Different from case-based models, stylized models can offer the possibility of experimenting with multiple situations, which helps to formulate generalizable structures rather than focusing on regularities of a specific case (Brenner and Werker, 2007; Kunc & Morecroft, 2007). While the two projects can represent the basic behavior of a portfolio, this model can be extended to multiple projects by connecting multiple projects through key interdependencies and formulating operating policies that allocate the resources to each project.

In real cases, the portfolio implementation system may overlap with a series of decision-making processes or other project portfolio systems within the business, which increase the degree of uncertainty and complexity (Cooper et al., 1997). Thus, more constraints and assumptions should be considered and the system and variables involved require further adjustment. For instance, the value creation index (*VCI*) is assumed as an external variable in our model, nevertheless, it can be influenced by remedial actions causing further Disruptions&Delays (Howick, 2003); or, sometimes, remedial actions can improve *VCI* forming different feedback loops, e.g. higher *VCI* reduces the need to invest more resources as the efficiency of the project is higher. Moreover, the *VCI* function can also change due to the environment turbulence (Loch& Kavadias, 2002). The stock and flow diagram for our stylized model is presented in Figure 2.



**Figure 2 The system dynamics model of portfolio implementation**

As shown in Figure 2, two self-organized project sub-systems (Project A and Project B) are coordinated by a centralized investment adjustment process (Aritua et al., 2009). The balanced feedback loops B1 and B2 dominate each sub-system respectively: If remedial actions are taken to increase the project’s investment priority, its realized value will increase, which mitigates the deviation and then decreases the corresponding investment priority (Lyneis & Ford, 2007; Schultz et al., 1987). Synergetic effects (*SE*) connect the two projects through a reinforcing feedback loop R3 (follow the bold lines). When *SE* increase, the value creation of Project A increases, which in turn decreases its deviation from the expected value and, thus, the investment rate of Project A declines. Since the total budget is limited, resources for Project B increase correspondingly at the expense of resources for Project A (Loch& Kavadias, 2002). Another situation that may occur is the organization reserves the budget for one specific project, then no resource competition exists in the portfolio. This situation is explored with the ‘Pet project’ effect in Section 4.3.

The total value creation, i.e. the value of Project A and B together, involves the impact of all three feedback loops so it is difficult to estimate intuitively (Sterman, 2000). To isolate the impacts of uncertainties, interdependencies and behavioral factors, the two projects are set of the same size and contribute to the same strategic goal, of which Project A is the control project free from uncertainties and project B is assumed to be initially preferred, e.g. the ‘Pet project’, but suffering from *DD*. The variables for the project sub-system and portfolio-level links will be described in the following section and the corresponding equations are presented in the Appendix.

**3.1 Project Implementation Sub-system**

We take Project A (feedback loop B1) as an example since the two projects share the same structure. When implementing projects, an expectation for the project development in each period,, is set and accumulates into the Expected Value. As uncertainties cause  and in turn reduce the work progression, the value yield for the project cannot match , thus it creates the deviation. The requests for additional investment are reported to the portfolio manager, who will adjust the investment priority ,i.e. an index determining the investment of projects, and improve the investment. The value creation productivity of the investment is denoted by Value Creation Index ().

**3.2 Portfolio-Level Links**

The portfolio is constrained by total budget ** and the goal is to maximize the overall strategic benefits *.* The implementation of Project B facilitates the value creation of Project A through *SE*, e.g. two marketing projects where one project creates a brand (project B) and another project is for the advertising campaign (project A), so the brand effects created by Project B improves the value creation efficiency of Project A, and if the investment in Project B expands, the synergetic effects on project A will be more obvious. The rise of  decreases its deviation and, thus, the investment rate of Project A declines. The portfolio manager takes remedial actions  to adjust the investment priorities. In our experiments, if only  occurs and induces, we will test if the main  is to decide whether or not to increase.In other words, our model focuses on the interrelationships that are responsible for overrun and overspend, which are the critical advantage of System Dynamics models in project management (Rodrigues & Bowers, 1996b).

**4 Experimental Results**

We investigate how portfolio managers should react to uncertainties with the consideration of interdependencies and behavioral factors using System Dynamics modeling software Vensim DSS. The time horizon for the implementation of the two projects is 100 months and it is similar for both projects that run in parallel. A comprehensive set of plausible parameters have been tested to present the results of the model and extreme conditions have been tested. Moreover, the experimental results are presented comparing with an Equilibrium situation where the portfolio is exempt from any uncertainty or complexity.

**4.1 The Interactive Effects of *DD* and *SE***

This section firstly explores how  and  influence the portfolio value creation without specific managerial interventions. The interactive effects of  and are investigated by Monte Carlo simulations using a range of values (in [0.5%, 1.5%], and in [0, 1]). In Figure 3, -axis represents the value of,-axis represents the level, and -axis represents the deviation of with respect to the equilibrium (in percentage). A positive value at -axis denotes an increase of the portfolio value, and vice versa. We can see that with constrained resources, the increase of  generally generates an uptrend of while a higher level of uncertainties may decrease the value. Their interactive effects, however, makes the landscape complex and difficult to estimate.



**Figure 3 The interactive effects of *DD* and *SE***

**4.2 Managerial Interventions and the Influences of Project Interdependencies**

**4.2.1 Remedial Actions for Portfolio Implementation**

When the projects underperform, adding additional investment to the troubled projects is the common policy to bring them ‘back on track’. Literature suggests that project managers use a basic heuristic of taking remedial actions in proportion with the project deviation (Lyneis & Ford, 2007; Wang et al., 2017). In response to the request for additional investment from project B, the portfolio managers have two choices to prevent the portfolio from failing:

***No Remedial Actions (NRA).*** No remedial actions are taken.

***Taking Remedial Actions (RA).*** Remedial actions are taken for project B.

If resources are sufficient, remedial actions can increase the portfolio benefits by improving the each individual project’s benefits. However, resources are always limited (Engwall & Jerbrant, 2003), thus improving one project’s use of resources, or investments, will reduce the available investment for the others if the resources are specifically partitioned. In other words, resource competition can easily occur between Project A and Project B so we experiment with a wide range of data in order to investigate how SE affects the decisions.

**4.2.2 Influences of *SE* on Remedial Action decision-making**

is set as normal distribution following the previous literature, e.g. Son& Rojas (2011) and Wang et al. (2017). Under certain, the decision on remedial actions varies according to differentlevels. Comparing the portfolio value with and without RA, Table 2 shows that doing nothing would be a good choice without synergetic effects but the situation is different when exceeds a certain level. For example, when  affects the advance of the project significantly, e.g. a variation of 50%, and is high, the value creation for project A increases substantially, the total value for the project portfolio generated by adding investment to project B is profitable. The existence of alters portfolio implementation decisions.

The above results demonstrate that the traditional project control logic is not fit for portfolio implementation as it moves resources towards ‘troubled’ projects, instead of the strategically important ones. We suggest the relative strategic importance, dynamically evaluated by strategic return on investment (), should be taken into consideration as a driver of the operating policy to adjust resources. We define as the ratio between the net value created and cost of investment resulting from both the value creation process and synergetic effects, e.g. at the time, theof Project B can be calculated by the function. After the impact of, the value created by per unit investment of Project B () is lower than that of Project A, thus the flow of investment to Project B actually reduces the value creation efficiency. Meanwhile, can compensate the losses and increase. As  is a real-time variable determined by both the project’s realized benefits and non-linear synergetic benefits, tracking its exact value means modelling the projects in much detail, which is outside the scope of this paper. Our proposed system dynamics model can integrate the effects of and present the overall portfolio value from the strategic perspective, which facilitates the policies driving remedial actions.

**Table 2 The influence of SI on RA decision-making**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  ***DD(B)******SI******Level*** | ***DD(B)*** | ***DD(B)*** | ***DD(B)*** | ***DD(B)*** | ***DD(B)*** |
| **No *SI*** | NRA | NRA | NRA | NRA | NRA |
| ***SI***  | RA | ,NRA,RA  | ,NRA,RA | ,NRA ,RA | NRA |

\* NRA denotes ‘No remedial actions’, and RA denotes ‘Taking remedial actions’.

\*\* The values used have been tested using sensitivity analysis.

**4.3 Influences of Behavioral Factors on Portfolio Implementation**

We run experiments with the model to investigate how behavioral factors in remedial actions affect the portfolio implementation results with different combinations of  and  levels (the value of each level is presented in the Appendix). Since is often underestimated, a behavioral bias called planning fallacy, it induces competition for resources and further triggering fights for setting the priorities of projects, another bias called ‘Pet Project’ Effect. As the two behavioral biases are interwoven, their impacts are discussed together.

When a project underperforms, except for business-as-usual () and taking remedial actions (), switching the implementation priorities () is the usual choice (Childs & Triantis, 1999). In our experiment, means periodically allocating investment to guarantee the success of Project A. The previous Section 4.2 has already embodied the effects of planning fallacy and ‘Pet Project’ Effect: the lack of additional investment is induced by the underestimation of risks, and the business-as-usual policy allows for sufficient investment to Project A. We also set other experiments: is only 70% and 50% with respect to the equilibrium level. Table 3 shows the deviation gap between and with respect to the Equilibrium (in percentage) to demonstrate the impacts of ‘Pet project’ effect. We can see that briefly more severe planning fallacy bias induces higher deviation gap. The losses can be almost 20% from the benchmark (e.g. in the 3rd experiment when ). In some occasions, changing the priority is not reasonable, e.g. in the 4th, 6th and 7th experiment, because switching priority induces more losses.

**Table 3 The deviation gap between *RA* and *SP* (% with regard to Equilibrium)**

|  |  |  |  |
| --- | --- | --- | --- |
|  ***TB*** ***DD(B), SI*** | ***TB*=100%** | ***TB*=70%** | ***TB*=50%** |
|  High, High | 2.01% | 6.21% | 10.39% |
| High, Medium | 3.85% | 9.39% | 14.08% |
| High, Low | 5.70% | 12.57% | 17.77% |
| Medium, High | -2.62% | -3.85% | -2.57% |
| Medium, Medium | -0.54% | 0.79% | 3.13% |
| Medium, Low | 1.56% | 5.44% | 8.83% |
| Low, High | -3.95% | -11.58% | -14.01% |
| Low, Medium | -2.22% | -5.91% | -6.58% |
| Low, Low | -0.51% | -0.23% | 0.85% |

**5. Discussion**

**5.1 From ‘Project Control’ to ‘Portfolio Coordination’: the strategic perspective matters**

 Adding additional investment to underperforming projects is a common practice to bring them ‘back on track’ (Lyneis& Ford, 2007). However, when we simulate this process, counterintuitively, remedial actions may even induce more losses (see Table 2). The reason lies that the value generated by the ‘troubled’ project is not as much as that yield by the other projects in the portfolio. This result shows the erroneous belief in most *PPM* practice and literature that the portfolio goals cannot be fully satisfied by individual project management but requires a strategic perspective (Alexandre & Bower, 1996a, b; Engwall& Jerbrant, 2003; Serra& Kunc, 2015). Although a multitude of instructions have been made on how to strategically select and allocate resources to initiatives (Chiang& Nunez, 2013; Jafarzadeh et al., 2015; Chao& Kavadias, 2008), our research, as far as we know, is one of the pioneering works to support strategic portfolio implementation by providing an overview of the portfolio behavior. Moreover, we further define the portfolio coordination logic as re-allocating resources to the relatively important projects other than the ‘troubled’ ones. The strategic return on investment (*SROI*) index is proposed to present the complexities of calculating the projects’ contributions, thus a systemic model is highlighted for portfolio coordination to improve the overall strategic benefits.

**5.2 Incorporating project interdependencies at the implementation stage is vital for portfolio success**

Our preceding experiments investigate two typical project interdependenciesoccurring during the portfolio implementation process: resource competition and synergetic effects. The results demonstrate that considering the constraint of resource competition and uncertainties in the environment, synergetic effects may make the portfolio behavior complex to estimate (Figure 3) and alter the decisions on portfolio remedial actions (Table 2). As the previous literature indicates the dynamism and complexities surrounding portfolio implementation are far from being well-understood, and once the portfolio is constructed, project interdependencies are always put aside other than discussed in adjusting the resources for multiple on-going projects (Killen, 2013), our experiments demonstrate the significant role of project interdependencies in portfolio implementation. Moreover, our System Dynamics model also provides an analytical tool for managers to understand and model various project interdependencies on an ongoing basis.

**5.3 Project Portfolio Management should concentrate more on human factors**

The simulation study shows the losses caused by planning fallacy and pet project effects, which highlight the importance of contemplating the behavioral aspects involved in the portfolio implementation process. Some mitigation actions to reduce these behavioral biases, based on authors’ experiences, are to separate the responsibilities for project execution and portfolio governance and bring in third-party consultants to initiate and monitor the portfolio. Further discussions regarding the rewards and penalty policies and the construction of a transparent and collaborative team culture (Pederson& Nielson, 2011) that can influence the stakeholders’ behaviors are important. Some of these policies can be tested by modifying this model such as the impacts of reward criteria on portfolio implementation can be formulated and tested. Furthermore, the results provided by models similar to our model can reduce deviations generated by inconsistent decision-making processes as the consequences of different remedial actions can be directly compared. Although this paper just focuses on the portfolio-level behaviors, the impacts of project managers’ behavioral biases can also be studied through the use of simulation, which may reduce the escalation of commitment by providing a broad view of the overall portfolio (Pala et al., 2015).

**6. Conclusion**

Considering the uncertainties and complexities in the portfolio implementation process, a system dynamics model is proposed to illustrate how portfolio managers make resource adjustment decisions from a strategic and behavioral perspective. The contribution of our work is threefold: From the managerial side, this research provides a first step towards constructing an integrated decision support system for portfolio coordination, which improves *PPM* practice by transparently demonstrating how projects are connected in a portfolio, comparing possible alternatives and providing reasonable evidence for coordinating multiple projects. Moreover, it complements the *PPM* theory by emphasizing the strategic perspective of portfolio implementation, the importance of project interdependencies and the impacts of ‘pet project’ effects using experimental results. Last but not least, the introduction of SD into portfolio implementation also implies new opportunities for applying behavioral OR to facilitate problem-solving in multiple projects.

As discussed in Section 2 and Section 3, since this research mainly highlights the model’s generalizability, the details of specific cases are omitted. Further research will investigate the applications to empirical studies in specific contexts to adapt the model to contextual issues, for example running projects sequentially or with some overlaps over time instead of parallel. Furthermore, this paper just investigates the behavioral biases arising at the portfolio-level in a simplified way (e.g. the planning fallacy is modelled as the underestimation of the total budget, yet more implications regarding the benefits and risks can also be considered). More efforts can be done to study a wide scope of behaviors and the further involved organizational restrictions (e.g., prizes, penalties, collaborations) applying the behavioral OR methods.

**Conflict of interest**

The authors declare that there is no conflict of interests regarding the publication of this article.

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**Appendix**

**Table 1A Portfolio implementation variables and equations**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variables****(with dimensions)** | **Description of Variables** | **Symbols** | **Equations** | **References** |
| *Project-level variables* |
| Expected Value Creation Rate of A(dollar /month) | Expected value creation per period |  | , | Son&Rojas (2011);Wang et al. (2017) |
| Expected Value of A(dollar) | Accumulated expectations for value creation |  |  | Son&Rojas (2011);Wang et al. (2017) |
| Value Creation Rate of A(dollar/month) | The value created in each period by project implementation and synergetic benefits |   |  | Son&Rojas (2011);Wang et al. (2017) |
| Realized Value of A(dollar) | The accumulated value created by project implementation  |   |  | Son&Rojas (2011);Wang et al. (2017) |
| Deviation of A(dimensionless) | The discrepancy between and  |   |   | Son&Rojas (2011);Wang et al. (2017) |
| Perceived Deviation of A(dimensionless) | Deviation Perceived by the portfolio manager |   | $PD=SMOOTH($ | Son&Rojas (2011);Wang et al. (2017) |
| Budget Demand of A(dollar/month) | Original investment demand for each period |  | A constant value 50 | Wang et al. (2017) |
| Investment Priority of A(dimensionless) | An index showing the priority of A  |   | Determined by remedial action and  | Wang et al. (2017) |
| Investment Rate of A(dollar/month) | Available Investment for A in each period |  |   | Wang et al. (2017) |
| Total Cost of A(dollar) | The total consumed investment of Project A |  |   | Son&Rojas (2011);Wang et al. (2017) |
| Value Creation Index of A(dimensionless) | Amount of value created by per unit investment |   | A constant value of 0.5 | Loch& Kavadias (2002); Wang et al. (2017) |
| Value Creation Capacity of A(dollar) | The maximum value created by the available fund  |   |   | Wang et al. (2017) |
| Expected Work Progression of A(dimensionless) | Expected work to accomplish in each period |   | A constant value 1 | Wang et al. (2017) |

**Table 1A Portfolio implementation variables and equations(continued)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variables****(with dimensions)** | **Description of Variables** | **Symbols** | **Equations** | **References** |
| Disruptions& Delays of A (dimensionless) | Impact of uncertainties on work progression, modeled a random normal distribution |   | High Level=Medium Level=Low Level= | Son&Rojas (2011);Wang et al. (2017) |
| Work Progression (dimensionless) | Work accomplished in each period |   |  | Son&Rojas (2011);Wang et al. (2017) |
| *Portfolio-level variables* |
| Total Budget(dollar) | Investment Constraint for portfolio implementation |  | A constant value 10000 | Expert opinion |
| Total Value Creation (dollar) | Value realized by the portfolio |  |  | Loch& Kavadias (2002) |
| Remedial Action(dimensionless) | Adjustment Policies for the component projects |  | Determined by the portfolio manager | Lyneis& Ford (2007) |
| Synergetic Index(dimensionless) | The synergetic value created by per unit value of project B |   | A constant valueHigh Level =1.5%;Medium Level =1.0%;Low Level =0.5% | Expert Opinion |
| Synergetic Effects (dollar) | The synergetic value created by Project B to A |   |  | Loch& Kavadias (2002) |