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Realizing value from project implementation under uncertainty: An exploratory study using system dynamics☆

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Abstract

Project Implementation is not a trivial task even after careful planning and scheduling. One of the reasons is the existence of unexpected events at strategic and operational levels during the project execution process. This paper presents a system dynamics model of a project monitoring and control system. Embedded with both strategic and tactical uncertainties, the model experiments with typical remedial actions to disturbances during the implementation of a project under a behavioral paradigm. Simple proportional adjustment seems to work well under low levels of unexpected disturbances but prospect theory-based behavior works better under extreme situations. Our findings indicate over-reacting behavior, which is influenced by biases and reporting errors, can generate project escalation. Thus, thresholds for remedial actions should be implemented in project control and monitoring systems to avoid over-reacting behavior leading to escalation and waste of resources.

Keywords: System dynamics; Project management; Behavioral OR

1. Introduction

Organizations undertake projects as vital means to implement strategy and realize value (Chih and Zwikael, 2015). However, a great proportion of projects fail, e.g. in 2015 only 29% of software projects are successful, with 52% of the projects canceled and 19% failed to deliver the expected results (Dannis, 2015). One of the main reasons for this situation lies in today's rapidly changing environment. Uncertainties, which cannot be fully estimated and often involve 'unknown-unknown' events like evolving strategy, introduction of new technology and resource conflicts, have impact on project implementation and force the deviation of perceived value from expected goals. Thus even if organizations make great efforts to maintain accurate evaluation of the uncertainties and devise well-designed project plans, project plans never perform in the predicted way, and if the deviation grows, projects will fail. Under these circumstances, effective project implementation processes that consider dynamism under uncertainty should be explored.

The conventional project implementation methodologies follow a linear logic to bring projects 'back on track' with respect to the pre-determined operational plans (Hazır, 2014), whereas recent research suggest that the on-going project is an open system, with both its goals and implementation status evolving (Lee et al., 2006; Aritua et al., 2009). In the dynamic environment, projects have to continuously interact with their implementation context, adapting and evolving requirements

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throughout the system's lifetime to cope with uncertainties (Locatelli et al., 2014). Thus project implementation process should involve not only foresight, but also remedial actions in response to unexpected changes, requiring the combination of both proactive and reactive activities. Some research refer to this perspective as 'bounded planning' and 'interactive problem solving', and claim that the value of a project is not well-known in advance, but being defined and updated with uncertainty prevailing (Engwall, 2003; Ahern et al., 2014). Moreover, the non-linear interdependencies between different project components make the system more complex. These interdependencies may form multiple feedback mechanisms, with which even small variation in individual components may diffuse into serious crisis on the overall project (Williams et al., 2003). Thus without looking into the comprehensive system structure, the effects of both uncertainties and remedial actions on project outcomes are difficult to understand.

Since human activities dominate the project implementation processes, including perceiving and reporting the changes, evaluating the remedial action proposals and making reactive decisions, we should look beyond the 'hard' operational data and focus more on 'soft' factors like stakeholders' perceptions and behavioral biases (e.g. reporting errors and escalation of commitment) (Meyer, 2014). System dynamics (SD) modeling is applicable here, which can combine both 'soft' and 'hard' paradigms in the following way (Pidd, 2009; Rodrigues, 2000): Firstly, when formulating the SD model, multiple stakeholders have to coordinate on the central structure of the system (main components, links and feedback loops) and then draw up the causal diagram. This procedure promotes the organizational learning and provides insights into project implementation. The second procedure is the computer-based simulation, which provides explicit suggestions such as what the possible remedial actions would bring, and when and how to intervene. At this procedure, the SD model can use operational data monitored by conventional methods (Lee et al., 2006).

Based on the above analysis, we propose a SD model to analyze, from a strategic perspective, the management of organizational projects where project goals can evolve in a dynamic and uncertain environment and the remedial actions adopted by managers are influenced by behavioral biases. Our approach is based on a concept of projects as open systems, where project managers intend to maintain equilibrium between the value expected to be created and the value that is being created. Thus, our research aim is to identify what project managers' responses are more adequate given the impact of uncertainties on project implementation.

A theoretical background is illustrated in Section 2, with discussions of the research framework and dynamism of project implementation processes. In Section 3, a system dynamics model that incorporates both strategic and tactical uncertainty effects is constructed. Experiments are carried under diverse situations in Section 4 including the impact of remedial actions and disturbances from reporting errors. In Section 5, two unanticipated crises on a project system are tested, followed by the discussion and conclusions sections.

2. Theoretical background

Project implementation system aims to maintain a dynamic match between strategy and operations (Serra and Kunc, 2015; Slevin and Pinto, 1987). At the strategic level, organizational strategy can be broken down to the individual project's major targets (Lee et al., 2006), which we call 'Expected Value' (e.g. expected productivity or expected function of products); while at the tactical level, the real advance or development of the project ('Realized Value') is achieved. Both Expected Value and Realized Value can be defined as a single target or evaluated by multiple performance indicators.

Uncertainties in the environment generate changes to the system. Strategic Change may arise at organizational level and then be interpreted as a variation in project's strategic targets. Meanwhile, the tactical uncertainty may cause disruptions and delays on project progress even without strategic changes. Thus, there may be situations where the strategic objective for the project cannot be achieved or the project is of little value to new strategic objectives. Remedial actions (i.e. adjustments to schedule priority or investment in additional funds or both) are required to mitigate the deviation (Loch and Kavadias, 2002). Thus the objective of this paper is to present a simulation study of behavioral remedial actions for on-going projects taken to minimize the deviation between Realized Value and Expected Value (see Fig. 1).

2.1. Uncertainty and its impact on project management

There are always unforeseen events, which cannot be conceived or analyzed before projects progress, and have vital effects. If some uncertainties are unknown, how can they ever be planned for? Thus a great deal of research calls for moving from conventional project risk management (PRM) to events that 'come out of the blue' (Petit, 2012; Ramasesh and Browning, 2014). Cleden (2012) clarifies two categories of project risk and uncertainty, of which the 'unfathomable uncertainty' that is ill-understood in probability and impact is the context considered in this paper. When we consider unfathomable uncertainty, events happening without warning require a backward thinking and a 'reactive' way, i.e. remedial actions, to help mitigate the impacts on the development of the project. Uncertainty manifests in two aspects: evolving goals and disruptions and delays (D&D).

2.1.1. Evolving goals

The strategic alignment of projects is always evaluated based on a static plan, with the assumption that the project goals are well-determined and unchangeable. However, this alignment seldom stays stable and 'even "perfect" alignment today would soon turn into misalignment'. The prevailing uncertainties and ambiguity may induce exogenous disruptions on or stakeholders' better understanding of the projects' strategic expectations. Research on project management demonstrated that on average 34% of project strategic priorities change during five years in NSW state (Young and Grant, 2015). Recent, Project Management Institute studies also found that Strategic Change causes the

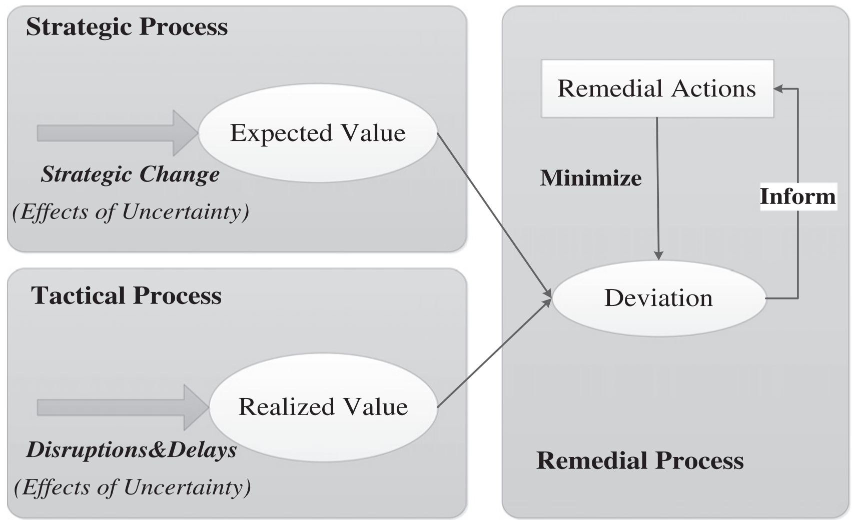

Fig. 1. Project implementation processes.

realignment of project portfolios (Serra and Kunc, 2015). If strategic changes are not considered, even if the project is executed well, outdated projects mean wasting resources without delivering the expected value.

2.1.2. Disruptions & delays

At the tactical level, the key issues are disruptions and delays (D&D) originated from unknown situations. The term D&D often appear together as influences on schedule and cost overruns. SD is commonly applied to demonstrate the interrelations that determine the project behavior, 'vicious cycle' of D&D, and the management response to project changes (Williams et al., 2003). In most circumstances, D&D arise from either a feedback phenomenon or exogenous events (Howick, 2003). SD models can contemplate external events, managerial actions taken to correct the impact of the events and the consequences of these actions (Howick, 2003). Thus, SD can provide a useful view to the conceptualization of projects as open systems. However, SD does not capture the detailed and operational level of project management such as in project scheduling models (Howick, 2003). Since SD and the traditional project management tools have different limitations, both of these techniques have been used alongside one another to analyze projects (Howick and Eden, 2004).

2.2. Dynamic adjustment on project management processes

Complex causal relationships are the main characteristic of project implementation processes and an important source for the dynamism observed in the project life (Roberts, 2007). The causal relationships in the project system form feedback loops, either reinforcing (positive feedback loop) or balancing (negative feedback loop) the changes. Considering the project implementation system, moving the project behavior towards the goal involves a negative feedback loop and the remedial action typically changes corresponding to the deviation size (Lyneis and Ford, 2007). The dynamic adjustment process is as follows (see Fig. 2): when uncertainties generate Strategic Change and Disruptions & Delays on the execution of a project, the Realized Value of a project (i.e. the level of advance and development) deviates from the Expected Value. The Deviation between both components is a signal for Remedial Actions to be taken. The Remedial Actions will improve the Realized Value and thus help to reduce the Deviation, mitigating the impacts of the unforeseen events. The cycle of monitoring the deviation, developing remedial actions and reevaluating iterates until the end of the project.

The changes arising from the open environment cause this adaptive behavior, which acts as the core feedback loop of the project implementation system. More interrelations or multiple feedback loops may also be learned in specific projects, examples see Abdel-Hamid (2011) and Howick (2003).

2.3. Remedial process

As described in Figs. 1 and 2, the remedial process comprises two components: 1) monitoring and control of deviations, and 2) remedial actions. Monitoring transmits the signal requesting remedial actions and remedial actions help to mitigate and control the deviation.

2.3.1. Monitoring and control of deviations

Crawford and Bryce (2003) investigate the monitoring and evaluation of project implementation in non-governmental organizations and claim that 'monitoring is the ongoing process of data capture and analysis for control purposes, while evaluation is a periodic (typically at mid-term and end-of-project) examination for the purpose of learning'. Our research aims at continuously capturing how well the actual implementation matches the evolving expectations and providing suggestions for in-time control activities between different evaluation stages. These activities often are more incremental than decisions made after evaluation (e.g. decisions on killing/adding projects at different stage-gate).

Some approaches have already been applied to mitigate the deviation, such as Critical Path Method (CPM), Program

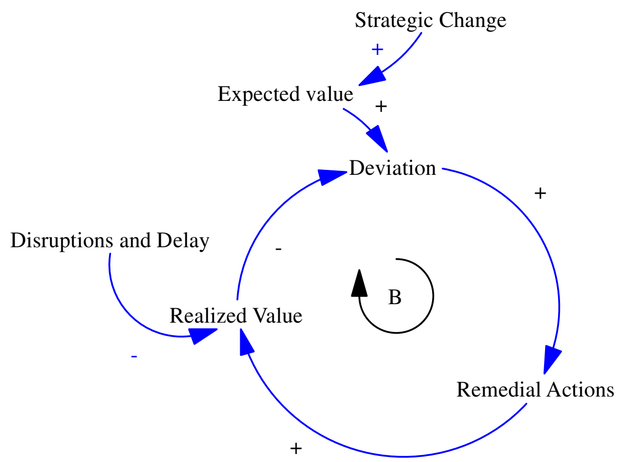

Fig. 2. Dynamic adjustment process of project implementation.

Evaluation and Review Technique (PERT), and Earned Value Method (EVM). These network-based tools, though widely adopted, are not fully applicable to the project implementation system. Their deficiencies comprise the narrow focus on specific operational aspects (cost, schedule and quality), inability to deal with non-linear interrelations and the static perspective to recover the projects to pre-determined baselines (Lee et al., 2006).

System dynamics (SD), which proves to be effective in analyzing and modeling complex and dynamic social systems (Zhang et al., 2014), is thus introduced to support project implementation. For example, Love et al. (2002) look into how unplanned disturbances impact the expected work progression and project management system in construction projects. They found that it is important to develop an ability to respond promptly to changes within the construction project. The applicability of SD manifests in three aspects (Rodrigues, 2000): (1) SD adopts a holistic and systemic perspective, thus the strategic achievements of projects can be analyzed with a comprehensive consideration of operational dimensions; (2) SD focuses on the dynamic interactions between different project components, hence, the overall impacts of changes (both from environmental disturbances and human reactions) can be observed considering various feedback effects embedding an ‘open system’ view of project implementation; (3) SD explicitly captures the subjective factors, and then human behaviors can be incorporated.

2.3.2. Remedial Actions

Organizations often have to modify the investment strategy and/or project execution to improve performance, which is called ‘Remedial Actions’ or ‘Corrective Measures’. Some work points to the role of remedial actions to adjust productivity or remove delays to bring projects back to the initial plans. For example, Lyneis and Ford (2007), who employ SD models, illustrate two types of project remedial actions as: easing performance targets, like slipping the milestone deadlines, reducing the scope of the project or increasing the budget; and/or increasing the available resources, like hiring more staff and work overtime (Lyneis and Ford, 2007).

There is an important set of the literature on project management that focuses on the behaviors of project managers, for a review see Keil et al. (2000). Son and Rojas (2010) evaluate the management of projects from the perspective of the individual attitudes existing in managers. They evaluate a project planning and control model aiming to minimize the deviation between forecasted productivity and perceived productivity when managers are affected by optimism bias (Son and Rojas, 2010). Meyer (2014) suggests three investment strategies when the expected returns are not achieved: escalation (invest more than originally planned), persistence (invest as originally planned) and terminate (withdraw the investment) (Meyer, 2014). The previous literature provides behavioral aspects of project managers’ responses to issues during projects, which is an area not considered specifically in SD modeling.

3. Model construction

System dynamics modeling has been employed to construct stylized models of dynamically complex phenomenon occurring in organizations, e.g. Repenning and Sterman (2002). Stylized models differ from case-based models in the level of complexity represented in the model, as they aim to look for generalizable structures rather than focusing on specific regularities of a specific case (Kunc and Morecroft, 2007). Stylized models offer the possibility of experimenting with multiple situations with the intention of extract either general patterns or special situations where complex behaviors may be observed.

3.1. Stylized model

According to the previous discussion, the project implementation system consists of three sub- systems: Goal sub-system (Strategic process), Project Implementation sub-system (Tactical process) and Investment sub-system (Resource Allocation process). As illustrated in Fig. 3, the output of Goal sub-system is Expected Value, which is defined during the project design and tries to align the project with the strategy of the firm but it can be modified accordingly if there is a change on strategy. Project Implementation sub-system includes the tactical activities to achieve the Realized Value of a project. Project Implementation consumes funds from the Investment sub-system. The deviation between the output of the Project Implementation sub-system and the Goal sub-system requires an Adjustment in the investment funds to narrow the existing gap, which is part of the remedial process. The three sub-systems dynamically interact with each other and affect the value realized in a project.

Uncertainties are modeled in two ways according to their frequency of occurrence and feature of impacts:

- **Continuous uncertainties**. Continuous uncertainties are disturbances to the implementation of a project, which are not significant enough to cease implementation, but they still require monitoring and control due to their long-term impacts. This kind of uncertainties is frequently part of any project implementation.

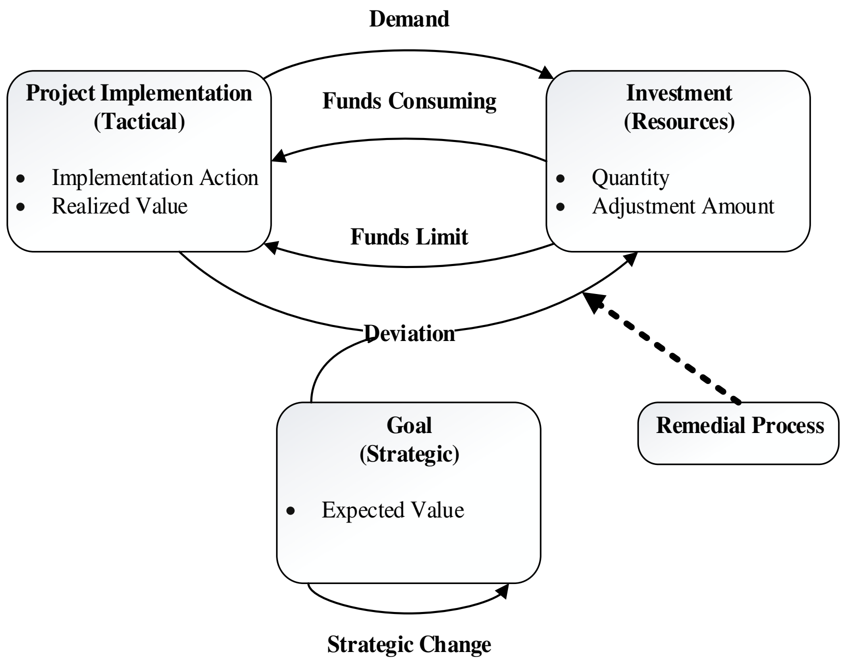

Fig. 3. Project implementation stylized system.

- **Unanticipated crises**. Unanticipated crises are originated by discrete seldom events but, once occurring, their impacts are felt substantially in a project. Their one-off and ambiguous nature makes these events difficult to define or prevent even though some researchers tried to clarify their main sources (Petit, 2012; Petit and Hobbs, 2010).

3.2. System dynamics model

A SD model was developed based on the stylized model shown in Fig. 4. This model evolved from well-established and validated SD models including those developed by Son and Rojas (2010), Ford and Sterman (1998) and Lyneis and Ford (2007). We represented the general function of project implementation, but this model should be structured with project stakeholders and additional feedback loops representing ripple effects may exist (e.g. when using overtime to improve the work progression, 'a fatigue cycle' may function (Sterman, 2000) for specific projects). The model is constructed and tested using Vensim DSS.

3.2.1. Goal sub-system

The goal sub-system fulfills the duty of transforming the strategic goals to the measurable project Expected Value. Project managers have an expectation for the project (Δ EV) in each period, e.g. when a new project is agreed, a plan is defined with the expectations about the development of the project for each month or quarter. These expectations accumulate over time into a total Expected Value (EV), which becomes the goal for the implementation sub-system to 'catch up'. However, companies may adjust their strategy, which affect the expected development of the project, so we translate these changes in expectations using the variable Strategic Change (SC) (Table 1).

3.2.2. Implementation sub-system

Realized Value (RV) accumulates the value yield by the project. We assume there is a certain productivity of the investments in a project due to the efficiency of the process, e.g. the amount of salaries paid to researchers developing a new product may not translate exactly as value if researchers are not efficient. Therefore, a Value Creation Index (VCI) is applied to transform each unit of funding into value. This is an innovative concept that has not been defined in the literature previously. Then, when real Work Progression (WP) can be less than expected due to the impact of Disruptions & Delays (D&D), which are independent from the efficiency of the project resources (Table 2).

3.2.3. Investment sub-system

When a remedial action is required, project funding increases since the project manager requires either accelerate the investment in the project to compensate for delays or require additional funding. We capture this action in the variable Investment Priority (IP). In some cases, the increase in funding can be compensated by additional budget as Expansion Rate (ER) but the Total Budget sets the constraint for project implementation (Table 3).

3.2.4. Remedial process

The performance of the project is measured by the Deviation (D) between the expected and realized values and further perceived by project managers (PD). Then project managers adopt Remedial Actions to modify the investment priority (changes in funding) and schedule priority (accelerating the rate of tasks), which separately improves/reduces the value creation capacity (funding) and accelerates/decelerates the work progression (Table 4).

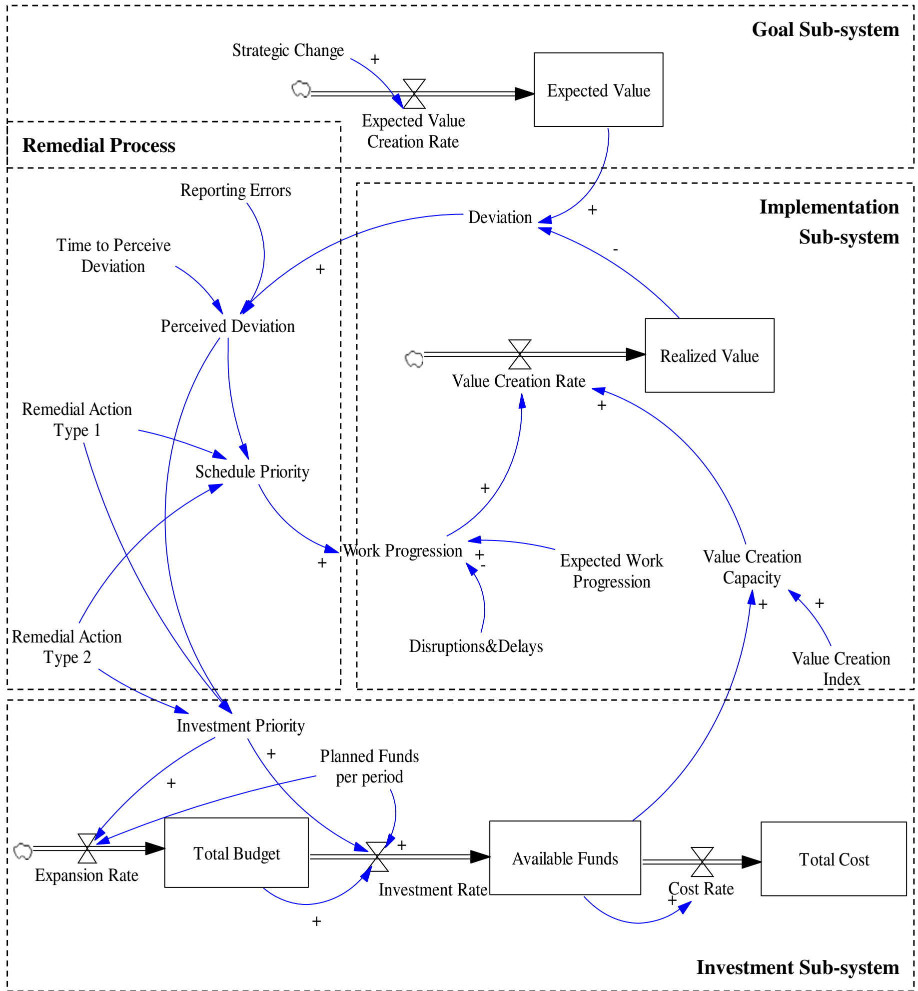

Fig. 4. Dynamic adjustment process of project implementation system.

4. Project implementation under continuous uncertainties

We investigate how project managers react to project implementation under continuous uncertainties. Firstly we evaluate the losses caused by uncertainties before identifying the role of remedial actions. Then a comparison is made in selecting remedial actions with regard to two behavioral decision making processes: Proportional adjustment (Lyneis and Ford, 2007) and prospect theory (Kahneman and Tversky, 1979; Keil et al., 2000). Finally, the impact of reporting errors on the remedial process is evaluated.

Table 1
Variables and equations for goal sub-system.

Variables	Description of variables	Names	Equations
Expected Value	The expected strategic targets for the project to achieve	EV	EV=INTEGRAL(ΔEV,20)
Expected Value Creation Rate	The expected development of project during each period	ΔEV	$\Delta EV = \Delta EV_0 + SC$, Here $\Delta EV_0 = 20$
Strategic Change	Changes to the expected value, can be positive or negative	SC	Positive: STEP (5, 20) Negative: STEP (−5, 20)

4.1. Project implementation value gap due to uncertainties

Assuming the total project duration is 100 months, we address the impact of uncertainties on strategic goals and operations respectively. For Strategic Change (SC), we illustrate two scenarios: positive SC and negative SC. D&D (DD), which is represented by a random normal distribution, is set with low level, medium level and high level. Note we just intend to provide a wide range of uncertainty levels to represent their impact, but, in practice, a low DD level may be within a project manager's tolerance thus no remedial actions are required and with a high DD level the project may require re-planning since the disruption is too high.

Fig. 5 shows the potential losses caused by uncertainties at a strategic level. For positive SC, the issue of *Unrealized Value* occurs due to the rise of expectations. The new Expected Value cannot be fully achieved since the work progression and investment are not accelerated correspondingly. The decline of Expected Value, on the contrary, induces a different type of

Table 2
Variables and equations for project implementation system.

Variables	Description of variables	Names	Equations
Realized Value	The real advance or development of the project	RV	RV = INTEGRAL(ΔRV, 0)
Value Creation	The real development of project during each period	ΔRV	ΔRV = VCC * WP
Value Creation Capacity	Maximum value created by the available funding	VCC	VCC = VCI * AF
Value Creation Index	The efficiency of each unit of funding	VCI	A constant value 0.5
Work Progression	Work accomplished in each period	WP	WP = (EWP − DD) * SP
Expected Work Progression	Expected work to accomplish in each period	EWP	A constant value 1
Disruptions & Delays	Impact of uncertainties on work progression, here is modeled a random normal distribution	DD	High: RANDOM NORMAL (0,1,0.7,0.3,0.5) Medium: RANDOM NORMAL (0,1,0.4,0.2,0.3) Low: RANDOM NORMAL (0,1,0.2,0.05,0.225)

Table 3
Variables and equations for investment system.

Variables	Description of variables	Names	Equations
Available Fund	Fund available for the project to consume in each period	AF	AF = INTEGRAL(IR − CR, 0)
Total Budget	Investment Constraint for project implementation	TB	A constant value 2800 or 6000
Investment Rate	Investment for project in each period	IR	IR = NF * IP
Normal Fund per period	Funds for project in each period according to the initial plan	NF	A constant value 40
Cost Rate	Funds consumed in each period	CR	CR = AF
Expansion Rate	Expansion for total funds in each time period	ER	ER = CR*(IP − 1)
Total Cost	Overall consumed funds	TC	TC = INTEGRAL(CR, 0)

Table 4
Variables and equations for remedial process.

Variables	Description of variables	Names	Equations
Deviation	The gap between expected value and realized value. The smaller the deviation, the better project performs	D	D = 1 − RV/EV
Perceived Deviation	The deviation information perceived by decision maker, which determines the remedial actions	PD	PD = SMOOTH(D + RE, TP)
Time to Perceive Deviation	Time delay for perceiving deviation information	TP	A constant value
Reporting Errors	Errors exist in reporting the deviation	RE	RANDOM NORMAL (−1,1, mean, 0.4, seed)
Schedule Priority	Effort to adjust the work progression	SP	Determined by Remedial action type and Perceived Deviation
Investment Priority	Effort to adjust the investment amount	IP	Determined by Remedial action type and Perceived Deviation

loss related with *Excessive Value*. When the project is not required to achieve the original goals, resources keeps being invested in the project even though it will not contribute to the organization. If DD is large, the value yield by the project cannot meet the expectations in each period leading to *Unrealized Value* in Fig. 6.

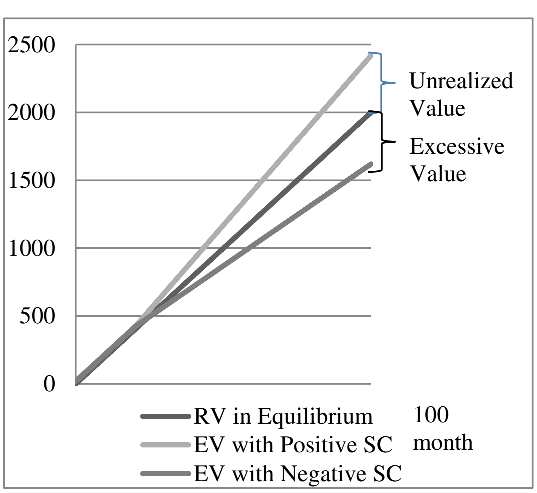

Fig. 5. Losses caused by SC.

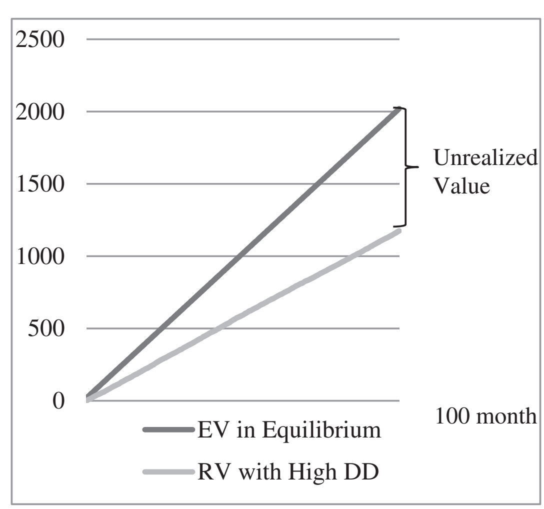

Fig. 6. Losses caused by DD.

Table 5
Scenarios for sensitivity analysis.

Scenarios	Strategic Change	Disruption & Delays
1	Positive	High
2	Negative	High
3	Positive	Medium
4	Negative	Medium
5	Positive	Low
6	Negative	Low

By combining different Strategic Changes types and D&Ds levels, we developed six scenarios for experimentation (see Table 5) with different remedial actions.

4.2. Impacts of Remedial Actions

We experiment with two remedial action types in order to find how efficiently they can tackle the uncertainties and reduce the value losses: one based on proportional adjustment and the other based on prospect theory. Lyneis and Ford (2007) suggest the adjustment amount for remedial actions is usually set as a proportion of deviation. According to the prospect theory (Kahneman and Tversky, 1979), the value function of decision-makers is not linear but loss averse (and convex). When the deviation is positive and higher, i.e. more money is lost compared with the expected value, and when the deviation is negative and its absolute value is higher, i.e. more funds are wasted; the problems are more severe for decision makers. Following this logic, the importance of remedial actions increases with the absolute value of deviation rising. Thus two remedial action types are developed as follows:

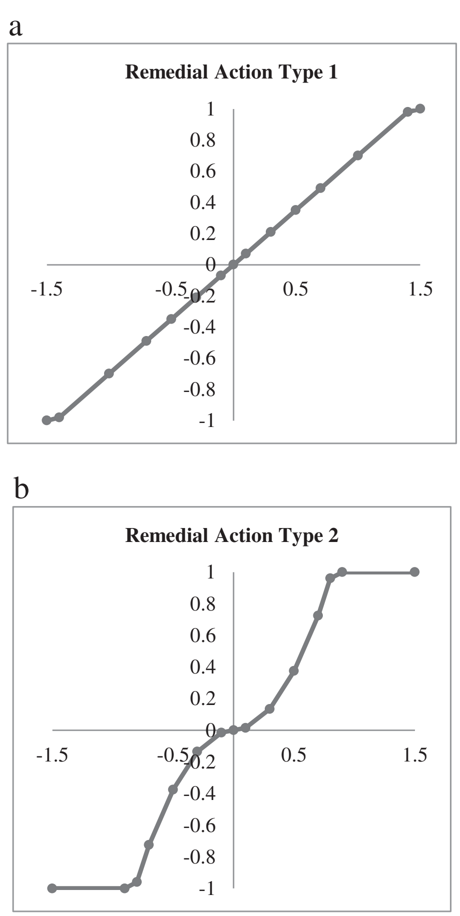

Fig. 7. a: Shape of Remedial Action Type 1. b: Shape of Remedial Action Type 2.

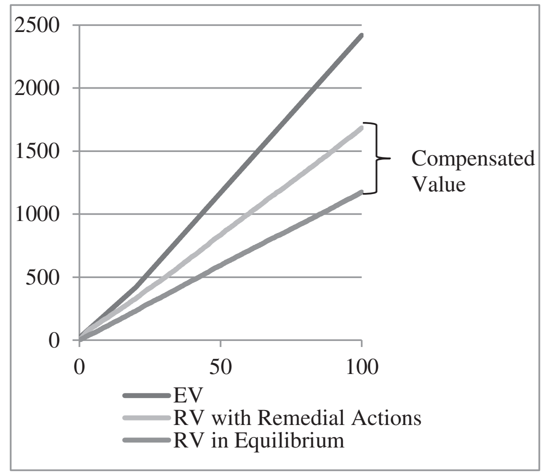

Fig. 8. Unrealized value compensated by Remedial Actions.

- ***Remedial Action Type 1***: The priorities determined by the remedial action (y-axis) are a fixed proportion of deviation (x-axis) (see Fig. 7a). The values are normalized.
- ***Remedial Action Type 2***: With the absolute value of deviation increasing, more importance is focused on the remedial action. The relationship between the remedial action (y-axis) and deviation (x-axis) is set as a convex increasing function (see Fig. 7b). The values are normalized.

With Remedial Actions, the deviation caused by uncertainties would be mitigated and the value created would better match the Expected Value, e.g. Fig. 8 illustrates the impact of remedial actions in a positive Strategic Change and medium D&D scenario. Almost half of the value is compensated.

Comparing the two remedial actions in different scenarios, with respect to the base case deviation and cost without remedial actions in each scenario, Table 6 shows Type 1 has better performance in reducing the deviation between Expected and

Table 6
Deviation and cost of the two remedial actions in different scenarios with respect to equilibrium.

Scenarios	Deviation (%with regard to equilibrium)			Cost (index 100 is the baseline)		
	Type 1	Type 2	No Remedial Actions	Type 1	Type 2	No remedial actions
1	47%	47%	70%	132	132	100
2	30%	33%	55%	124	121	100
3	30%	34%	51%	120	116	100
4	11%	15%	28%	111	108	100
5	18%	23%	34%	111	108	100
6	-2%	-2%	1%	102	102	100

Realized Value than Type 2. In scenario 6, when the uncertainty impacts are small, remedial actions taken actually broaden the deviation. Note that *Deviation* reflects the difference between RV and EV in percentage terms, and *Total Cost* is expressed as an index from the initial budget, where initial budget is equal to 100. It is clear that reactions from project managers improve performance but they also increase costs. Thus, type 2 responses seem to be more adequate if costs are considered but type 1 are better when deviation is taken into account.

4.3. Issues affecting the reporting process

In practice, the project implementation system is subjected to issues on the reporting process like reporting errors. Reporting errors are modeled as factors affecting the deviation perceived by decision makers and further influence the behavior of the project monitoring and control system.

Reporting errors can distort the perceived value with respect to its original value. We conduct a Monte-Carlo simulation considering RE as a normal distribution function with a positive mean as 0.2 (conservative) or a negative mean as - 0.2 (optimistic) to demonstrate different preferences of project managers. With positive reporting errors, i.e. when managers tend to demand for additional investment, the perceived deviations are higher than without reporting errors so deviations tend to be reduced faster. On the contrary, if there is a tendency for negative reporting errors, i.e. managers prefer to hide bad news, the deviation tends to be higher than without reporting errors. The results are shown in Table 7 with respect to Equilibrium, which is 0% deviation. We see that the perceived deviation and real deviation show opposite tendencies because of the balanced feedback loop that tends to over-compensate the real deviation by requiring more resources and reducing the gap. Table 7 shows that conservative project managers, positive RE, tend to obtain lower deviation with respect to plans in both type of remedial actions.

Table 7
Impact of different reporting error types with respect to equilibrium.

Scenarios	Reporting Errors	Remedial Action Type 1		Remedial Action Type 2	
		Perceived Deviation	Deviation	Perceived Deviation	Deviation
1	Positive RE	52%	41%	50%	39%
	Negative RE	39%	48%	40%	49%
2	Positive RE	41%	29%	36%	35%
	Negative RE	29%	38%	32%	40%
3	Positive RE	34%	22%	36%	24%
	Negative RE	23%	31%	26%	34%
4	Positive RE	20%	8%	24%	12%
	Negative RE	11%	19%	14%	22%
5	Positive RE	21%	12%	24%	12%
	Negative RE	11%	21%	12%	21%
6	Positive RE	7%	−6%	8%	−4%
	Negative RE	−2%	6%	−5%	4%

5. Reactions to unanticipated crises

Section 4 demonstrates how remedial actions help to reduce the losses caused by continuous uncertainties. There also exist unanticipated substantial events that rarely happen but can cause severe impacts. Looking into responses to those crises can help companies to react properly. Hence, subsequent experiments of two unanticipated substantial crises: strategic disruption and resource constraints will complete a comprehensive research on managing projects under uncertainty.

5.1. Strategic disruption

Assuming that half way through the project the organization encounters a market shift, after which the project is no longer required so there is a strategic disruption. In other words, strategic disruption has a negative impact on the expected value. The rational response to this situation is to abandon this project immediately because the project has accomplished its goal. However, this action may not be taken due to a lack of regular Strategic Change sensing process or other factors hinder abandoning the project. To discuss the actual loss caused by strategic disruption, we model the possible scenarios as:

- The project is abandoned immediately;
- The project is not abandoned, and no actions are taken: business-as-usual;
- The project is not abandoned, but remedial actions are taken according to the deviation perceived.

Experimental results show an increase in the deviation experiences at time 50. If the project is abandoned after perceiving the crisis, no more investment is committed. When the project is not abandoned, leaving aside the scenario when no actions are taken, the remedial actions will reduce the value creation rate but the realized value is still increasing and the commitment continues. See Table 8 for the results.

5.2. Resource constraints

Due to the wrong estimation of resources or resource conflicts with other projects, a project may be short of funds or resources (Petit, 2012). Assuming that the project is implemented under a medium level of D&D, the total budget is only 45% of the necessary budget and two scenarios are set considering the resource constraints:

Table 8
Comparison of project escalation with strategic disruption under different delay times in total cost.

Policy	Remedial Action Type 1	Remedial Action Type 2	Abandon the project	Business-as-usual
Total Cost	78	72	52	100

Table 9
Comparison of deviation and total cost under different scenarios with respect to equilibrium.

Investment type	Remedial Action Type 1		Remedial Action Type 2		No Remedial Actions	
	Deviation	Total Cost	Deviation	Total Cost	Deviation	Total Cost
Normal Adjustment	39%	125	43%	120	57%	100
Maintain Performance	21%	164	26%	159	57%	100

- **Normal Adjustment:** Remedial actions can adjust the investment according to deviation perceived.
- **Maintain Performance:** Project managers keep committing funds to the project to maintain the original performance instead of waiting for remedial actions to adjust funds.

When the budget is used up, if the manager intervenes and forces the project to maintain the original performance, more investment is required. If remedial action performs as usual, the broaden of deviation induces an increase in the expansion rate of investment rate but this remedial process cannot compensate the poor budgeting.

Comparing the two remedial action types at the end of the project and with limited resources, the final cost would be more than the original total budget due to the escalation of funding to catch up with the past deviation if the decision maker chooses to maintain the performance. See Table 9 with the comparison between the base case of no remedial actions and the remedial actions under this situation.

6. Discussion

6.1. Remedial actions and project escalation

The preceding experiments show two types of losses occurring during the implementation of projects under uncertainty: unrealized value and excessive value. These losses can be perceived as project failures when the value perceived is not aligned with the expected goals (White and Fortune, 2002). Remedial actions are usually taken to compensate the deviation. However, remedial actions are not one size fits all solutions.

Project Escalation, defined as 'continuing commitment of failing projects', is a pervasive phenomenon that induces significant loss. For example, in scenario 1 the project cannot achieve expected goals since the impact of uncertainty is extremely high but the project keeps running regardless of the efforts made by remedial actions. In this case, the remedial process gives rise to more escalation (occupation of more resources, higher schedule priorities) when the project can potentially be abandoned. Therefore, when the project is no longer needed, such as in the case of strategic disruption, and the project cannot be abandoned, the incremental withdrawal of investment by remedial actions needs to help reducing the escalation.

Comparing the two project managers' responses, Type 2, which applies prospect theory, does not perform well with low level or continuous uncertainty (higher deviation but lower cost than Type 1) but it performs better in unanticipated crises. However, project managers' responses, remedial actions, may induce ripple effects to the organization (Lyneis and Ford, 2007). Hence, in practice, insignificant impacts of uncertainty are often tolerated and project managers may not make unnecessary changes for a relatively small deviation. Type 2 responses actually reflects this mentality of avoiding over-reacting and makes the simulation results more realistic under low uncertainty levels. However, project managers need to be aware of the impact of deviations and specify the thresholds for remedial actions together with the remedial action type choice according to a balance between estimated efforts (costs, resources) and potential achievements (tolerable level of deviation or failure).

6.2. Importance of flexible reporting procedures

Providing that the changes generated by uncertainties require reactive efforts other than can be prevented in advance, a prompt monitoring and reporting procedure is of significant importance in project implementation. For decision makers, in order to handle the performance of projects, the accuracy of information origins (Reporting Errors) should be accentuated.

From the experiment results of Section 4.3, we can conclude reporting errors do have impacts on project implementation and may amplify the deviation. Most often, when projects run out of control, the project members are prone to hide the bad performance in order to avoid responsibilities or hold a 'wait and see' attitude based on optimism expectations for the future. For some projects, the deviation does exist but it is difficult to be detected. In those occasions, the real problem cannot be fully recognized by the decision makers. There also exist situations when perceived deviation is larger than the real one. For project managers who are conservative and demand for more investment to accomplish the projects, the deviation may be exaggerated but the final result may be better as they reduce the deviations. Different theories can be applied for its explanation, like Goal Incongruence, Self- Justification, and Optimism Bias (Keil et al., 2000; Son and Rojas, 2010). Organizations capability to guarantee prompt and transparent information is necessary to avoid escalation.

6.3. Monitoring and control of unanticipated events

When unanticipated events deemed significantly serious happen, they should be tackled as soon as possible. However, many of them just 'come out of the blue' and no well-planned actions can be prepared in a limited time. In these emergent situations, the microanalysis of the events can provide an efficient tool to determine the remedial actions from past experience (Howick and Eden, 2004).

For example, consider the experiment related to resource constraints in Section 5.2. Decision makers may be motivated by the pressure to accomplish the project or attracted by its promising outcome so they keep escalating the amount of funding. However, we found the final investment turns out to be more than half of the original funds if they persist on achieving the original goals.

Since the sources of uncertainties are difficult to clarify, modeling their impacts on different project implementation sub-systems, i.e. sensitivity analysis, may be a way to categorize the events and generate knowledge for newly arrived disruptions.

7. Conclusions

To analyze the impact of uncertainties on project implementation, we developed a system dynamic behavioral model to evaluate the value realization of on-going projects. Our model extracts the fundamental dynamism of project implementation and provides a transparent interpretation for project managers, which can be adapted to projects in multiple industries. We do not focus on the conventional triangle (cost, budget and quality) performance existing in project management literature but provide an open systems frame for strategic project management. Analyzing the possible losses caused by strategic and tactical uncertainties, the impacts of remedial actions and disturbances of behavioral biases are discussed from an individual perspective. Specifically, two unanticipated events are modeled, which gives a clue on how to efficiently response to unexpected crises. The results demonstrate the development of project escalation and the impact of prospect theory, a cornerstone in behavioral economics. We also evaluated the impact of reporting processes on the final results. Therefore our study contributes to three areas: project management under 'unk unks', the impact of behavioral biases on the achievement of project objectives, and system dynamics applied to project management.

Since this research mainly focus on the individual projects' behavior when faced with uncertainties and corresponding remedial actions, the synergies among multiple projects in realizing value have not been interpreted. Moreover, the emphasis on the model's generality at the same time omits the details of specific cases. Further research will focus on multi- project implementation and applications to empirical studies in specific contexts to adapt the model to contextual issues. Additional research can be performed on the use and combination of multiple tools, e.g. CPM/PERT and project benefits realization with system dynamics, to address the issues discussed in this paper.

Conflict of interest

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

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