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Managing and Modelling Project Risk Dynamics
A System Dynamics-based Framework

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Abstract

The fast changing environment and the complexity of projects has increased risk exposure. The PMBOK proposes a structured risk management process, integrated within the overall project management framework. However, unresolved difficulties call for further developments in the field. In projects, risks take place within a complex web of numerous interconnected causes and effects, which generate closed chains of feedback. *Project risk dynamics* are difficult to understand and control, and not all types of tools and techniques are appropriate to address their systemic nature. System Dynamics (SD), as a proven approach to project management, provides this alternative view. A methodology to integrate the use of SD within the established project management process has been proposed by the author. In this paper, this is further extended to integrate the use of SD modelling within the PMBOK risk management process, providing a useful framework for managing project risk dynamics.

Risk Management in Projects

Overview

In response to the growing uncertainty in modern projects, over the last decade the project management community has developed project-specific risk management frameworks. The last edition of PMI's body of knowledge (the PMBOK; PMI 2000), presents perhaps the most complete and commonly accepted framework. Further crucial developments are underway, like the establishment of project risk management maturity models (e.g. Hillson 1997), to help organisations evaluate and improve their ability to control risks in projects. However, most organisations fall short from implementing effectively these structured frameworks. In addition, there are certain types of risks that are not handled properly by the traditional tools and techniques proposed.

Current Framework for Project Risk Management

The latest 2000 edition of PMI's Project Management Body of Knowledge (PMBOK; PMI 2000) considers six risk management processes: planning, identification, qualitative analysis, quantitative analysis, response planning, and monitoring and control. While this framework provides a comprehensive approach to problem solving, its effectiveness relies on the ability of these processes to cope with the multidimensional uncertainty of risks: identification, likelihood, impact, and occurrence. The traditional tools and techniques used in these processes were not designed to address the increasingly systemic nature of risk uncertainty in modern projects. This problem and limitation calls for further developments in the field.

Project Risk Dynamics

Risks are dynamic events. Overruns, slippage and other problems can rarely be traced-back to the occurrence of a single discrete event in time. In projects, risks take place within a complex web of numerous interconnected causes and effects, which generate closed chains of feedback. *Risk dynamics* are generated by the various feedback loops that take place within the project system.

The feedback perspective is particularly relevant to understand, explain, and act upon the behaviour of complex social systems. Its added value for risk management is that it sheds light into the systemic nature of risks. No single factor can be blamed for generating a risk nor can management find effective solutions by acting only upon individual factors. To understand why risks emerge and devise effective solutions, management needs to look at the *whole*. As an example of this analysis, figure 1 shows the feedback structure of a project, focused on the dynamics that can generate risks related to requirements changes imposed by the client. This understanding of risks is crucial for better identifying, assessing, monitoring and controlling them (see Rodrigues 1999 for more details).

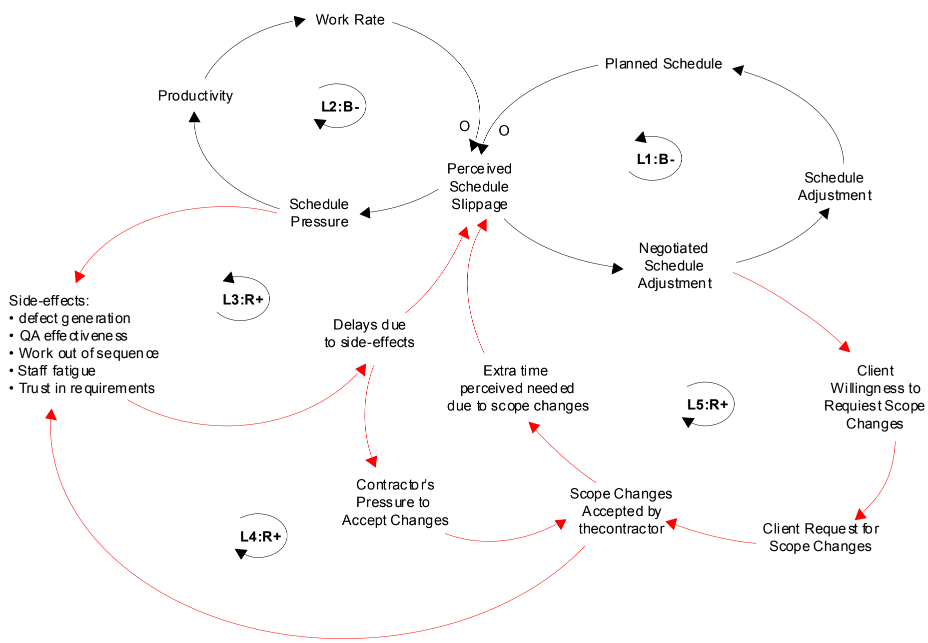


Figure 1 – Example of a project feedback structure focused on scope changes

Feedback loops identified as “R+” are reinforcing effects (commonly referred to as “snowball effects”), and the ones identified as “B-“ are balancing effects (e.g. control decisions). The arrows indicate cause-effect relationships, and have an “o” when the cause and the direct effect change in the opposite direction. The arrows in red identify the cause-effect relationships likely to generate risks. This type of diagram is referred to as “Influence Diagram” (ID).

If we ask the question: what caused quality problems and delays? The right answer is not: “staff fatigue”, “poor QA implementation” or “schedule pressure”. It is the *whole* feedback structure that, over-time and under certain conditions, generated the quality problems and delays. In other words, the feedback structure causes problems to *unfold* over-time. To manage effectively systemic risks, it is necessary to act upon this structure. This type of action consists in eliminating problematic feedback loops and create beneficial ones.

Project risk dynamics are difficult to understand and control. The major difficulties have to do with the subjective, dynamic and multi-factor nature of systemic risks. Feedback effects include time-delays, non-linear effects and subjective factors. Not all types of tools and techniques are appropriate to address and model problems of this nature. The more classical modelling approaches tend to deliver static views based on top-down decomposition and bottom-up forecast, while focusing on the readily quantifiable factors. Managing project risk dynamics requires a different approach, based on a systemic and holistic perspective, capable of capturing feedback and of quantifying the subjective factors where relevant.

A Proposed Framework for Managing and Modelling Project Risk Dynamics

Overview

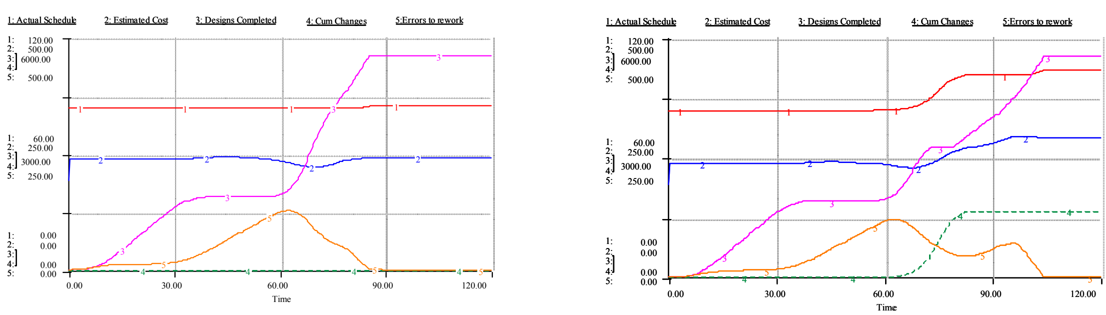
Managing systemic risks requires an approach supported by specialised tools and techniques. System Dynamics (SD) is a simulation modelling approach aimed at analysing the systemic behaviour of complex social systems, like projects. The framework here proposed is based on the integrated use of SD within the existing project risk management framework, supporting the six risk management processes proposed by the PMBOK (PMI 2000). This is an extension to the more general methodology developed by the author, called SYDPIM (Rodrigues 2000), which integrates the use of SD within the generic project management framework. The use of SD is proposed as a complementary tool and technique to address systemic risks.

System Dynamics

SD was developed in the late 50s (Forrester 1961) and has suffered a sharp increase in popularity during the last decade. Its application to project management has also been growing impressively, with numerous successful applications to real life projects (Rodrigues 1994). An overview of the SD methodology can be found in Rodrigues (2000).

The SD modelling process starts with the development of qualitative influence diagrams and then moves into the development of quantitative simulations models. These models allow for a flexible representation of complex scenarios, like mixing the occurrence of various risks with the implementation of mitigating actions. The model simulation generates patterns of behaviour over-time. Figure 2 provides an example of the output produced by a SD project model, when simulating the design phase of a software project under two different scenarios.

SD models work as experimental management laboratories, wherein decisions can be devised and tested in a safe environment. Their feedback perspective and "what-if" capability provide a powerful means through which systemic problems can be identified, understand and managed.



(a) Simulation "as planned"

(b) Simulation "with scope changes"

Figure 2 – Example of behaviour patterns produced by a SD project model

The SYDPIM framework

The SYDPIM methodology integrates the use of SD modelling within the established project management process. A detailed description can be found in Rodrigues (2000) (see also Rodrigues 1997 for a summary description). SYDPIM comprises two main methods: the model development method and the project management method. The first is aimed at supporting the development of valid SD models for a specific project. The latter supports the use of this model embedded within the traditional project management framework, and formally integrated with the PERT/CPM models. An overview of the process logic is provided in figure 3. The arrows in black identify the flows within the traditional project control process. SYDPIM places the use of a SD project model at the core of this process, enhancing both planning and monitoring and thereby the overall project control.

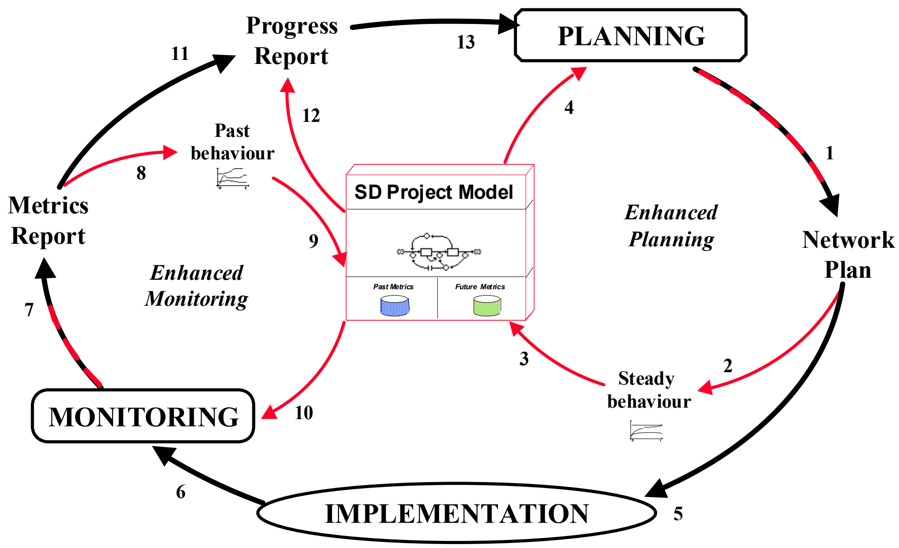


Figure 3 – Overview of the SYDPIM process logic

The use of the SD model adds new steps to the basic control cycle (the numbers indicate the sequence of the steps). In planning the SD model is used to pro-actively test and improve the current project plan. This includes forecasting and diagnosing the likely outcome of the current plan, uncover assumptions (e.g. expected productivity), test the plan's sensitivity to risks and test the effectiveness of mitigating actions. In monitoring, the SD model is used to explain the current project outcome and status, to enhance progress visibility by uncovering important intangible information (e.g. undiscovered rework), and to carry out retrospective "what-if" analysis for process improvement while the project is underway. Overall, the SD model works as a test laboratory to assess the future plans and to diagnose the project past. The model also works as an important repository of project history and metrics.

Using SYDPIM to Manage Risk Dynamics Within the PMBOK Framework

According to the SYDPIM framework, the SD model can be used in various ways to support the six risk management processes identified in the PMBOK. Given the limited size of this paper, this is now briefly described separately for each risk process. A more detailed explanation is forthcoming in the literature.

Risk Management Planning

The implementation of SYDPIM within risk management planning allows for the definition of the appropriate level of structuring for the risk management activity, and for the planning of the use of SD models within this activity.

Adjusting the level of structuring for the risk management activity is crucial for the practical implementation of the risk management process. A SD project model can be used to analyse this problem. Various scenarios reflecting different levels of structuring can be simulated and the full impacts are quantified. Typically, a "U-curve" will result from the analysis of these scenarios, ranging from pure *ad hoc,* to over-structuring. An example of the use of a SD model for this purpose can be found in Rodrigues (2001).

Risk Identification

A SD project model can support risk identification in two ways: at the qualitative level, through the analysis of influence diagrams, risks that result from feedback forces can be identified; at the quantitative level, intangible project status information (e.g. undiscovered rework) and assumptions in the project plan can be uncovered (e.g. required productivity).

Risks can be identified in an influence diagram as events that result from: (i) balancing loops that limit a desired growth or decay (e.g. the lack of available resources leads to a balancing loop that limits the potential growth of work accomplishment); (ii) reinforcing loops that lead to undesired growth or decay (e.g. schedule pressure leads to QA cuts, which in turn lead to more rework and delays, thereby reinforcing schedule pressure; see "R+" loop L3 in figure 1); (iii) external factors that exacerbate any of these two types of feedback loops (e.g. training delays exacerbate the following reinforcing loop: "the more you hire in the later stages, the worst the slippage due to training overheads."). This type of analysis also allows for risks to be managed as opportunities: feedback loops can be put to work in favour of the project.

SD simulation models allow the project manager to check whether and how certain feedback loops previously identified as "risk generators" will affect the project. In this way, irrelevant risks can be eliminated, preventing unnecessary mitigating efforts. Secondly, the calibration of the SD model uncovers important quantitative information about the project status and past, which typically is not measured because of its intangible and subjective nature. In this way, it forces planning assumptions to made explicit and thereby identifying potential risks.

Qualitative Risk Analysis

Influence diagrams can help to assess risk probability and impacts through feedback loop analysis. Given a specific risk, it is possible to identify in the diagram which feedback loops favour or counter the occurrence of the risk. Each feedback loop can be seen as a dynamic force that pushes the project outcome towards (or away) from the risk occurrence. The likelihood and the impact of each risk can be qualitatively inferred from this feedback loop analysis.

A SD simulation model can be used to identify the specific scenarios in which a risk would occur (i.e. likelihood). Regarding impact, with simple models and preliminary calibrations, quantitative estimates can be taken as qualitative indications of the order of magnitude of the risk impacts.

Quantitative Risk Analysis

In quantifying risks, a SD project model provides two additional benefits over traditional models: first, it delivers a wide range of estimates, and secondly these estimates reflect the full impacts of risk occurrence, including both direct and indirect effects.

Quantifying the impact of a risk consists in calibrating the model for a scenario where the risk occurs (e.g. scope changes), and then simulate the project. One can virtually analyse the impact of the risk occurrence in any project variable, by comparing the produced behaviour pattern with the one obtained when a risk-absent scenario is simulated. For example, figure 2(b) shows the behaviour patterns produced by a SD project model when scope changes are introduced by the client over-time (curve 4). These patterns can be compared with the ones of figure 2(a), which shows the scenario where no scope changes are introduced. This type of analysis allows the project manager to identify a risk's impact on various aspects of the project (and over-time; not just the final value). In addition, the feedback nature of the SD model ensures that both direct and indirect impacts of risks are quantified – ultimately, when a risk occurs it will affect *everything* in the project, and the SD model captures the full impacts.

A SD project model generally includes variables related to the various project objectives (cost, time, quality, and scope). One can therefore assess the risk impacts on all dimensions of the project objectives. The SD model also allows for scenarios combining several risks to be simulated, and thereby their cross impacts are also captured. Sensitivity analysis can be carried out to analyse the project's sensitivity to certain risks as well as to their intensity (e.g. what is the critical productivity level below which problems will escalate?).

Risk Response Planning

Influence diagrams and SD simulation models are very powerful tools to support the development of effective risk responses. They provide three main distinctive benefits: (i) support the definition and testing of complex risk-response scenarios, (ii) provide the feedback perspective for the identification of response opportunities, and (iii) they are very effective in diagnosing and better understanding the multi-factor causes of risks; these causes can be traced-back the through the chains of cause-and-effect, with counter-intuitive solutions often being identified.

Influence diagrams provide the complementary feedback perspective. Therefore, the power to influence, change and improve results rests on acting over the project feedback structure. Risk responses can be identified as actions that eliminate the vicious loops, attenuate or reverse their influence on the project behaviour. By looking at the feedback loops and external factors identified as risks, the project manager can devise effective responses.

A SD simulation model provides a powerful test-bed, wherein, at low cost and in a safe environment, various risk-responses can be developed, their effectiveness can be tested for the full impacts, and can be improved prior to implementation.

Risk Monitoring and Control

A SD project model can be used as an effective tool for risk monitoring and control. The model can be used to identify early signs of risk emergence, which otherwise would remain unperceived until problems would aggravate. The implementation of risks responses can also be monitored and their effectiveness can be evaluated.

Risk occurrence can be monitored by analysing the project behavioural aspects of concern (i.e. the risks “symptoms”). A SD model has the ability to produce many of these patterns, which in the real world are not quantified due to their intangible and subjective nature (the amount of undetected defects flowing throughout the development life-cycle is a typical example). The SD model provides a wide range of additional risk triggers, thereby enhancing the effectiveness of monitoring risk occurrence.

The implementation of a risk response can be characterised by changes in the project behaviour. These changes can be monitored in the model, to check whether the responses are being implemented as planned. The effectiveness of the risk response (i.e. the expected impacts) can be monitored in the same way. When deviations occur, the SD model can be used to diagnose why the results are not as expected.

Placing System Dynamics in the PMBOK

System Dynamics modelling is a very complete technique and tool that covers a wide range of project management needs, by addressing the systemic issues that influence and often dominate the project outcome. Its feedback and endogenous perspective of problems is very powerful, widening the range for devising effective management solutions. It is an appropriate approach to manage and model project risk dynamics, to which most of the traditional modelling techniques are inappropriate. SD has therefore a strong potential to provide a number of distinctive benefits to the overall project management process. One of the necessary conditions is that its application is integrated with the traditional models, within that process. The SYDPIM methodology was developed for that purpose, integrating the use of SD project models with the traditional PERT/CPM models, based on the WBS and OBS structures (Rodrigues 2000). SYDPIM provides SD models with specific roles within the project control process. One of these roles is to support the risk management activity.

As a proven tool and technique already applied with success to various real projects (Rodrigues and Bowers 1996), SD needs to be properly placed in the PMBOK. This paper briefly discussed its potential roles within the six project risk management processes presented in the latest edition of the PMBOK (PMI 2000). It is concluded that SD has potential to provide added value to these processes, in particular to risk identification, risk quantification and to response planning.

Influence diagrams are already proposed by the PMBOK for risk identification (process 11.2). SD simulation models are also proposed for activity sequencing (process 6.2). This is an important first step as an acknowledgement that systemic problems in projects may require specialised techniques, different from and complementary to the more traditional ones. However, from practical experience in real projects and extensive research carried out in this field, it is the author's opinion that the range of application of SD within the project management process is much wider. There are many other processes in the PMBOK framework where SD can be employed as a useful tool and technique. These benefits can be maximised based on the SYDPIM methodology.

It is also the author's opinion that by implementing the SYDPIM-based risk framework here proposed, the project manager can take better advantage of the benefits offered by System Dynamics modelling, while enhancing the performance of the existing risk management process.

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