# *Impact of Project Complexity Factors on New Product Development Cycle Time*

**Dr. M. R. Lebcir**

University of Hertfordshire Business School Working Paper (2011)

# Impact of Project Complexity Factors on New Product Development Cycle Time

**Dr. M. R. Lebcir**

**m.r.lebcir@herts.ac.uk**

**University of Hertfordshire Business School**

**College Lane**

**Hatfield**

**AL10 9AB**

**United Kingdom**

**Abstract**

The aim of this paper if to investigate the factors driving project complexity in New Product Development (NPD) projects and how they impact on development cycle time. This issue has been addressed in two steps: (i) building a framework for project complexity in NPD projects, and (ii) evaluating their impact on development cycle time through a System Dynamics (SD) simulation model integrating these factors with the operational aspects of the project and its time performance

The results indicate that project complexity is driven by four factors: Project Uncertainty, Product Newness, Product Interconnectivity, and Product Size. The simulation model output shows that an increase in project uncertainty has a significant impact on development cycle time. With regard to the remaining factors, they tend to impact development cycle time as they increase, however their impact is not significantly different in projects involving medium or high levels of these factors.

***Key Words*:** Project Management, Project Complexity, Project Uncertainty, New Product Development, Development Cycle Time, System Dynamics

## Introduction

Development of new products is becoming increasingly crucial to the survival and performance of companies in terms of market share, revenues, and competitive advantage (Bessant & Tidd, 2007; Trott, 2005). However, developing such new products is a daunting task. Rapid changes in customers' preferences coupled with a high rate of technological innovation have reduced products life cycles and complicated development of new products. Consequently there is increasing pressures on organisations to shift new products from development labs to markets in increasingly short period of time.

However, this is much easier said than done. The development of new products is complicated, difficult, and involves high levels of risk and uncertainty. Research suggests there are several strategic and operational variables, which interact in a complex manner to shape the performance of New Product Development (NPD) projects and determine their cycle times (Griffin, 1997, 2002; Hull et al, 1996; Murman, 1994; Olson et al, 2001; Sanchez & Perez, 2003; Swink & Song, 2007; Tessarolo, 2007; Wheelwright & Clark, 2002).

Many of the recurrent factors appearing in this stream of literature influence what is known as the level of "project complexity" in the NPD project and include factors such as "project size", "uncertainty", "product complexity", "technical risk*, "project scope" and so on (Griffin, 1997, Kim & Wilemon, 2003; Sicotte & Bourgault, 2008; Tatikonda & Rosenthal, 2000a). However, these factors have not yet been integrated into a single comprehensive framework, which categorise and integrate all the factors driving "project complexity" in NPD projects. As a result, there is an urgent need for a review of this literature so that a new, non-confusing, and comprehensive framework for project complexity in NPD projects is derived from this extensive body of knowledge.

Furthermore, the endeavour to determine and operationalize the factors contributing to project complexity in NPD projects is also motivated by the fact that project management processes and techniques are influenced by the level of "complexity" in a project. Project management activities such as planning, co-ordination, control, goals determination, organisational form, and project resources evaluation and management are all affected by the level of complexity in a project (Baccarini, 1996. Remington & Zolin, 2009, Tatikonda & Rosenthal, 2000a). The effectiveness of these processes and techniques is obviously a strong determinant of the NPD project performance especially development cycle time, hence the link between project complexity and NPD project development cycle time..

There are, consequently, two issues warranting investigation in this context. First, what are the factors driving “project complexity” in NPD projects. Second, what is the impact of these factors on NPD project development cycle time. It is important to remember that different project complexity factors are present simultaneously in the NPD project, however their level and relative influence on the project development cycle time are independent and different. For example, the decision regarding the level of technological uncertainty in the project is independent from the number of parts or functions in the new product (Clark & Fujimoto, 1991; Griffin, 1997)   Whilst it is implicitly known that all these factors contribute to make the project difficult and complicated to manage, hence impacting the project development time performance, it is not fully known how each factor taken individually affects project time performance.

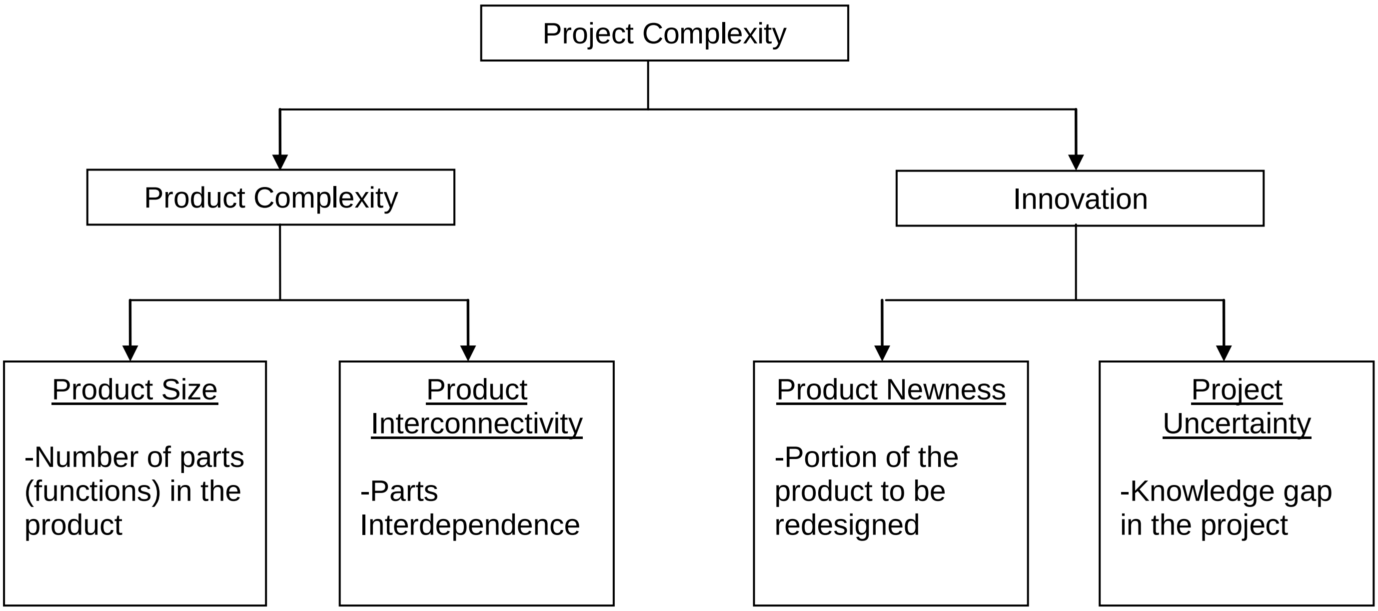
The aim of this paper is, therefore, two folds: First, to develop a “project complexity” framework for NPD projects. Second, to evaluate the relative influence of each of these factors on the NPD project development cycle time. The paper is organised as follows. The first section focuses on the NPD project complexity framework. This is followed by a description of the conceptual framework and the NPD project simulation model developed in this research. A description of the simulation scenarios tested on the model and the analysis of their results are then presented. The paper concludes with a discussion and a conclusion including the main findings of the research.

## Project Complexity in NPD projects

Although there is an implicit acknowledgement among practitioners and academics that NPD projects are complex, there is still a great deal of confusion about the factors driving this complexity (Clark 1992, Clark & Fujimoto 1991; Kim & Wilemon, 2003; Lebcir, 2006; Novak & Eppinger 2001; Smith & Reinertsen 1998; Tatikonda & Rosenthal 2000 a, 2000b; Ulrich & Eppinger, 2000). Thus far, there has not been a single comprehensive framework which includes and integrates all the aspects of project complexity in the context of NPD projects. Concepts such as, “structural complexity”, “product complexity”, “technological novelty”, “technical risk”, “technical uncertainty”, “project scope” have been used interchangeably to represent similar factors and without clear reference to how these factors relate or affect “project complexity” in NPD projects..

To respond to this inconsistency, a new NPD project complexity framework has been developed in the current research. The framework is grounded in the above mentioned NPD literature related to project complexity and is significantly influenced by the project complexity framework developed in the general project management literature (Baccarini, 1996; Williams, 1999). The framework includes the following: (see Figure 1)

Figure 1: Project Complexity Factors in New Product Development (NPD) projects




**Product complexity**

The concept of "product complexity" in NPD projects reflects what is known in the project management literature as "structural complexity". The latter literature posits that "structural complexity" (as a driver of project complexity in projects in general) is determined by two factors: (i) *differentiation,* that is the number of varied components in the project (tasks, specialists, sub-systems, parts) and (ii) *interdependence* or *connectivity*, that is the degree of inter-linkages between these components (Baccarini. 1996; Williams, 1999). The NPD literature is nicely aligned to this and indicates that "product complexity" is driven by the number of parts in the product to be developed (Detoni et al, 1999, Zirger & Hartley 1994, 1996) (differentiation) and the degree of interdependence among them (Baielti et al 1994; Novak & Eppinger 2001) (connectivity). Hobday (1998) and Tidd (1995) articulated further this link between the concept of "structural complexity" and "product complexity" through the class of products known as "Complex Products and Systems (CoPS)". They stipulated that CoPS products share three characteristics: (1) systemic (consists of numerous components and subsystems), (2) multiple interactions (across different components, subsystems, and levels), and (3) non-decomposable (cannot be separated into its components without degrading performance).

To conclude, it is safe to say that “product complexity” is a driver of “project complexity” in NPD projects and it consists of two factors: (i) “Product Size”, that is the number of elements (components, parts, sub-systems, functions) in the product and (ii) “Product Interconnectivity”, that is the level of linkages between these elements.

**Innovation**

A “new” product carries, by definition, a certain amount of “innovation”. This may originate from new designs incorporated in the product, new product or new process technologies (Swink 1999; Trott, 2005). Developing a product involving a high level of innovation is complex and fraught with risks. Such projects consume scarce resources, need substantial investment and commitments of personnel to develop new technologies, and, above all, increase the difficulty to manage the NPD project itself (Tatikonda & Rosenthal 2000 a, 2000b, Ulrich & Eppinger, 2000)

There has been some amalgam about the innovation dimension in NPD projects. Most of the early studies restricted innovation to technological uncertainty. However, an analysis of the recently published research suggests that innovation has a remit beyond just technological uncertainty (Kim & Wilemon, 2003; Remington & Zolin, 2009, Sicotte & Bourgault, 2008. Tatikonda & Rosenthal 2000a, 2000b) and includes the following factors

*Product newness*

Product newness represents the portion of the new product which has to be redesigned from previous generations of the same product (if applicable). The importance of this factor as a driver of NPD project complexity was first acknowledged by Clark (1989) and Clark and Fujimoto (1991) in their semantic work in the auto industry. They represented “product newness” as the fraction of the pioneering (new) components in the vehicle and the major changes in body process technologies. Subsequently a more generic definition of product newness was put forward, which stipulated that “product newness” reflects the degree of change required in the product and/or process technologies (Adler 1995; Koufteros et al 2001; Langerak et al, 1999; Liker et al, 1999; McDermott, 1999; Murmann 1994; Tatikonda, 1999; Tatikonda & Montoya-Weiss 2001; Tatikonda & Rosenthal 2000).

Product newness increases project complexity for several reasons. Increased product newness leads to an exponential increase in the number of tasks to be performed to finish the project.  If the number of new parts to be designed in the product is considerable, significant problems of interfaces and fitness between the new parts are likely to arise increasing the size of the solution set regarding design possibilities and alternatives. Furthermore, significant levels of product newness require high levels of knowledge creation, transfer, and synthesis in the project (Kazanjian et al, 2000).

*Project uncertainty*

Uncertainty is inherent in NPD projects since each project includes a certain jump into the unknown. Project uncertainty renders the project complex to manage because the suitable means, methods, and capabilities to be deployed in a project are not always well known at the start of development work. Project uncertainty increases the knowledge gaps in the project and, therefore, requires significant efforts from the development team to create and disseminate this knowledge so that the project work can be executed (Olson et al, 1995; Sicotte & Bourgault, 2008.  Tatikonda 1999; Tatikonda & Rosenthal 2000a, 2000b)

From a project management perspective, uncertainty makes projects more difficult to organise and manage. The more uncertain is the project, the more difficult it becomes to perform development tasks as learning curves are slow, problem solving methods inaccurate, and the set of possible solutions large. In addition, project uncertainty increases dependence between members of the project team as they become dependent on colleagues in other functions to perform their own tasks leading to substantial information transfer and feedback loops between different functions and team members in the project (Swink 2000). High degrees of uncertainty have been found to be associated with significant levels of error generation and rework, requires developers to go through many iterations before solutions to proceed with development work are found (Liker et al, 1999; Loch & Terwiesch 1999.  Souder et al, 1998, Swink et al, 1996).

## Simulation Model: framework and description

The model presented here is grounded on and combined the findings of two streams of literature: (i) the theoretical frameworks developed in the field of NPD management and (ii) previous SD models in which many feedback structures central to project dynamics have been identified, simulated, and validated.

NPD theoretical frameworks include those which linked the use of CFTs to the project performance (Brown and Einsenhardt, 1995; Wheelwright and Clark, 1992) and which focused on the impact of innovation on the relationship between CFTs and NPD project performance. These frameworks included variables such as team and group integration, decision authority, communication, resource availability, top management support, and co-ordination mechanisms (Liker et al, 1999; Tatikonda & Montoya-Weiss, 2001; Tatikonda & Rosenthal, 2000a)

SD models informed the model building process by providing information with regard to some generic processes in NPD project management. Such processes include work progress, schedule pressure and alteration, productivity, workforce level, error discovery and correction, quality assurance activity, project scope, perceived versus real progress, developers learning and experience, normal and overtime work, project priority, coordination mechanisms (Abdelhamid & Madnick, 1991; Black & Repenning, 2001; Ford & Sterman, 1998; Taylor & Ford, 2006).

The simulation model includes several phases reflecting the evolution of NPD projects over time. Each phase is simulated through a model incorporating several interlinked sectors such as planning, development process, human resource management, targets, scope, productivity, work allocation, and top management support (Lebcir, 2004).

**The development process sub-system**

The development process activities sub-system simulates the mechanisms determining the execution of the NPD project work. Development work execution is represented through the transformations affecting the state of the development tasks in the NPD project phase from the initial state of “Tasks for planning” until the final state of “Tasks released” through the intermediate states “Tasks to Complete”; “Tasks Completed Not Checked”, “Tasks in Rework”, and “Tasks Approved”.. These transformations are determined by the project development activities, which include planning (gathering information about a task execution), base-work (executing a task for the first time), quality assurance (checking tasks for flaws) rework (correcting flawed tasks), and internal co-ordination (communicating with other developers).

The planning activity generates the necessary information, which enables developers to carry out the execution activities in the project. During the planning phase, the development team identify consumers’ needs, market segments, and competitive situation; perform technological evaluation of the current capabilities and requirements, specify the resources needed to complete the project, identify risks and challenges, determine key project participants, and define sources of required functional support needed to carry out the development work.

The planning rate (the number of planning activities completed per unit time) is determined by the number of tasks available for planning and the average planning duration. The number of tasks available for planning is introduced because information on how to proceed to plan some tasks may not be available until late into the project phase. In some situations, it is worth to isolate some tasks which are impossible to plan at the project phase start, plan and execute other tasks in the meantime, and then use the generated information by the development execution process to plan the isolated tasks (Laufer et al, 1996).

Once tasks are planned, they are not released immediately for execution. The information generated by the planning process is kept for a while until a sufficient amount of information is available to allow the start of the development work execution.

The development process starts by the execution of development activities. The rate at which tasks are executed is determined by the base-work activity, which is defined as the execution of a development task for the first time. Completed tasks are checked for possible flaws. If a task passes this checkpoint successfully, it is approved. Otherwise, the task will have to be corrected (reworked). Approved tasks are put on hold until enough information is generated and released to other phases in the project.

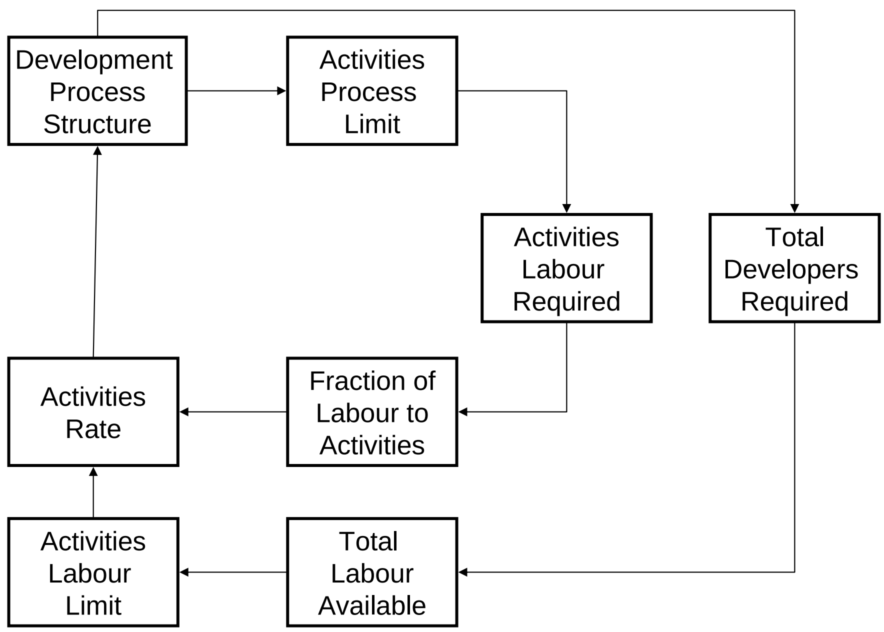
Once flawed tasks have been reworked, they are checked again for possible flaws. It is important to notice here that because developers are not perfect in detecting flaws, some of the tasks which are flawed go undetected and are, consequently, approved and released The flawed tasks due to the execution of development work are not the only tasks to be reworked. Sometimes, if some tasks are found flawed, the tasks which are connected to them and already approved may have to be reworked again. Once these tasks have been approved for rework, they have to be co-ordinated by the development teams responsible for generating flawed tasks due to execution and the development team who executed the tasks which become flawed due to product interconnectivity. These teams meet to decide about the best course of action to rework the extra flawed tasks. This activity is referred to in the model as “co-ordination”.

**The human resources management sub-system**

The execution of any project cannot be accomplished unless the right mix of resources is deployed in the project. In the particular case of NPD projects, it has been observed that human resources play a central role in allowing a successful completion of projects. If a project is suitably staffed with the right mix and quality of developers, the development work will be carried out without delays and with a high execution quality.

In the current model, the human resources management policies are driven by the requirements to execute the development activities in the project. The structure of the links between the human resources management and the development process aspects of the project are presented in Figure 2. The figure shows that the total size of the workforce (in terms of the number of developers) needed in the project at any given time depends on the total labour required to execute all the development activities on the available development tasks as determined by the development process structure. In addition, the fraction of labour directed to execute each development activity is proportional to the labour pressure associated with that development activity. This pressure depends on the number of tasks available to undergo the development activity at any given time in the project.

Figure 2: Links between the human resources management and the development process aspects in the NPD project phase.



**Representation of project complexity factors in the model**

One of the most important shortcomings of the project management SD models developed so far is that either they omit completely the effects of project complexity factors or represent them in an extremely simple way. For example, in some models, project complexity was represented as a single factor and it was blended with the operational variable it affects (Joglekar and Ford, 2005; Notzon, 2002). This is a serious shortcoming as these models assume implicitly that either all projects are similar or that project complexity is driven by a single factor and this cannot be further from the truth especially that NPD projects vary significantly in terms of their level of project complexity and the factors driving this complexity.

To overcome these shortcomings, in the current model, the effect of project complexity factors on the project operational variables is represented through a set of non-linear functions, where each non linear function links an input variable representing the project complexity factor to an output variable representing the effect of the project complexity factor on the project operational variable. This representation allows us to include all the four project complexity factors mentioned above and the impact of each factor on all the project operational variables it affects. For example, if the factor "project uncertainty" affects the operational variables "productivity" and "quality of development work", there will be two non-linear functions, one representing the effect of "project uncertainty" on "productivity" and the other the effect of "project uncertainty" on "quality of development work".

## Model parameterisation and validation

The aim of model validation in SD is to build confidence in the model such that it can be used for the purpose of policy design and analysis. The SD validation process includes qualitative, quantitative, and behaviour reproduction tests (Sterman, 2000). The current model was validated through a real world project to develop a new navigation system for an aircraft. The validation process involved the active participation of the project team.

The selected project is adequate for the validation of the model built in this research for many reasons. It is a new product development project as the product being developed is a completely new navigation system. In addition, the product is structurally quite complex as it includes many parts, sub-systems, hardware, and software elements and it is well known that products involving these elements (hardware and software) are notoriously complex (Kim & Wilemon, 2003). Finally, the project included several phases (concept development, product design, process design, and testing) and the project management team selected a CFT organisation (called Integrated Functional Teams in the company) to manage the project.

The model parameters were determined in a number of ways. Some parameters were readily available on the project documents (for example the number of developers in the project). Other parameters were estimated from the project progress reports and from observations of the project work (for example the average time for the project activities). The last category of parameters was estimated based on the judgment and experience of the project team (for example, effects of fatigue on project work productivity).

Following model parameterisation, validations tests were performed. The qualitative structure of the model was validated through workshops involving several project teams in the organisation. The quantitative structure of the simulation model was validated by a thorough check of the model equations and variables and by performing extreme conditions tests on the model. The behavioural reproduction tests were performed through comparison of the simulation model outputs and the real world behaviour of a large set of variables on different phases of the project. The simulated and real world behaviours over time of the variables "Base-work rate", and "Tasks released" from the design phase of the project are presented in Figures 3 and 4.

Figure 3: Model replication of the "base-work rate" variable.

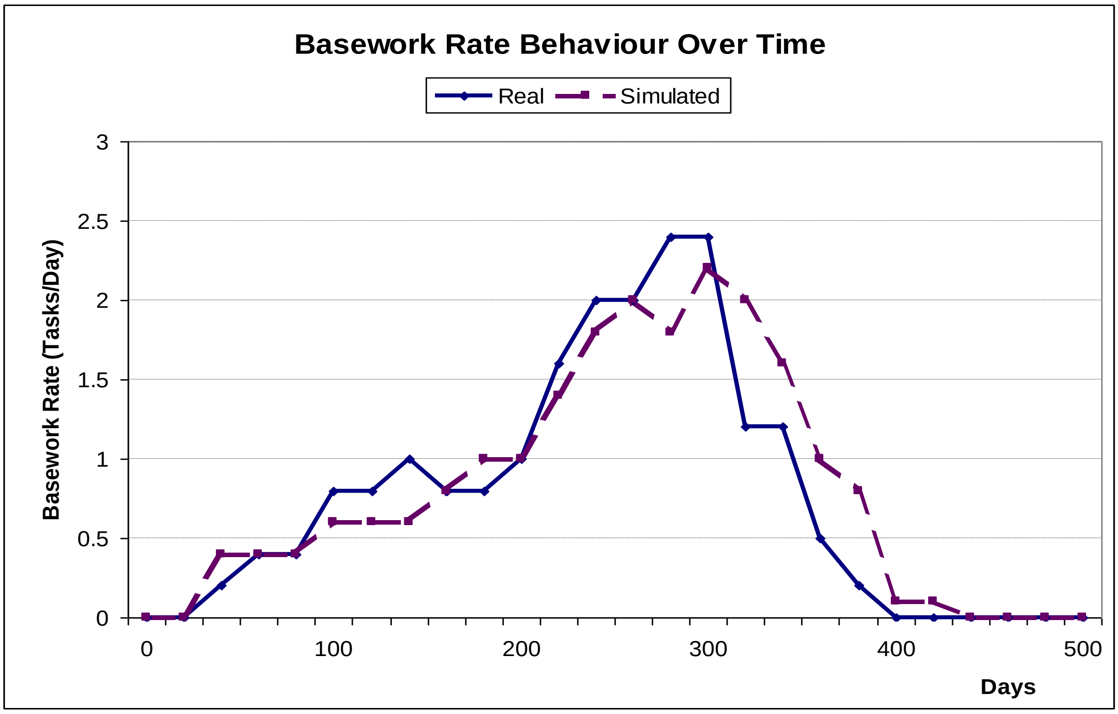
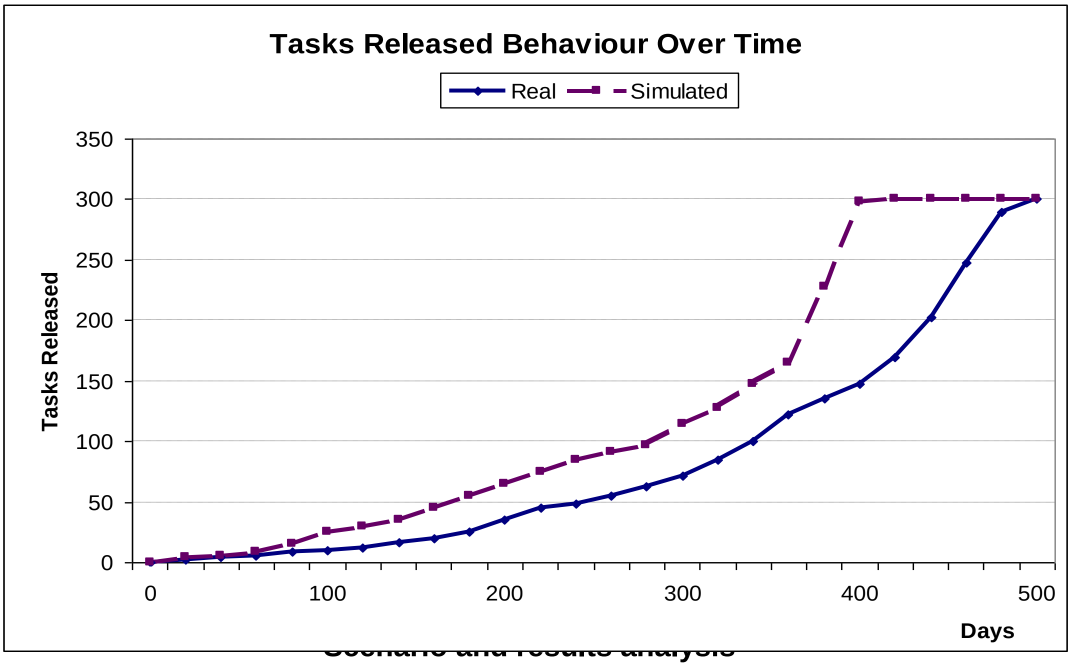


Figure 4: Model replication of the ”tasks released” variable




## Scenario and results analysis

The experiments on the model were conducted by varying the level of the four “project complexity” factors and the operational variables representing the co-ordination activity (both internal and external). Each of the four project complexity factors, that is “project uncertainty” (PU), “product newness” (PN), “product inter-connectivity (PI), and “product size” (PS), was assigned three different levels defined as **“Low”**, **“Reference”** and **“High”** (Shenhar, 2001; Swink, 2000). A scenario represents a project in which each of the four project complexity factors is assigned one of the three levels mentioned above. For example, a project in which PU is low, PN is reference, PI is reference and PS is high is a scenario. Given that we have four project complexity factors each accepting 3 possible levels, the number of possible scenarios is equal to the number of combinations of 4 factors and 3 levels, that is ($3^4$) or 81. The simulation results (development cycle time) for the 81 trials are presented in Table1.

The impact of the four project complexity factors on development cycle time is analysed separately for each project complexity factor. The rationale being that the levels of the project complexity factors are determined in projects independently from each other and impact development cycle time separately (Clark & Fujimoto, 1991, Griffin, 1997). Therefore, for each project complexity factor, graphs are constructed to represent the change in development cycle time as the level of the factor changes from “Low” to “Reference” to “High” for the same combination of the levels of the remaining three project complexity factors. For example the graph representing the impact of PU on development cycle time (Figure 6) represents the development cycle time for the three levels (Low, Reference, High) for the same combination of the remaining three factors PN, PI, and PS (in this order). This enables the analysis of the impact of the PU factor without interference from the other ones.

In addition, and in order to understand better the influence of the project complexity factors on development cycle time, the average development cycle time, for every level of each factor, is presented in Table 2. For example, the average development cycle time for all projects with low PU is 638 days and for all projects with high PI is 1285 days.

Table 1: Simulation results: development cycle time for all combinations of the project complexity factor (In days)

| Trial | PU | PN | PI | PS | Cycle Time |
|---|---|---|---|---|---|
| 1 | Low | Low | Low | Low | 193 |
| 2 | Low | Low | Low | Reference | 419 |
| 3 | Low | Low | Low | High | 501 |
| 4 | Low | Low | Reference | Low | 443 |
| 5 | Low | Low | Reference | Reference | 633 |
| 6 | Low | Low | Reference | High | 711 |
| 7 | Low | Low | High | Low | 548 |
| 8 | Low | Low | High | Reference | 711 |
| 9 | Low | Low | High | High | 828 |
| 10 | Low | Reference | Low | Low | 340 |
| 11 | Low | Reference | Low | Reference | 507 |
| 12 | Low | Reference | Low | High | 584 |
| 13 | Low | Reference | Reference | Low | 543 |
| 14 | Low | Reference | Reference | Reference | 736 |
| 15 | Low | Reference | Reference | High | 839 |
| 16 | Low | Reference | High | Low | 618 |
| 17 | Low | Reference | High | Reference | 831 |
| 18 | Low | Reference | High | High | 917 |
| 19 | Low | High | Low | Low | 389 |
| 20 | Low | High | Low | Reference | 505 |
| 21 | Low | High | Low | High | 595 |
| 22 | Low | High | Reference | Low | 583 |
| 23 | Low | High | Reference | Reference | 814 |
| 24 | Low | High | Reference | High | 885 |
| 25 | Low | High | High | Low | 662 |
| 26 | Low | High | High | Reference | 908 |
| 27 | Low | High | High | High | 984 |

| | | | | | |
|---|---|---|---|---|---|
| 28 | Reference | Low | Low | Low | 614 |
| 29 | Reference | Low | Low | Reference | 801 |
| 30 | Reference | Low | Low | High | 852 |
| 31 | Reference | Low | Reference | Low | 877 |
| 32 | Reference | Low | Reference | Reference | 1105 |
| 33 | Reference | Low | Reference | High | 1106 |
| 34 | Reference | Low | High | Low | 1054 |
| 35 | Reference | Low | High | Reference | 1354 |
| 36 | Reference | Low | High | High | 1351 |
| 37 | Reference | Reference | Low | Low | 728 |
| 38 | Reference | Reference | Low | Reference | 919 |
| 39 | Reference | Reference | Low | High | 999 |
| 40 | Reference | Reference | Reference | Low | 1072 |
| 41 | Reference | Reference | Reference | Reference | 1283 |
| 42 | Reference | Reference | Reference | High | 1498 |
| 43 | Reference | Reference | High | Low | 1240 |
| 44 | Reference | Reference | High | Reference | 1552 |
| 45 | Reference | Reference | High | High | 1562 |
| 46 | Reference | High | Low | Low | 753 |
| 47 | Reference | High | Low | Reference | 975 |
| 48 | Reference | High | Low | High | 1059 |
| 49 | Reference | High | Reference | Low | 1117 |
| 50 | Reference | High | Reference | Reference | 1318 |
| 51 | Reference | High | Reference | High | 1421 |
| 52 | Reference | High | High | Low | 1259 |
| 53 | Reference | High | High | Reference | 1528 |
| 54 | Reference | High | High | High | 1650 |
| 55 | High | Low | Low | Low | 767 |
| 56 | High | Low | Low | Reference | 901 |
| 57 | High | Low | Low | High | 1019 |
| 58 | High | Low | Reference | Low | 1140 |
| 59 | High | Low | Reference | Reference | 1462 |
| 60 | High | Low | Reference | High | 1576 |
| 61 | High | Low | High | Low | 1307 |
| 62 | High | Low | High | Reference | 1465 |
| 63 | High | Low | High | High | 1620 |
| 64 | High | Reference | Low | Low | 850 |
| 65 | High | Reference | Low | Reference | 1044 |
| 66 | High | Reference | Low | High | 1120 |
| 67 | High | Reference | Reference | Low | 1213 |
| 68 | High | Reference | Reference | Reference | 1469 |
| 69 | High | Reference | Reference | High | 1627 |
| 70 | High | Reference | High | Low | 1441 |
| 71 | High | Reference | High | Reference | 1788 |
| 72 | High | Reference | High | High | 1937 |

| | | | | | |
|---|---|---|---|---|---|
| 73 | High | High | Low | Low | 897 |
| 74 | High | High | Low | Reference | 1126 |
| 75 | High | High | Low | High | 1212 |
| 76 | High | High | Reference | Low | 1271 |
| 77 | High | High | Reference | Reference | 1616 |
| 78 | High | High | Reference | High | 1759 |
| 79 | High | High | High | Low | 1562 |
| 80 | High | High | High | Reference | 1927 |
| 81 | High | High | High | High | 2100 |

Table 2: Average development cycle time for all levels of the project complexity factors (In days)

| | Low | Reference | High |
|---|---|---|---|
| PU | 638 | 1150 | 1378 |
| PN | 939 | 1084 | 1144 |
| PI | 766 | 1115 | 1285 |
| PS | 884 | 1120 | 1215 |

The impact of each project complexity factor is discussed in the following section

**Project Uncertainty (PU)**

The effect of project uncertainty on development cycle time is presented on Figure 5. It is clear that development cycle time is affected by project uncertainty as it tends to increase as the level of PU changes from low to reference to high and this is valid regardless of the levels of the other project complexity factors PN, PI, and PS. However, the increase in development cycle time is not of the same magnitude as PU level increases. Development cycle time goes up much more sharply when PU increases from low to reference than when it moves from reference to high. As an illustration the average development cycle time leap is four times more important when PU moves from low to reference (from 638 days to 1150 days) than when PU moves from reference to high (from 1150 to 1378 days).

**Product Newness (PN):**

The impact of PN on development time is less dramatic than that of PU. In fact although, as Figure 6 indicates, changes in development cycle time show an ascending trend as PN becomes higher, this change is not substantial. This is especially the case as PN changes from reference to high. This observation is strengthened by the fact the average development cycle time increases with 15% (from 939 70 1084 days) as PN changes from low to reference and only by 5% (from 1084 to 1144 days) as PN changes from reference to high.

Figure 5: Development cycle time for the 3 levels of Project Uncertainty (PU)

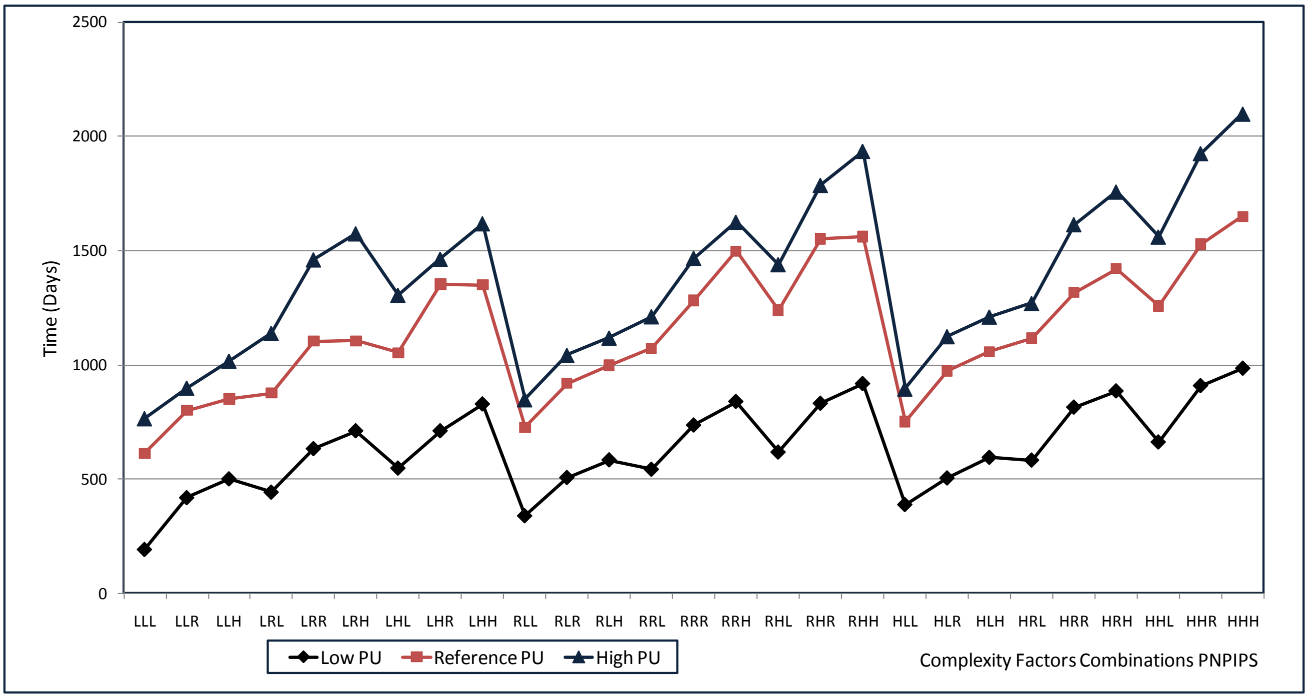
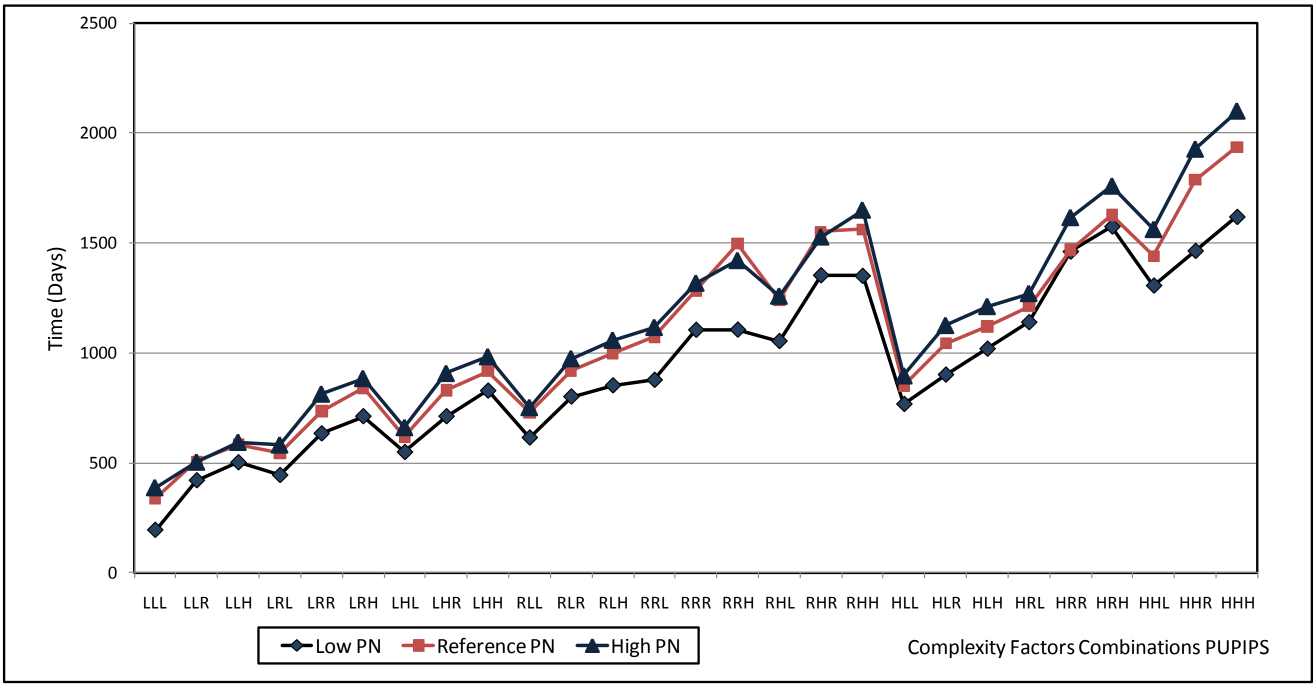



Figure 6: Development cycle time for the 3 levels of Product Newness (PN)



**Product Interconnectivity (PI)**

Figure 7 shows that PI is a factor which influences project development cycle time, which climbs as the level of PI moves up. This observation is valid for all combinations of the remaining project complexity factors PU, PN, and PS. In other words, regardless of the decisions determining the level of PU, PN, and PS, a project with higher levels of PI will require more time to complete. The other important finding from Figure 8 is that the influence of PI tends to be more significant as PI changes from low to reference than if it changes from reference to high. As an illustration, the average development cycle time varies by 45% (from 766 to 1115 days) as PI changes from low to reference, but varies only by 15% (from 1115 to 1285 days) as PI changes from reference to high.

**Product Size (PS)**

PS appears, from Figure 8, to be the project complexity factor associated with the lowest influence on development cycle. Of course, development cycle time grows as PS increases, however to a less extent than the other project complexity factors. In this context, the average development cycle time is 884, 1120, and 1215 days for low, reference, and high PS respectively. In percentage terms, the increase is around 26% from low to reference and 8% from reference to high. Further evidence to this observation can be seen on Figure 9. The change in development cycle time is more important from low to reference PS than from reference to high PS.

## Discussion and Conclusions

The aim of this paper is to understand the influence of project complexity on New Product Development (NPD) development cycle time. This issue was investigated in two steps: (i) development of a project complexity framework for NPD projects and (ii) building of a System Dynamics (SD) computer simulation model representing a multi-phase development project.

The NPD project complexity framework is grounded on the project complexity framework developed in the project management literature (Baccarini, 1996; Kim & Wilemon; 2003; Williams, 1999). The analysis of this literature led to the development of the project complexity framework in this research and which includes four factors driving project complexity in NPD projects: (i) Project Uncertainty. (ii) Product Newness, (iii) Product Interconnectivity, and (iv) Product Size.

Figure 7: Development cycle time for the 3 levels of Product Interconnectivity (PI)

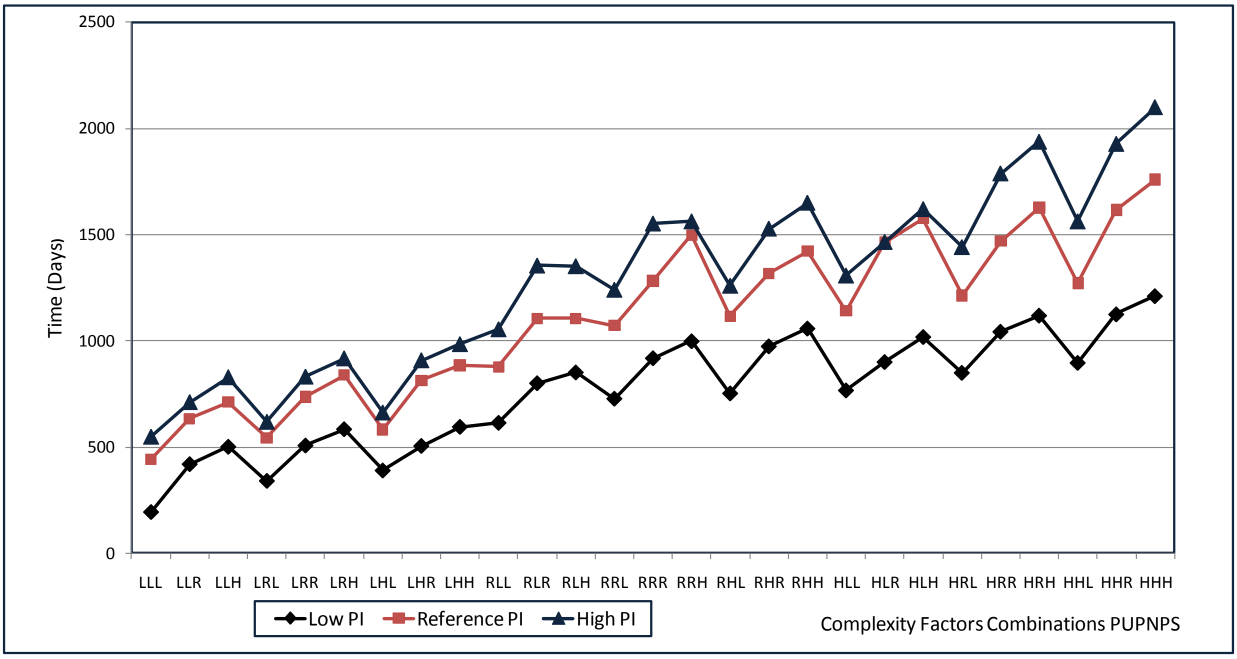
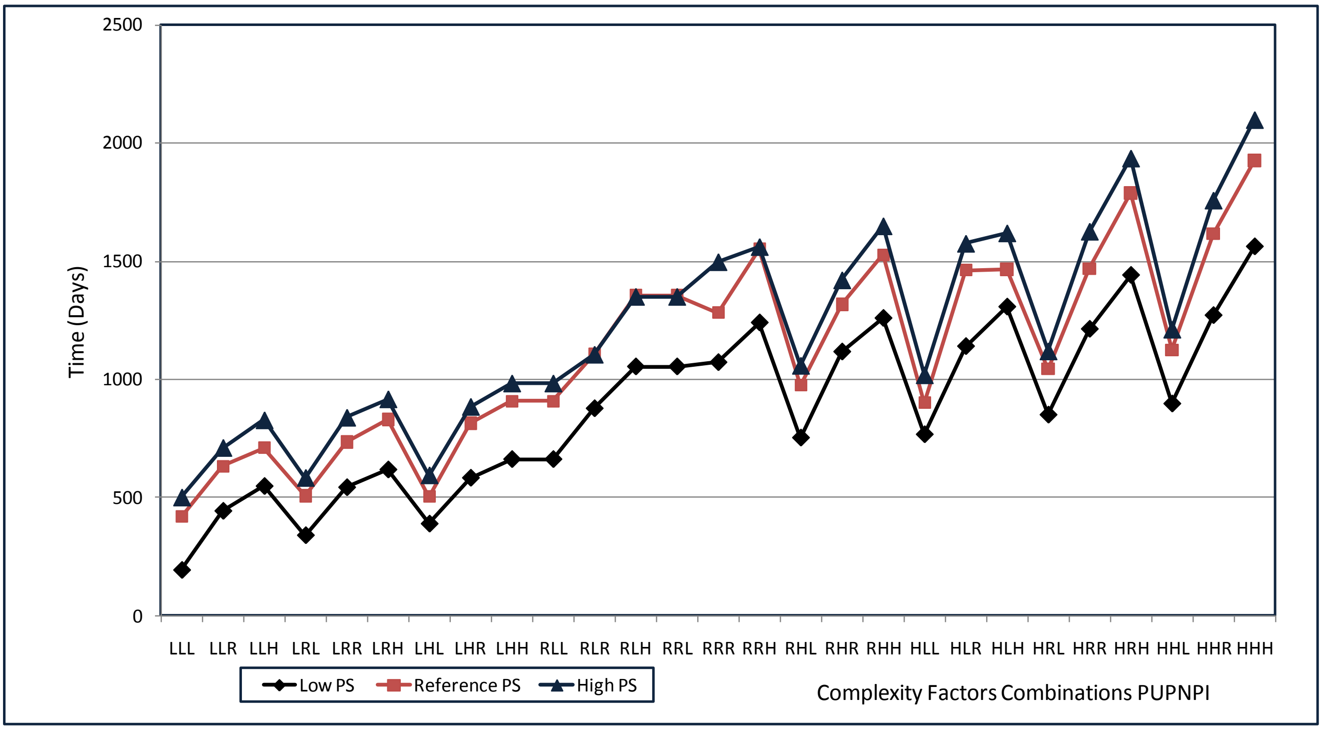



Figure 8: Development cycle time for the 3 levels of Product Size (PS)



The SD simulation model built in this research constitutes a step further in the successful application of SD in Project Management. The model combines the NPD and SD literatures and sub-models and integrates the project complexity framework developed in this research and the NPD project operational variables such as development tasks, project management decision making processes, resource management, project objectives, top management support, and so on. As such the model combines both the strategic and operational decisions and policies of the NPD project.

The simulation results have yielded some interesting findings. It is crystal clear than project complexity factors have an inflating effect on development cycle time and this is valid for each of the four project complexity factors. The implication of this is that project managers must be aware of this finding as they make the strategic decisions (which determine the level of the project complexity factors) during the planning and formative phases of the project. Decisions regarding the level of technological innovation to be used in the project, the breadth and depth of the technologies to include in the project, the fraction of the new product to re-develop or to take “out of the shelf” from previous generations of the product, the number of elements and functions to be included in the product to be developed, the architecture and map of the product, will have significant influence on the development cycle time. This is important as these strategic decisions “are fairly immutable after project initiation” (Griffin, 1997, p. 26). Project managers must resist the attempt of overlooking or ignoring the consequences of their strategic decisions as these have a significant impact on the level of project complexity, the operational evolution of the project, and ultimately its time performance.

In addition, the research yielded some interesting finding regarding the effect of each of the project complexity factor on development cycle time. Project uncertainty, which reflects the depth of the innovation in the project, is clearly a strong determinant of the time required to complete the project. Projects involving medium or high innovation are associated with far longer completion times than project involving low innovation. When making decisions determining the level of innovation in the project, project managers must make a trade-off between its effects on the development cycle time, and the other objectives of the project linked to the competitive environment, market segments to be targeted, pricing power for the new product, project financial rewards, and so on.

Interestingly enough, there seems not to be a great difference between project involving medium and high levels of innovation in term of development cycle time. The managerial consequence of this is that if there is a choice between the two options of medium and high innovation, it is better to choose the latter option especially if this does not affect significantly the expected success of the product in the market.

The impact of product newness on development cycle is less acute than that of project uncertainty. This finding has important consequences for the management of NPD projects. Unless the target is to develop a derivative product (low PN), there is no significant difference in terms of the impact of PN on cycle time when its level is medium or high. Therefore, other considerations (marketing, financial, strategic,...) should be taken in account when faced with these two alternatives decisions (medium or high PN) as the development cycle time seems not to be affected and should not, therefore, be the most important criteria used in order to set a medium or high level of PN in the project.

The product architecture, reflected by the level of product interconnectivity, is influential on development cycle time. Projects to develop products in which parts and functions are tightly linked take longer to complete than projects in which the linkages are less integrated. Therefore, whenever possible project managers are advised to choose a modular architecture (low PI) for the new product as this reduces cycle time. If, this is not possible, then the impact of PI on development cycle time is not very different if a product with medium or high interconnectivity is developed. In this case, the decision should be driven by other performance criteria than development cycle time.

The number of parts (functions) to be included in a new product, which indicate the level of PS in the project, is another driver of NPD cycle time. As intuition suggests, products including a higher number of parts (functions) are finished later than projects including a low number. So, from a time performance perspective, it is preferable to reduce the number of parts (functions) in a new product. However, it can also be observed from the results that once this number is above a certain level (medium or high PS), its effect is seriously reduced. In such contexts, the level of the PS factor is not very significant as far as the development cycle time is concerned. In this case, other performance criteria should guide the decision making process to set the level of PS in the project

Although this research has addressed some important research questions regarding the factors affecting project complexity in NPD projects and how they relate to the project development cycle time, it can be extended in different directions. For instance, it is possible to include other performance indicators (cost, quality, finance, marketing) in the model. In addition, it would be interesting to see how these factors interact with some operational decisions such as the use of Cross Functional Teams and adoption of Concurrent Engineering practices in the project. Another possible extension to the research will be to explore the trade-off between the structural complexity element (Product Size and Product Interconnectivity) with the innovation element (Project Uncertainty and Product Newness) of project complexity and its impact on project performance.

In conclusion, it can be said that this research has shed some light on the impact of the NPD strategic decisions on project cycle time using an innovative tool (computer simulation modelling). Further research is, however, required to further improve our understanding about the relationship between strategic, operational, and the performance of these projects.

## References


Abdelhamid, K., & Madnick, S. (1991). *Software project management dynamics: an integrated approach.* New Jersey: Prentice Hall.

Adler, P. (1995). Interdepartmental interdependence and coordination: the case of the design/manufacturing interface. *Organization Science*, 6(2), 147-167.

Baccarini, D. (1996). The concept of project complexity-a review. *International Journal of Project Management,* 14(4), 201-204.

Bailetti, A., Callahan, J., Di Pietro, P. (1994). A coordination structure approach to the management of projects. *IEEE Transactions on Engineering Management,* 41(4), 394-403.

Bessant J., &Tidd J. (2007). *Innovation and Entrepreneurship*. Chichester: Wiley.

Black, L., & Repenning, P. (2001). Why fire fighting is never enough: preserving high quality product development. *System Dynamics Review,* 17, 33-62.

Brown, L., & Eisenhardt, .M. (1995). Product development: Pat research, present findings, and future directions. *Academy of Management Review*, 20, 343-378.

Clark, B. (1989). Project scope and project performance: The effect of part strategy and supplier involvement on product development. *Management Science*, 35, 1247-1263.

Clark, B., & Fujimoto, T. (1991). *Product development performance: strategy, organization and management in the world Auto industry*. Cambridge: Harvard Business School Press.

De Toni, A., Nassimbeni, G., Tonchia, S. (1999). Innovation in product development within the electronics industry. *Technovation,* 19, 71-80.

Ford, D., & Sterman, D. (1998). Dynamic modelling of product development processes. *System Dynamics Review,* 14, 31-68.

Griffin, A. (1997). The effects of project and process characteristics on product development cycle time. *Journal of Marketing Research,* 34(1), 24-35.

Griffin, A. (2002). Product development cycle time for business to business products. *Industrial Marketing Management,* 31, 291-304.

Hobday, M. (1998). Product complexity, innovation and industrial organisation. *Research Policy,* 26, 689-710.

Hull, M., Collins, D., Liker, K. (1996). Composite forms of organisation as a strategy for concurrent engineering effectiveness. *IEEE Transactions on engineering Management,* 43, 133-142.

Joglekar, N., & Ford, D. (2005). Product Development resource allocation with foresight. *European Journal of Operational Research*, 160, 72-87.

Kazanjian, R., Drazin, R., Glynn, A. (2000). Creativity and technological learning: The roles of organisation architecture and crisis in large-scale projects. *Journal of Engineering and Technology Management*, 17, 273-298.

Kim, J., & Wilemon, D. (2003). Sources ands assessment of complexity in NPD projects. *R&D Management,* 33, 15-30.

Koufteros, X., Vonderembse, M., Doll, W. (2001). Concurrent engineering and its consequences. *Journal of Operations Management*, 19, 97-115.

Langerak, F., Peelen, E., Nijssen, E. (1999). A laddering approach to the use of methods and techniques to reduce cycle time of new to the firm products. *Journal of Product Innovation Management*, 16, 173-182.

Laufer, A., Denker, G., Shenhar, A. (1996). Simultaneous management: the key to excellence in capital projects. *International Journal of Project Management,* 14(4), 189-199.

Lebcir, R. (2004). *Integration in New Product Development projects: Effect of project complexity on project performance*. Unpublished PhD Thesis, University of London.

Lebcir, R. (2006). A Framework for Project Complexity in New Product Development (NPD) Projects. *University of Hertfordshire Business School Working Paper,* UHBS, 2006-1

Liker, K., Collins, P., Hull, M. (1999). Flexibility and standardization: Test of a contingency model of product design-manufacturing integration. *Journal of Product Innovation Management*, 16, 248-267.

Loch, L, & Terwiesch, C. (1999). Accelerating the process of engineering change orders: Capacity and congestion effects. *Journal of Product Innovation Management*, 16, 145-159.

Mc Dermott, M. (1999). Managing radical product development in large manufacturing firms: a longitudinal study. *Journal of Operations Management*, 17, 631-644.

Murmann, P. (1994). Expected development time reductions in the German mechanical engineering industry. *Journal of Product Innovation Management,* 11, 236-252.

Notzon, I. (2000). Effective design of phase overlapped product development processes- a system dynamics based analysis. *Unpublished Mphil thesis, University of Bergen.*

Novak, S., & Eppinger, D. (2001). Sourcing by design: Product complexity and the supply chain. *Management Science*, 47(1), 189-204.

Olson, M., Walker, C., Reukert, R. (1995). Organising for effective new product development: The moderating role of product innovativeness. *Journal of Marketing*, 59, 48-62.

Olson, M., Walker, C., Reukert, W., Bonner, M. (2001). Patterns of co-operation during new product development among marketing, operations, and R&D: Implications for project performance. *Journal of Product Innovation Management,* 18, 258-271.

Remington, K., & Zolin, R. (2009). A model of project complexity: Distinguishing elements of complexity from severity. *Proceedings of the 9th International Research Network of Project Management Conference, Berlin, Germany.*

Sanchez, M., & Perez, P. (2003). Flexibility in new product development: a survey of practices and its relationships with the product's technological complexity. *Technovation,* 23, 139-145.

Shenhar, A. (2001). One size does not fit all projects: Exploring classical contingency domains. *Management Science*, 47(3), 394-414.

Sicotte, H., & Bourgault, M. (2008). Dimensions of uncertainty and their moderating effects on new product development project performance. *R&D Management*, 36(5), 468-479.

Smith, G., & Reinertsen, D. (1998). *Developing products in half the time*. New York: Van Nostrand Reinhold.

Souder, E., Sherman, D., Davis-Cooper, R. (1998). Environmental uncertainty, organisational integration, and new product development effectiveness: a test of contingency theory. *Journal of Product Innovation Management*, 15, 520-533.

Sterman, D. (2000). *Business dynamics. Systems thinking and modeling for a complex world*. Singapore :Mc-Graw Hill/Irwine.

Swink, M. (1999). Threat to new product manufacturability and the effects of development team integration processes. *Journal of Operations Management*, 17, 691-709.

Swink, M. (2000). Technological innovativeness as a moderator of new product development design integration and top management support. *Journal of Product Innovation Management*, 17, 208-220.

Swink, M., & Song, M. (2007). Effects of marketing-manufacturing integration on new product development time and competitive advantage. *Journal of Operations Management*, 25, 203-217.

Tatikonda, V. (1999). An Empirical study of platform and derivative product development projects. *Journal of Product Innovation Management*, 16, 3-26.

Tatikonda, V., & Rosenthal, R. (2000a). Technology novelty, project complexity, and product development project execution success: A deeper look at task uncertainty in product innovation. *IEEE Transactions on Engineering Management*, 47(1), 74-87.

Tatikonda, V., & Rosenthal, R. (2000b). Succesful execution of product development projects: Balancing firmness and flexibility in the innovation process. *Journal of Operation Management*, 18, 401-425.

Tatikonda, V., & Montoya-Weiss, M. (2001). Integrating operations and marketing perspectives of product innovation: The influence of organizational process factors and capabilities on development performance. *Management Science*, 47, 151-172.

Taylor, T., & Ford, D. (2006). Tipping point failure and robustness in single development projects. *System Dynamics Review*, 22, 51-71.

Tessarolo. P. (2007). Is integration enough for fast product development? An empirical investigation of the contextual effects of product vision. *Journal of Product Innovation Management*, 24: 69-82.

Tidd, J. (1995). The development of novel products through intra- and inter-organizational networks. *Journal of Product Innovation Management*, 12, 307-322.

Trott, P. (2005). *Innovation Management and New Product Development*. Harlow: Prentice Hall.

Ulrich, K., & Eppinger, D. (2000). *Product design and development*. Singapore: Mc-Graw Hill.

Wheelwright, S., & Clark, B. (1992). *Revolutionizing product development: Quantum leaps in speed, efficiency and quality*. New York: The Free Press.

Williams, T. (1999). The need for new paradigms for complex projects. *International Journal of Project Management*, 17(5), 269-273.

Zirger, B., & Hartley, L. (1994). A conceptual model of product development cycle time. *Journal of Engineering and Technology Management*, 11, 229-251.

Zirger, B., & Hartley, L. (1996). The effect of acceleration techniques on product development time. *IEEE Transactions on Engineering Management,* 43(2), 143-152.