“Drivers of Complexity in New Product Development Projects: Why some projects are more complex than others? ”

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Abstract: Project complexity has recently become an important element of project management theory and, therefore, has attracted a lot of attention from academics and practitioners alike. However, what does project complexity mean and what are its contributing factors is still unclear and confusing.

The aim of this paper is to structure the different factors described in the literature so far and articulate them into a new framework of project complexity. This new framework integrates both the structural complexity dimension and the uncertainty dimension of project complexity. These general dimensions are then applied to the specific case of NPD projects to generate a new framework for this important class of projects.

Introduction

Many project managers are using the term "complex projects" in their description of current projects, yet it is not clear what are the factors contributing to this complexity nor how they can be quantified (Williams 1997,1999a). Practitioners describe projects as being "complex" or "simple" when they discuss management issues (Baccarini 1996), implicitly recognising that complexity does have an impact on project management methods and practices. Therefore, it is becoming increasingly important to specify the factors contributing to project complexity, factors which seemingly go beyond just the size of the project. As pointed out by Williams (1999a), there is a widespread feeling among project managers that a "complex" project is more than just a "big" project.

The endeavour to determine, operationalise, and quantify the elements contributing to project complexity is 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, project resources evaluation, personnel management, and project cost and time are all affected by the level of complexity involved in a project (Baccarini 1996). Therefore, the effectiveness of project management policies, techniques, and procedures is contingent upon project complexity level.

The aim of this paper is, therefore, to define the concept of "project complexity" and the factors contributing to it. The paper is divided into two main sections. The focus of the first section is to determine and describe, from the broad perspective of project management, the factors contributing to project complexity.. In the second section, these factors are translated into a "project complexity" framework for the specific class of NPD projects. Conclusions are given at the end of the paper.

1. Project complexity: Project management perspective

The first logical step towards a better understanding of the effects of project complexity, in order to determine the most appropriate project management tools and procedures to deal with them, is to define the factors contributing to this complexity. Clearly one cannot address efficiently the effects of project complexity unless its underlying causes are determined and operationalised. This was the incentive behind the growing interest shown recently in project management literature to this topic (Williams 1999a,1997, Shenhar 1998, 2001, Baccarini 1996, Shenhar and Dvir 1996, Laufer et al 1996 Turner and Cochrane 1993). A review of this body of literature indicates that project complexity has two contributing factors: structural complexity and uncertainty.

1.1 Structural complexity

The first factor contributing to project complexity is related to the underlying structure of the project. This factor was introduced by Baccarini (1996) who defined project complexity, in a broader sense, as "consisting of many varied interrelated parts". Project structural complexity was broken down into two elements. The first is *differentiation,* that is the number of varied components in the project (tasks, specialists, sub-systems, parts). The second is *interdependence* or *connectivity*, that is the degree of inter-linkages between these components. Because the complexity dimensions introduced by Baccarini are related to the structure of the project, Williams (1997,1999a) refers to this factor as "structural complexity".

Differentiation and *interdependence* contribute to project complexity through two dimensions: organisational and technological.

1.1.1 Organisational complexity

This source of complexity reflects the view that a project is a task which include many organisational aspects such as communication and reporting, determination of responsibilities, authority for decision making, and allocation of work. With respect to this dimension, *differentiation* means the number of hierarchical levels, formal organisational units (departments, groups), number of different occupational specialisation utilised to accomplish the work, and the variety of tools and techniques used in the project. *Connectivity* means the degree of operational interdependencies and interaction between the project organisational elements mentioned earlier.

1.1.2 Technological complexity

Technology is broadly defined as the transformation process which converts inputs to outputs. In this particular context of NPD projects, technology reflects the process used to execute a development and involves the utilisation of material, means, techniques, knowledge, and skills. *Differentiation,* with respect to this dimension, indicates the variety of tasks' inputs and outputs, the number of separate actions to deliver the end product of the project, and the number of specialities involved in the project. *Connectivity* means the structure of linkages between tasks, networks of tasks, teams, inputs, and techniques.

Although the structural complexity factor is important in the conceptualisation of the sources of complexity in projects, it has been presented in a simple manner making it sometimes difficult to fully understand why it makes some projects more complex than others. In this context, Williams (1999a) mentioned that to understand the link between structural complexity and project complexity, it is not sufficient to admit the existence of interdependencies between project's elements, but it is also necessary to define what is the kind of interdependencies involved: pooled (in which each element gives a discrete contribution to the project, each element proceeding irrespective of the other elements), sequential (one element output is the other element input), and reciprocal (each element's output becomes other elements' input).

The last type of interdependence is an important driver of project complexity because it represents the case in which any change in a sub-system of the product will generate changes throughout all the other sub-systems. This is the reason why this type of interdependence is regarded as the ground for the rationale that a project to develop a more "structurally complex product" should be a more "complex project". In such projects, it is not sufficient to manage the project's elements but it is similarly important to account for the snowball effects which may be triggered by changes to some sub-systems in the project. For example, Ackermann et al (1996) found that the delays and disruption experienced in the Channel Tunnel project were rooted in the degree and type of interdependence between project's sub-systems. The project included 50 sub-systems, each managed by different sub-contractor. Because all the sub systems were tightly interconnected, changes in some of them had significant cross-impact effects on the others making effective and timely co-ordination between sub-contractors a daunting task and the project more difficult to manage.

In addition to these effects, it is necessary to notice that structural complexity generates other sources of difficulty for project managers. It is well known that most, if not all, projects have conflicting goals. The decision to add to the project's "structural complexity" has to be weighted against the probability of achieving the project's goals. For example, if a change in a sub-system will generate many other changes in other sub-systems and the project is in its final stages, it will be costly and time consuming to perform all the required changes. In such situations, careful consideration should be given to the possible trade-off between time and quality (Ha and Porteus 1995) especially if the project has many stakeholders. In a project described by Swink et al (1996), a company was developing a Digital Satellite System for home television. The company has to continually adapt to and negotiate the new broadcasting standards which were imposed by the governmental regulatory bodies to avoid costly late redesigns to the product.

The main limitation in the definition of structural complexity, as a driver of project complexity, is that this factor does not account for the level of difficulty to carry out project's tasks. Although, Baccarini (1996) mentioned that many elements in a complex project are "complicated", he did not explain how this "complication" is linked to the level of "project complexity" in a project. Williams (1997,1999a), based on a previous framework developed by Turner and Cohrane (1993), refers to this "complication" as the second factor of project complexity and define it as "uncertainty".

1.2 Uncertainty

The second factor contributing to project complexity is the level of uncertainty involved in the project. Turner and Cochrane (1993) indicated that, contrary to the widespread belief, project goals and execution methods are not always known and well defined at the beginning of the project execution phase. In many projects, there is still a great deal of uncertainty remaining even after the project execution is already underway. This uncertainty causes the project work to become difficult and its outcome unpredictable, therefore, increasing the overall level of project complexity.

There are two important dimensions of uncertainty in projects: *uncertainty in methods* and *uncertainty in goals*. *Uncertainty in methods* reflects the lack of knowledge on how to proceed to achieve project goals. The tasks to be performed and the ways to perform them are not well known and defined at the beginning of the project execution phase. This increases project complexity because the underlying structures of project management in the form of project breakdown structures, that is the Product Breakdown Structure (PBS), the Organisational Breakdown Structure (OBS), and the Work Breakdown Structure (WBS) cannot be defined with certainty. These breakdown structures are crucial to project management because, unless defined, the execution of the project work becomes very difficult. Moreover, the consequences of uncertainty in defining the previous breakdown structures are heavy penalties in terms of project time, cost, and quality (this is under the optimistic scenario that the project has not been "killed" prior to its completion).

Uncertainty in goals means that project requirements are ill defined at the beginning of its execution phase. In this situation, as the work proceeds, requirements will have to be changed and refined many times causing subsequent changes in the product components, layout, interfaces and architecture, hence amplifying the effects of the project structural complexity mentioned earlier. This type of uncertainty makes projects more difficult to manage because the basic project management activities such as planning, scheduling, monitoring, and control becomes ineffective as goals are continuously altered over the project life cycle.

The presence of high levels of these two types of uncertainty increases project management difficulty as many project elements become unpredictable. For example, it has been reported that most of the rework witnessed in many projects (the main driver of cost and time) is due to the conspiring effects of these two types of uncertainty especially in the project early stages when it is extremely difficult to make accurate forecasts regarding the work technical requirements, the time and resources needed to execute the work, the performance levels to be achieved, and so on. As reported by Mawby and Stupples (2000), the worst levels of uncertainty occur during the formative stages of a project, the period in the project life cycle which includes the maximum leverage upon the project outcome as the strategy and designs are frozen and the majority of costs committed.

In summary, from a project management perspective, both "structural complexity" and "uncertainty" contribute to the overall level of project complexity (see figure 1) and conspire to make the usual project management activities of planning, execution, monitoring, and control difficult and unstable. This only strengthens the argument that "project complexity" is a distinct and crucial dimension of project management and should be given special attention from both academics and practitioners.

Because the focus of this research is to investigate the effects of project complexity on NPD project performance, it is necessary to translate this general definition of project complexity to the specific class of NPD projects.

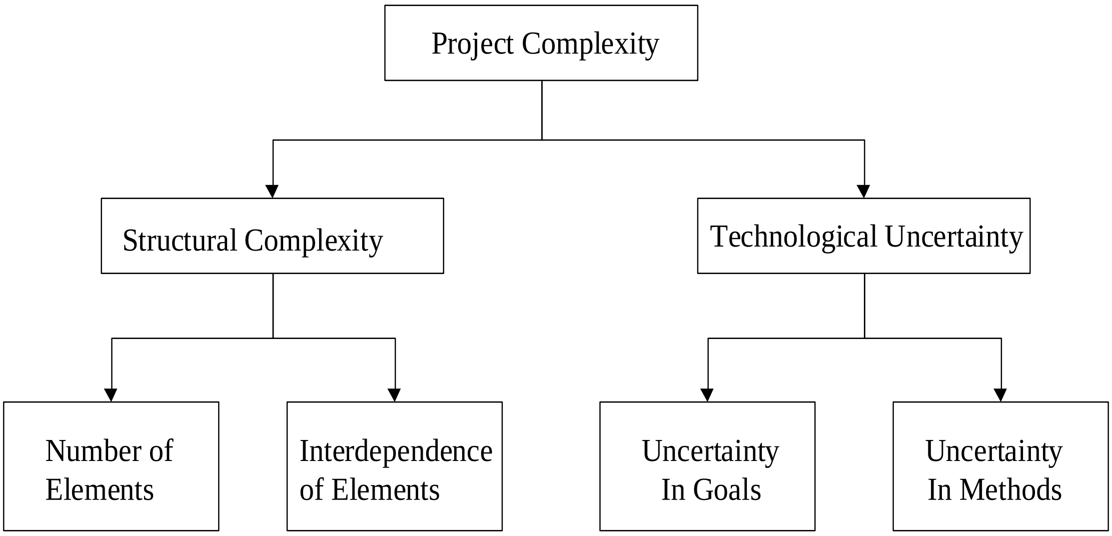

Figure 1: Factors contributing to "Project Complexity": Project Management perspective (Williams 1999a).

2. Project Complexity: The NPD perspective

NPD projects are inherently complex because they involve development of products which carry some degree of novelty meaning that some of the work to be performed in the project is new to the firm. However, if there is an implicit acknowledgement among practitioners and academics that NPD projects are complex, there is a great deal of confusion about the factors driving this complexity (Ulrich and Eppinger 1999, Smith and Reinertsen 1998, Wheelwright and Clark 1992, Clark and Fujimoto 1991). Clearly, NPD literature is quite immature in this area and lacks consistency in the determination and definition of the project complexity factors in NPD projects. The positive side, however, is that there is an increasing interest to this aspect within the NPD community. The last decade witnessed the publication of a sizeable and ever growing body of literature dedicated to NPD project complexity (Novak and Eppinger 2001, Tatikonda and Rosenthal 2000a,b, Clift and Vandenbosch 1999, Tatikonda 1999, Souder et al 1998, Griffin 1997a,b, Zirger and Hartley 1996,1994, Olson et al 1995, Ulrich 1995, Murmann 1994, Wheelwright and Clark 1992, Clark and Fujimoto 1991, Kleinschmidt and Cooper 1991). If this impressive effort is much welcomed, there are still some lacunas in the process of definition and operationalisation of NPD project complexity factors. 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 "project complexity", "product complexity", "technological novelty", "technical risk", "technical uncertainty", "project scope" have been used interchangeably to represent similar factors. Furthermore, much attention has been devoted to the "technological novelty" dimension in NPD projects. The "structural complexity" dimension, as important as it is, has been relegated to a secondary level of importance. Fortunately, recent published research (Novak and Eppinger 2001, Tatikonda and Rosenthal 2000 a, Griffin 1997 a, Zirger and Hartley 1996,1994 Swink et al 1996, Ulrich 1995) has brought up this dimension to the forefront of the agenda related to NPD project complexity research.

In the next section, I will try to depict the different factors contributing to project complexity in NPD projects. These factors have been inferred from the NPD literature related to project complexity mentioned above. However, before describing the factors, it is important to notice that the investigation process followed here to determine these factors has been significantly influenced by the structure used within the project management literature as described in the previous section. As a consequence, the following presentation of project complexity factors is shaped into a structure similar to the one presented earlier under the project management headline (see figure 2)

2.1 Product complexity

The concept of “product complexity” within the context of NPD projects was introduced by Clark and Fujimoto (1991) in their semantic work on new product development in the automobile industry. In this study, they operationalised product complexity as the number of body styles in the new car model. They justified the use of this variable as an indicator of product complexity because they argued that in a new car, the number of body styles affects the physical shape of all major components (engine, transmission, chassis) and the possible types of linkages between them. The effects of product complexity on overall project complexity level were highlighted in a following study conducted by Murmann (1994) within the mechanical engineering industry in Germany. He found that, in order to reduce development cycle time (the focus of the study), it was important to reduce product complexity through reduction of the number of parts in the product. He observed that if a new product contains many parts, it becomes

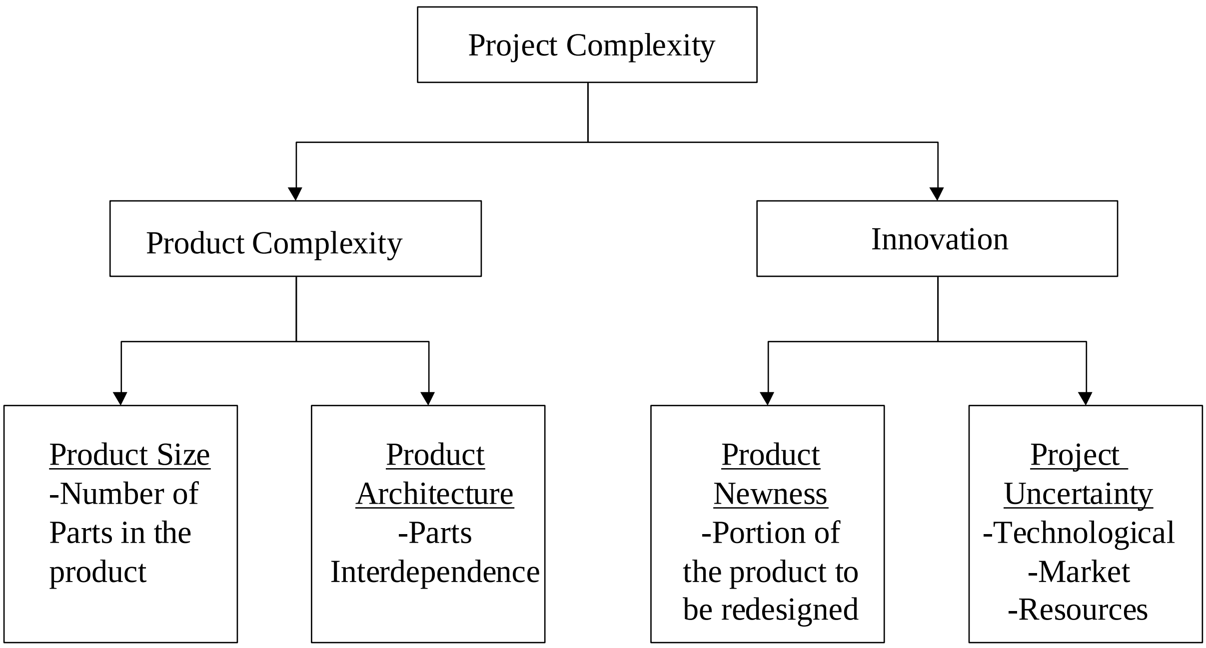

Figure 2: Factors contributing to “Project Complexity”: New Product Development perspective.

problematic to fit them together in a coherent whole as the number of possible combinations of interfaces between them increases exponentially. These studies recognised implicitly that product complexity, in terms of the number of parts in a product and their inter-linkages, was a powerful driver of overall project complexity. Zirger and Hartely (1994) refer to this factor as "component complexity" and stipulates that it affects the firm's ability to develop new products. From a project management perspective, this definition of product complexity is, in fact, similar to the concept of "structural complexity" described by Baccarini (1996) and Williams (1997,1999a). The latter author called NPD projects "design to manufacture" and argued that, for these projects "structural complexity" should be interpreted as "product complexity".

This argument that "product complexity" in the NPD literature is similar to "structural complexity" in the project management literature was strengthened in many recent studies. These studies indicate that the two dimensions of "product complexity", that is the number of parts in the product (Detoni et al 1999, Zirger and Hartley 1994,1996) and the degree of interdependence among them (Novak and Eppinger 2001, Baielti et al 1994) are similar to the "differentiation" and "connectivity" dimensions developed by Baccarini (1996) within the project management literature. Tidd (1995) and Hobday (1998) articulated further this link between the concept of "structural complexity" and "product complexity" by introducing a new class of products, which they define as Complex Products and Systems (CoPS). They stipulated that CoPS products have 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).

The previous definitions of product complexity show, without ambiguity, that a "complex product" is a product containing a considerable number of components which are highly interconnected. However, a recent stream of research defined "product complexity" from the perspective of the product functionality rather than from the product internal structure. In this context, product complexity has been operationalised as the number of functions designed in the product (Griffin 1997 a,b).

However, these two definitions of "product complexity" are not that much mutually exclusive. They can be, in fact, conciliated if the concept of product architecture developed by Ulrich (1995) is considered. He stipulated that each product function is generally embedded into a set of product components. Based on this definition, the more functions performed by a product, the more should be the number of parts in that product. So, the first dimension of "product complexity" is present. The second dimension is determined by the type of relationship function / components. A product which performs many functions is likely to include complex mapping structures from functional elements to physical components and/or coupled interfaces between components. In the words of Ulrich (1995), such product will include an "integral architecture" (as opposed to "modular architecture" for simple products which perform small number of functions). This dimension refers to the degree of interconnectivity between components, that is the second dimension of "product complexity".

2.2 Innovation:

A "new" product carries, by definition, a certain amount of innovation. This may originate from new designs incorporated in the product, new product technologies, which improve the translation of customer requirements into design parameters, or new process technologies which ensure compatibility between design specifications and process capabilities (Swink 1999, Souder and Moneart 1992). The degree of innovation in a product has important consequences. High innovative products may attract new market segments, open new markets for the firm, enhance product quality and reliability, reduce manufacturing costs, and put the firm steps ahead of its competitors. However, developing a product which carries a high level of innovation is not risk-free. Such projects consume scarce development time and resources, need substantial investment and commitments of personnel to develop new technologies, add to consumer confusion and, above all, increase the difficulty to manage the NPD project itself (Tatikonda and Rosenthal 2000 a,b, Ulrich and Eppinger 1999, Swink 1999, Meyer et al 1997, Swink et al 1996, Zirger and Hartley 1994, Wheelwright and Clark 1992, Clark and Fujimoto 1991, Cooper and Kleinschmidt 1991, Clark 1989).

The degree of innovation in a NPD project is an important determinant of the level of effort needed to execute the project development work. High innovation means that the new product to be developed is radically different from the previous ones meaning that developers are not fully confident regarding the best methods to be used in the project, the outcomes of these methods, and what are the performance targets to be associated with the product's components. In other words the degree of "innovation" in a NPD project is a reflection of the level of "uncertainty" as defined in the project management literature.

For these reasons, the innovation factor attracted much attention as an important contributor to project complexity in NPD projects. Unfortunately, there have been some amalgam about the dimensions of the innovation factor in NPD projects. Most of the early theoretical and empirical studies restricted the innovation factor to the technological novelty dimension. However, an analysis of the recently published research suggests that the innovation factor in NPD projects can be broken down into two dimensions: the product newness and the level of uncertainty (risk) in the project (Tatikonda and Rosenthal 2000a,b, Tatikonda 1999, Swink 1998, 1999 , Griffin 1997a, Swink et al 1996).

2.2.1 Product newness

A broader definition of product newness is that it represents the portion of the new product which has to be redesigned from previous generations of the same product (if applicable). However, this general concept of the degree of product newness has been conceptualised differently in many studies. A review of the body of literature focusing on this issue shows that the definition of product newness has evolved considerably driven by the growing interest regarding its impacts on many NPD success and failure indicators.

Clark (1989) and Clark and Fujimoto (1991) were among the first to acknowledge the importance of this dimension as a driver of success (or failure) of NPD projects in the auto industry. Their definition was highly driven by the specificity and the practices within the industry on which the study focused. They represented "product newness" as the fraction of the pioneering (new) components in the vehicle and the major changes in body process technologies. A more general definition was subsequently introduced by Wheelwright and Clark (1992) in their study of NPD strategy and practices in a wide range of industries. They found that "product newness" was reflected by the degree of change required in the product and/or process technologies. This definition was also the ground for a classification of different types of NPD projects. The latter conceptualisation of product newness has been quite influential on subsequent research in NPD (Detoni et al 1999, Tatikonda 1999, Langerak et al 1999, Liker et al 1999, McDermott 1999, Adler 1995, Murmann 1994). Another stream of research associated product newness with the technological component in the product (or the process). McDonough (1993) and McDonough and Barczak (1992) were among the first to recognise that the degree of technology newness incorporated in a product is an important element of differentiation between projects.

However, regardless of the different definitions of "product newness", recent research shows that the degree of newness in a product is a significant driver of NPD performance, project outcomes, and project management difficulty (Tatikonda and Montoya-Weiss 2001, Koufteros et al 2001, Tatikonda and Rosenthal 2000 a,b, Swink 1999, Clift and Vanderbosch 1999, Zirger and Hartley 1996,1994, Swink et al 1996, Meyer and Utterback 1995).

This brings us to the focus here, which is to demonstrate the existence of a link between the degree of product newness and the overall project complexity, whether product newness is represented by the fraction of the product to be redesigned or by the breadth of new technologies embedded in the product. Product newness increases project complexity because many features in the project become sizeable increasing its management difficulty. Clark (1989), Clark and Fujimoto (1991), (1997a,b), and Swink (1999) reported that increased product newness leads to an exponential increase in the number of tasks to be performed to finish the project. This, in turn, requires significant amounts of labour-hours, expands time to market, and inflates project costs. Murmann (1994) reached the same conclusion as he pointed out that 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 causing to more resources and time to be consumed in the development project. Swink (1999) argued that if the number of new parts to be designed becomes important, developers would have to consider more design possibilities and alternatives. This will, in turn, tends to require more engineering design, prototyping, testing, production time, and capital and labour resources (Zirger and Hartley 1996).

The level of knowledge creation and learning involved in the project is also closely linked to the degree of product newness. Significant levels of product newness require high levels of knowledge creation, transfer, and synthesis (Zirger and Hartley 1994). Major innovations are associated with an intensive use of highly skilled labour, market knowledge, process ability, and considerable transfer of information among the organisation (McDermott 1999). The strong link between the degree of product newness and the corresponding requirements in terms of new knowledge development has been well summarised by Kazanjian et al (2000) who investigated the learning process in large-scale development projects:

[A product including high levels of newness is breakdown into a series of discrete design problems. Analysis of such design problems demonstrates gaps where existing technologies, established design standards, and accepted approaches are inadequate. Through process of experimental learning, including problem re-framing, brainstorming, hypothesis generation, and trail and error testing, creative solutions emerge to fill the gaps, thus, existing technical knowledge is extended and new technical knowledge is developed].

2.2.2 Project uncertainty

Uncertainty is inherent in NPD projects since each project includes a certain jump into the unknown. Its effects are critical to project success given that any project can be represented as a small organisation striving to achieve certain targets using some known (or less known) methods. Many authors (Tatikonda and Rosenthal 2000a,b, Swink et al 1996, McDonough 1993) pointed out that NPD projects are, to a great extent, non-trivial exercises. The suitable means, methods, and capabilities to be deployed in a project are not always well known at the start of development work execution and constraints of time and cost create more uncertainties on how to proceed to achieve planned project targets.

The effects of uncertainty in NPD projects can be better understood if NPD projects are conceptualised as organisational tasks involving creation and processing of information (Tatikonda and Rosenthal 2000 a,b, Tatikonda 1999, Olson et al 1995). To develop a new product, information has to be acquired, treated, and communicated among the different departments responsible for delivering the product. Therefore, an NPD project can be seen as an organisational task in which significant amounts of information are created, used, and transferred among different project constituents (Tatikonda and Rosenthal 2000a)

The magnitude and quality of this information, which determines the efficiency of NPD project activities, depends on the level of the prior knowledge carried by the development team about the project targets and the means to achieve them. In this context, uncertainty occurs whenever there is a gap between "the amount of information required to perform the task (in this case the NPD project) and the amount of information already possessed by the organisation (in this case the development team)" (Galbraith 1977). Obviously, the extent of this gap varies from one project to another meaning that NPD projects carry different levels of uncertainty (Tatikonda and Rosenthal 2000 a).

There are many sources of uncertainty in NPD projects. They include market, technological, and resource uncertainties. Market uncertainty indicates the uncertainty about the market segment targeted by the new product, definition and articulation of customers' needs, the appropriate loading of distribution channels, and the customers level of experience in acquiring and using the resulting product (Souder and Moneart 1992, Olson et al 1995,2001, Souder et al 1998, Tatikonda and Montoya-Weiss 2001). Technological uncertainty relates to the uncertainty about different technological capabilities, best technologies to be used in the product and/or process, technical risks associated with different technologies, and the degree of familiarity of the team with the technologies involved in the project

(Souder and Moneart 1992, Adler 1995, Olson et al 1995, McDermott 1999, Souder et al 1998, Swink et al 1996, Swink 2000, Tatikonda and Rosenthal 2000 a,b). Resources uncertainty reflects the uncertainty about the quantity, quality, and mix of resources to be put in the project (Souder and Moneart 1992, Swink et al 1996).

Uncertainty is an important dimension of project complexity in NPD projects because it makes projects more difficult to organise and manage. If we recall the project definition given earlier, organising a mix of resources under significant constraints to achieve specific goals become more difficult as the level of uncertainty in the project increases (Chapman and Ward 1997). Many empirical studies based on different theoretical grounds have come to the conclusion that the higher the level of uncertainty in a project, the more difficult to manage the project, and, consequently, the longer it takes to finish it, and the higher are the costs involved. One stream of research conceptualised NPD projects as an information processing exercise and argued that the more the project is uncertain, the more is the gap between the required information to perform the project and the available information within the organisation, the more it becomes difficult and lengthy to perform the task as the learning curve is slow, problem solving methods inaccurate, and the set of possible solutions large. In such contexts, large amounts of information about technical details of new products and processes, project organisation forms, and customer preferences are usually not available at the beginning of the project (Emmanuelides 1993). This will create the need for new search procedures and information-processing patterns (Iansiti 1995). The consequence is that developers will be redoing the same tasks many times before converging to a solution (Zirger and Hartely 1994) leading to a lengthy project and inflated costs (Tatikonda and Rosenthal 2000a,b, Tatikonda 1999, Zirger and Hartley 1996, Souder and Moneart 1992). Resource dependency theory has been also used to demonstrate the negative effects of uncertainty on NPD project outcomes. Grounded on the rationale that NPD projects are inter-functional tasks, this theory posits that the more the project is uncertain, the more the personnel in a function become dependent on colleagues in other functions to perform their own tasks. This results in a huge amount of information transfer and feedback loops between different functions and team members in the project (Swink 2000, Olson et al 1995) leading to an extension of the time required to deliver the product to the market. Other authors like Souder et al (1998) and Liker et al (1999) developed a framework based on contingency theory to demonstrate that the outcomes of a project are contingent upon the level of uncertainty in that project. High degree of uncertainty calls for significant levels of integration between different functions involved in the project execution resulting in a significant increase in development cycle time and costs (Liker et al 1999, Souder et al 1998). Other authors, using case studies research, have also indicated that high levels of project uncertainty affects considerably how a project is managed and ultimately impacts its outcomes (McDermott 1999, Swink et al 1996).

The strong link between project uncertainty and overall project complexity, as demonstrated by the previous studies, arises from the fact that most activities in an NPD project are affected by project uncertainty from the planning stage until the project delivers its outcomes. In this context, project planning is affected by uncertainty because the more the project is uncertain, the more time is needed to determine the needs of customers targeted by the new product, to select the most promising technologies to be used in the product (or process), to determine which firm capabilities to be deployed in the project, and to trade-off different project goals. Similarly, uncertainty affects project execution phase with respect to many development activities. Poor understanding of technology in highly uncertain projects is likely to result in greater ambiguity on how to solve technical problems and which problems are crucial to solve (McDonough 1993). If uncertainty increases significantly, developers will have to carry out many iterations before a technical solution is found (Swink et al 1996). Engineering changes orders (ECOs) occur at higher rates as the understanding of the technological capabilities is low and increases slowly over time (Loch and Terwiesch 1999, Murmann 1994). In addition, co-ordination mechanisms have to be altered in order to facilitate transfer of information among functional departments. High levels of uncertainty require extensive communcation and information transfer among developers working in different parts of the project (Tatikonda 1999, Souder at al 1998, Olson et al 1995).

In summary, project uncertainty is an important driver of project complexity in NPD projects. Given that it has many possible sources (market, technology, resources) and affects all aspects of project management (planning, execution, co-ordination), it has to be included as a dimension of project complexity on its own right.

Conclusion

Although project complexity has been recognised recently as a major issue in project management, there is still a great deal of confusion on how it should be defined and articulated. The importance of determining project complexity factors and their levels in a project is crucial as these factors have a significant impact on project planning, execution, control, and management, and ultimately project success and failure.

The need to define project complexity is even more acute in NPD projects, which by their innovative nature, are difficult to manage and for which failure has been the rule rather than the exception. Determining these factors in NPD projects will certainly help project managers improve planning and execution procedures, predict sources of uncertainty and difficulty in projects, and better understand the sources of project failures. The framework developed in the current paper aims at alerting project managers to the sources of difficulty in NPD project such that they have a better estimate of the scale of the work required in these projects and, therefore, to be able to design the appropriate tools and methods to plan, execute, control, and manage these projects.

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