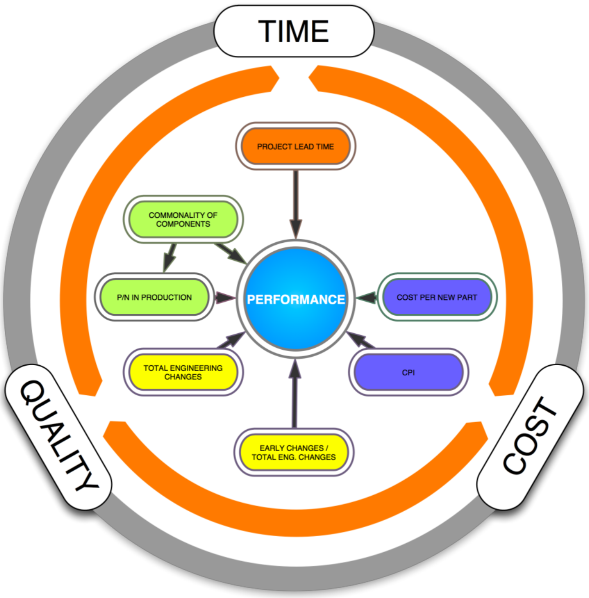

Defining a Framework to Measure Performance of Product Development Projects

Master of Science Thesis

in the Master's Programme International Project Management

JOSÉ ALBERTO CASTRO SÁNCHEZ

Department of Civil and Environmental Engineering
Division of Construction Management
CHALMERS UNIVERSITY OF TECHNOLOGY
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Master's Thesis 2010:114

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Cover:
Performance indicators to measure performance from different perspectives tested in the case study of this thesis (see Chapter 4).

Reproservice / Department of Civil and Environmental Engineering
Göteborg, Sweden 2010

Dedicated to my parents and my brother

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Abstract

There is a great opportunity in reducing waste in projects, but before any achievement in this field is claimed it is necessary to know where the organization stands. The implementation of performance measurements satisfies the curiosity of knowing how the organization is operating, and sets the baseline for evaluating objectives, programs, projects, and people. The definition of performance measurements affects the behavior of individuals, and for that reason the definition of performance measurements must align with organizational and individual goals in order to trigger behaviors that are beneficial for the operation of the firm. On the other hand, if performance measurements are not defined correctly, they may generate unease among individuals and behaviors that are detrimental to the firm.

The measurement of performance of product development projects, even in mature organizations, is a complex task due to the subjectivity of the concept, to the difficulty of appraising intangible deliverables, and to the different meanings that performance has for different parties. Furthermore, projects may have different duration, assigned budget and scope. Therefore it is necessary to define a common ground for assessing the performance of projects from different perspectives.

The purpose of this thesis is to define a framework to measure performance of product development projects, based on indicators that are suggested in the literature and that are proven to be applicable in a real context. A literature review and a case study fulfill the purpose of the thesis. The literature review supports the selection of eight indicators that assess performance from different perspectives. Theory from project management, product development, quality management, logistics, and marketing comprise the content of the literature review. A case study tested the applicability of those indicators and sustained the further selection of seven indicators.

It is concluded from this research work that no single indicator is capable of measuring performance in a complete manner; instead a set of indicators must be used in order to capture the different perceptions of performance surrounding product development projects. The use of indicators suggested by the literature depends on the context of the firm in which they are applied. However, general principles for measuring performance and fostering good performance were identified.

Key words: product development, performance indicators, performance measurement, project performance, weighting factors.

Contents

Preface

In words of Dr. Harvey Maylor (2005), the business world is shifting in many fields towards a more *projectified* structure in which professionals are often responsible for managing projects. A working environment that deals with projects, which increase in number and complexity, has forced project management to evolve towards a discipline that uses tools, knowledge and contributions from various other fields in order to achieve goals in the best possible way.

As with other specialized disciplines, project management also requires research and methods to evolve, correct itself and progress. On the one hand, research provides project management with findings to assemble its body of knowledge and set the foundation for practical applications. On the other hand, the use of methods provides the structure to incorporate the different parts of its body of knowledge to fulfill specific purposes. That is, how to do the right things right in projects.

The lifespan of projects to develop new products depends on the nature of the products and their associated applications. The duration of projects, the resources allocated to them, and the level of complexity varies. Therefore it is necessary to define a baseline for comparing projects with different characteristics and to unify the criteria of assessing projects across an organization.

This study focuses on product development projects and contributes to Project Management by proposing a method to link project deliverables to customer requirements in a systematic manner. It suggests a standard baseline to allocate weight to deliverables in the completion of the project and also proposes a framework to assess directly and indirectly the performance of product development projects. The ultimate purpose of measuring the performance of projects is to set a baseline to track the evolution of an organization towards maturity.

Beyond representing the culmination of my master studies, this research also represents the effort of many other people. Due to confidentiality restrictions I omitted the name of the company, as well as the names of the people that participated in this research. However, I would especially like to thank my mentor at the company and Mikael Frödell, my thesis supervisor at Chalmers, for supporting and encouraging me in this endeavor. I also would like to thank to all the people at the company that, in one way or another, made this thesis possible with their help, insight and feedback. In addition, I would like to recognize the contributions that Sven Gunnarson and Erika Andén made to conduct this project to a good conclusion.

Göteborg, April 2010

Alberto Castro S.

Notations

ABC	Activity Based Costing
AC	Actual Cost
CMMI	Capability Maturity Model Integration
CPI	Cost Performance Index
CV	Cost Variance
EV	Earned Value
EVA	Earned Value Analysis
PV	Planned Value
PMI	Project Management Institute
QFD	Quality Function Deployment
SPI	Schedule Performance Index
SV	Schedule Variance
WBS	Work Breakdown Structure

Glossary

Analysis of Variance

A collection of statistical models to test if the means of two or more groups are equal or not.

Anderson-Darling Normality Test

A statistical analysis to test if a sample of data arises from a normal probability distribution.

Cost Break Down Structure

A tool used to define the work element required to complete a project. It may be represented as a tree structure with subdivisions of tasks required to achieve the objectives of a project and it provides a framework for cost and schedule estimating and control.

Deliverable

Any tangible or intangible product of a project that is intended to be given to the customer, either internal or external.

Earned Value

The Work actually performed in a project. It does not constitute the actual cost of the project but the actual accomplishments of the project based on what was planned to be delivered.

Maturity

According to the CMMI (2006), the improvement path is characterized by maturity levels, each of them with characteristic processes and behaviors. Each maturity level has the purpose of removing uncertainty and creating a foundation for improvements that are lasting and incremental.

Portfolio

A collection of projects, grouped together to ease management and to achieve strategic business objectives. The projects within the portfolio may or may not be interdependent (PMI, 2004).

Project

The PMI (2004) defines project as a temporary endeavor undertaken to create a unique product, service, or result.

Statement of Work

The document in which the customer defines the work activities, deliverables, and schedule that a vendor or supplier shall fulfill. Pricing and regulations may also be included this document.

Work Package

A part of the project comprised by a set of actions to create a specific result. They are defined by brief statements containing description, necessary resources for completion, risk, budget, estimation of effort, and duration.

1 Introduction

In his foreword to the 2005 edition of Harvey Mayor's Project Management book, Professor D.T. Jones states that nowadays project management is an endeavor that goes beyond managing the sequence of tasks to produce an outcome (Maylor, 2005). Project management aims at incorporating the voice of the customer in a systematic manner, balancing the available resources and integrating the different parties and disciplines to deliver in the best possible manner. Jones also identifies a great opportunity in reducing waste in projects, but before quantifying the effects of process improvements, a baseline must be defined. Measuring performance constitutes one of the forms to define that baseline.

Levine (2002) defines that the implementation of performance measurements satisfies the curiosity of knowing how the firm is doing and indicates which parts of the process are not executed as expected. Performance measurements help to estimate the effects of improvements and trigger the investigation of root causes when drawbacks are detected. Moreover, measuring performance in the early phases of projects allow areas that need attention to be detected and corrective actions to be implemented. Regarding the managements of cash flow in projects, monitoring performance supports the billing of projects based on accomplishment rather than on schedule, which prevents overpaying and encourages on-time delivery. Hauser and Zettelmeyer (1997) declare that performance measurements within product development are used to justify investments and document the value of the product development efforts. Furthermore, performance measurements enable top management to evaluate people, objectives, programs, and projects in order to grant rewards and assign resources. Performance measurements affect the behavior of individuals since decisions are made and actions are taken in order to enhance the metrics and to secure resources. Bourne and Neely (2003) declare that defining the right performance measurements is fundamental in aligning individual goals with the organization's goals, but introducing the wrong measurements is counterproductive since it generates risk avoidance and inhibits the individuals' decisions and actions.

Cooper (2001) declares that new products are necessary for the long-term success of a firm. They broaden the product portfolio and provide a competitive and sustained advantage. Nevertheless, keeping a pipeline of new products requires a considerable investment of resources. A study, carried out by the Product Development and Management Association found that of every 7 new products ideas, 4 are transformed to product development projects, 1.5 complete the development process and are launched, and only 1 results in a successful product (Cooper, 2001).

Given the high odds of failure inherent to developing a new product, it is fundamental for a firm to enforce good practices to drive success and to introduce the right performance measurements. In addition it is advisable that the organization gathers as much information as possible regarding the market conditions and the execution of projects in order to make informed decisions, improve their profit or reduce their losses.

1.1 Purpose and research questions

The purpose of this thesis is to define a framework to measure performance of product development projects. First, a literature review of various fields is used to assemble the theoretical framework with a selection of indicators that measure performance from different perspectives. Then, a case study is used to determine which indicators from the theoretical framework can be measured in real conditions, and to expose the implications and limitations in the use certain indicators. Due to confidentiality restrictions, the real name of the firm is substituted with Specialized Vehicles Inc. Two research questions are formulated to guide the research:

a. What indicators are suggested in the literature for measuring performance of product development projects?

b. Which of the indicators suggested in the literature can be measured at Specialized Vehicles Inc. and how?

1.2 Structure of the thesis

As depicted in Figure 1.1, the thesis is divided into seven chapters that correspond with the different stages of the study. The first chapter describes the need that generated this research project. Chapter 2 contains the theoretical framework of the thesis, which comprises a set of indicators that were selected from a broad literature review. Chapter 2 also explains how the Quality Function Deployment (QFD) can be used to calculate weighting factors of deliverables in product development projects, in order to evaluate the performance and monitor the progress of projects in real time. Chapter 3 describes the methodology of the case study. Chapter 4 exposes the findings of an exploratory study conducted prior to this research and describes the case study used to test the applicability of the different indicators selected in the theoretical framework. Chapter 5 discusses the results of the case study, including the advantages and shortcomings in the use of different indicators to measure performance in product development projects. To conclude, chapter 6 summarizes the findings of this master's thesis and proposes lines for future research.

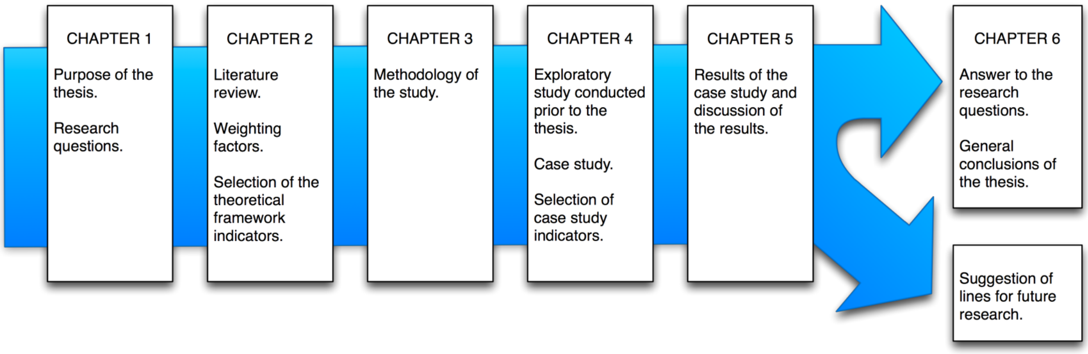

Figure 1.1 Structure of the thesis

2 Literature review

This chapter identifies indicators to measure the performance of product development from different perspectives. The content of articles and textbooks condenses the practitioners' experience and researchers' knowledge into the selection of the indicators presented at the end of this chapter. This first selection of indicators answers the first research question.

While some of the indicators can be measured directly from the data generated when the project is in progress, others cannot. Tools and concepts from product development, project management and quality management are combined to describe a method for dividing projects into smaller units that allow the assessment of projects during their execution and facilitate the data collection of indicators that cannot be measured directly.

2.1 Performance and the triple constraint in projects

Different authors define the performance of projects in terms of indicators that can be basic or derived depending on the way in which they are measured. While basic indicators are measured directly and their units are typically the same units used in the measurement, derived indicators are usually calculated through the mathematical combination of different types of data and their units are compound or scaled (Macedo and Rozenfeld, 2008; Echeveste, et al., 2005). In some situations, derived indicators may be obtained from the interpretation of observations, which gives them a more subjective character compared to basic indicators. In such cases, the participation of more than one appraiser is suggested to enhance the accuracy of the interpretation. Subjecting the appraisal to a methodical arrangement of standard steps can reduce the degree of subjectivity.

Levine (2002) mentions that the advantages of having a method to measure performance are the reduction of inaccuracies and subjectivity in the estimation of progress, and the increase of fidelity between the data and the real estate of the project. The latter helps to prevent creating a false sense of accomplishment and subsequent disillusionment, generating errors in time and cost forecasts, and making decisions based on inaccurate information. He states that the only one thing worse than not having performance information is having false information.

The product development literature reveals that in recent years the focus of measurement has shifted from the results to the early phases of the product development process. Different authors coincide in the choice of indicators that are used in projects to appraise performance in terms of cost, time and quality since these three elements are closely related and their interactions affect the outcomes of projects (Echeveste, et al., 2005; Borsato, et al., 2007). Figure 2.1 represents the direct relations between cost, time and quality. For instance, if the execution cost of the project is to be cut, it is expected to experience differences in the quality of the outcomes of the project and its duration. In another scenario, if quality of execution is improved in a project, it may result in savings derived from the avoidance of rework cycles, which may outweigh the additional costs and result in shorter overall project duration. Sections 2.1.1 through 2.1.3 explain how quality, time and cost are defined in projects and how certain indicators address these three elements.

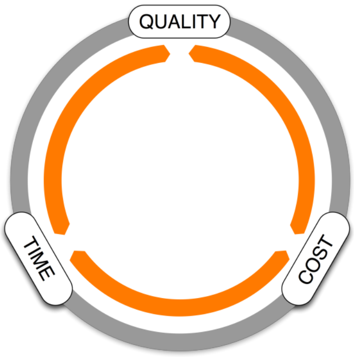

Figure 2.1 Direct interaction between quality, execution time and cost of projects

2.1.1 Cost

One of the most common variables mentioned in the product development literature used to monitor the performance of projects is cost (Borsato, et al., 2007; Echeveste, et al., 2005; de Toledo and Souza, 2005). Several authors indicate that while costs set the lower limit for prices, the customer perception of value sets the upper limit (Freixo and de Toledo, 2004). Armstrong and Kotler (2007) point out that a company must consider a number of internal and external factors when setting prices within these limits. Internal factors affecting pricing include the company's overall marketing strategy, products mix and the organization's objectives. External factors include the market conditions and nature of the demand, competitors' strategies and prices, and other environmental factors. More importantly, they define that pricing must be based on the value of the product as perceived by the customer. Therefore any pricing method that ignores the customer value and competitor prices is unlikely to lead to an adequate price.

Although markup pricing, break-even pricing and target profit pricing are among the most popular pricing methods, they are focused only on costs and fail to consider the customer value, the relationship between price and demand, and the likelihood that the needed volume will be achieved at each possible price (Armstrong and Kotler, 2007). Besides the possible negative effects on the market success of a product as a result of inappropriate pricing, inaccuracies in price definition may result in the reduction of profit margins if the costs are to remain unaltered. In another scenario, a considerable pressure on costs may result if the profit margin is to be kept (Maylor, 2005). Similarly, a faulty estimation of cost produces a reduction of profit margins if the price is to be maintained.

Maylor (2005) describes the price build-up as the addition of direct labor and material costs, project overheads, general overheads, and profit. These elements, depicted in Figure 2.2, are parts of an equation in which price, profit or cost may be fixed objectives that depend on the strategy of an organization and affect the other two elements. Maylor explains that, among others, the aerospace and automotive industries have increasingly used target costing to offer competitive prices in their markets. He explains that under that pricing scheme, the price of the final product is set to appeal the customer, profit is typically set at corporate level, and target cost results from the difference of price and profit. Armstrong and Kotler (2007) explain that target costing focuses on the customer's willingness to pay for a certain product and delimits the costs necessary to ensure that the price set by the customer is met.

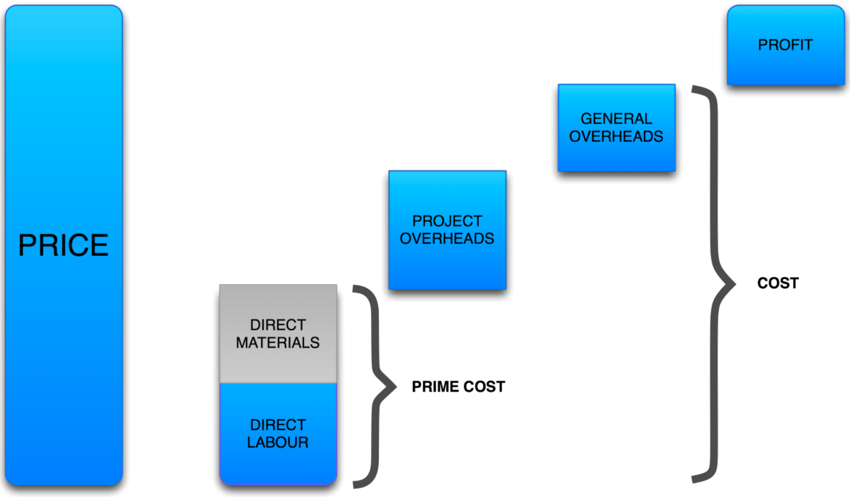

Figure 2.2 Elements of price and cost (Maylor, 2005)

Freixo and de Toledo (2004) define that the total cost of a product comprises the costs for the physical production of a product, and other less evident ones such as development, distribution, operation, maintenance, and disposal. Maylor (2005) explains that development costs may be internalized if the organization carries out the development and production of new products, or externalized if their suppliers do it instead. In the case of externalizing the product development process, a large portion of the target cost is moved towards the suppliers, who will set target costs for their own organizations as well.

Estimation of costs in product development projects

Ben-Arieh and Qian (2003) depict the current market reality as one that fosters a reduced life cycle expectancy of products. This situation has increased the share of the development phase in the overall product life cycle. As a result, the development cost has become an important part of the total cost of products. In order to have a correct estimation of the product costs, the design and development cost have to be accurately measured. Freixo and de Toledo (2004) explain that the determination of product target costs can be carried out by surveying the clients, by comparing with similar products in the market, or by consulting the product development team and the decision makers in the organization.

Price and therefore cost, are characteristics which target value should be defined during concept development or during early phases of the development of new products (Freixo and de Toledo, 2004). Jans, et al. (2008) define development costs as the costs incurred in the creation of a new design. Ben-Arieh and Qian (2003) indicate that some of the activities that contribute to the cost structure during product development include, but are not limited to, design, engineering, production planning, production of prototypes, and testing. According to these authors, traditional costing techniques distort the cost information by only considering overheads.

Activity Based Costing, or ABC, is a technique to define the cost structure of product development projects. It is mentioned in the product development literature that the project costs can be identified more precisely using ABC because the activities are mapped in detail, the resources necessary to perform those activities are monitored, and finally the costs per activity are estimated (Filomena, et al.,2005; Ben-Arieh and Qian, 2003). This approach links the costing objectives with product features, or in the case of projects, with specific deliverables that are verified during quality checks. Monitoring the cost per deliverable is hence important in tracking the execution of projects. New parts represent the natural deliverables of product development projects; therefore *cost per new part* is selected as a performance indicator. During the development of a product, several parts are created, modified and sometimes discontinued. The only parts suitable for commercialization are production part numbers and therefore used to calculate this indicator.

Moreover, Maylor (2005) mentions that ABC is a direct work measurement used in many organizations to determine the cost of specific activities. Timesheets are one of the preferred ways of registering in which activities individuals spent time on an hourly or on a daily basis. Filomena, et al. (2005) indicate that target costing, ABC costing and feature costing are the most commonly used costing techniques during product development. While target costing defines the cost objectives, feature costing and ABC constitute a way of estimating development costs in an accurate and traceable fashion. Both feature costing and ABC are helpful to determine the product development costs of highly customized and varied goods. As a complement, the use of ABC can lead to the classification of activities as value-added and non-value-added; which allows the simplification of the product development process (Ben-Arieh and Qian, 2003).

ABC enables conditions to refine the cost estimates of future projects. According to Filomena, et al. (2009), a company may not execute a project identical to another one carried out in the past, but some cost parameters of old projects will help to define a reference point for the current project cost. The authors suggest the use of databases to build an ABC system in which future estimates are based on the refinement of past estimates and experiences.

Factors that affect the costs of product development projects

Several characteristics of a product are decided early in the development process. Target values, the central concept of the product, technology, final applications, shape, and design principles are among those characteristics. In addition, during the development of a new product other key parameters related to the structure of final products are defined, such as relations between components, precedence of assembly, materials, and processes (Freixo and de Toledo, 2004). The definition of characteristics in the early phases of product development projects does not incur in great costs but it commits a greater deal of costs by fixing dependencies with other parts and processes. Figure 2.3 depicts both the incurred and committed costs during the conceptual phases of the product development process. It is in those phases where changes are easier and cheaper to implement because dependencies are not yet fixed, purchase orders are not submitted, and physical production has not started yet. Graham (2000) states that components of complex products can seldom be redesign without affecting other parts, and without rework cycles. A more comprehensive definition of rework cycles and their implication is described in section 2.1.2.

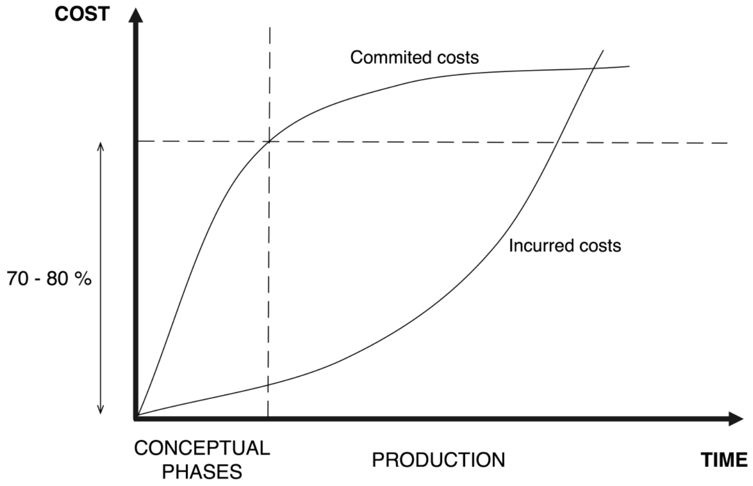

Figure 2.3 Commitment of the product cost curve (Freixo and de Toledo, 2000)

Graham (2000) states that the frequency of changes is much higher early in the product development process when customers are involved in the definition of characteristics. Paradoxically the projects seem to be in trouble and surrounded by chaos but in reality issues are being solved early in the project, when dealing with changes is much less expensive. The more advanced the development of a product is, the larger the impact of changes on cost and time. Conversely, the earlier the change is made, the quicker, easier and less expensive it will be (Freixo and de Toledo, 2004). As a result, a project is likely to perform better, in terms of cost and duration, when a higher number of engineering changes are performed in early phases of the development process. For this reason, the *ratio of early engineering changes over total engineering* is selected as a performance indicator of product development projects.

Component commonality is another factor with great impact on the development costs and other functions of the value chain of a firm (Jonsson, 2008; Jans, et al., 2008). It is defined as a strategy to limit the range of components, dimensions, material qualities, shapes, colors, and other characteristics to design and manufacture products. Developing common components are more expensive due to a large number of constraints and conditions to fulfill but the benefits may be worth the investment. Jans, et al. (2008) formulate the problem of increasing the component commonality as an investment decision. They compare the investment of developing a common component against a future extra profit using the net present value of the project. Their study is validated by a case study in which operation and production improvements and development savings resulted from the development of common components.

Regarding product development, commonality of components reduces the total product development costs since fewer components have to be developed. Jans, et al. (2008) indicate that component commonality is inversely related to the unit production cost and development cost per unit, which means that with an increase in component commonality it is expected one will also experience a decrease in unitary production and development costs. *Commonality of components* impacts the performance of product development projects from the cost perspective; therefore it is selected as a performance indicator. The measurement of this indicator helps to understand and communicate the advantages of commonality in the development of components for final products.

Other advantages mentioned by Jans, et al. (2008) are the avoidance of duplicated R&D costs and the simplification of operations. Fewer part numbers simplify forecasting and quality control systems, and may improve the quality of execution in projects since more time is available for the most profitable products. Commonality has an impact on the financial results of a firm since less capital is tied up, resources are utilized more intelligently and the development costs can be diluted in a larger number of production units. In addition, the risk of obsolescence of a particular component is reduced through its utilization in low and high turnover products (Jonsson, 2008).

Limiting the component range results in the reduction of administrative work required to control the flow of materials. Jonsson (2008) states that commonality also represents advantages in logistics, since the consolidation of manufacturing orders leads to less planning and follow-up work. Normally the total set-up time for starting a new order can be reduced and the level of service can be improved due to consolidation and flexibility of shipments.

2.1.2 Quality

Quality is the way of measuring the state of being free of flaws and deviations. When the right parameters are measured and the products of a project satisfy the customer's needs and expectations, the project is focused on quality (Angel, 2010). Quality evaluations should therefore measure functional performance oriented towards the satisfaction of customer requirements by estimating the deviation between the desired and planned characteristics and the actual ones (Echeveste, et al., 2005). In the case of projects, the customer is not always a person or an entity external to the organization, in many cases customers are other parts of the same organization. Therefore a project may be oriented to satisfy both external and internal customers.

Cooper (2001) affirms that having a formal product development process does not contribute to the success of new products; rather it is the quality of the process and best practices that drive success. Cooper identified that the best practices related to the quality of product development processes emphasize the attention on the market and technical assessment of the idea before moving to the development phase, defining the product as early and detailed as possible, having tough pass/fail decision points during the development phase, focusing on quality and completeness during the execution of activities, and have a development process that adjusts to the nature and risk of the project.

A clear and visible business strategy is another success driver identified by Cooper (2001). In addition to defining how new products contribute to the business, Cooper also suggests that clearly communicating the role of products in achieving business goals, defining the focus areas of new products, and having a long-term thrust and focus are the best practices related to the business strategy of a company. Cooper also points out that the best firms in each class commit the resources needed to undertake the development of new products throughout the entire project, and maintain a high quality in the execution of activities. Therefore it is crucial to align the allocation of resources with the objectives of the project and secure the resources needed to carry out projects without compromising quality.

Best practices help to have a healthy product development process, measuring the performance of product development projects is way of monitoring the effects of the best practices described before. In addition, performance measurements enable the evaluation of projects and signal when corrective actions must be taken. Measuring the performance of a project in terms of its quality of execution enhances the visibility of areas that need quality improvements. A way of measuring quality of execution in product development projects is to record the engineering changes experienced during the project. It is for this last reason that occurrence of *engineering changes* is also selected as a performance indicator.

Translation of customer requirements into characteristics

Echeveste, et al. (2005) indicate that product development projects experience adjustments that fit the outcomes of the project to physical, technological, and scope constrains. However they can also lead to considerable deviations from the scope and demands of the project.

Cooper (2001, pp 23) indicates that the most common source of failure in new products is the disconnection between the customer needs and the project outcomes, which may be caused by poor marketing or by misunderstanding the customer needs. Not understanding the priority of the customer needs also contributes to the failure of products and projects. Therefore a constant focus on the customer is fundamental throughout the development process. It is common that product development projects lack market orientation or adequate market assessment. If the success of new products is to be pursued, a market orientation of projects is needed, along with quality of execution. These two factors should constitute the rule to manage projects and not the exception.

The Quality Function Deployment, or QFD, is an approach to develop new products with characteristics that are important to the customer. The major benefits of using this approach are ensuring that the customer requirements are included in the final outcome, and reducing the design cost and development time. Moreover, QFD is aimed at satisfying the customer by translating their demands into design targets and major quality assurance points (Herrmann, et al., 2004).

The application of QFD is not limited to products, projects can also benefit from its application. QFD focuses on how certain product characteristics meet customer needs; in the case of projects those characteristics are embodied by the deliverables that help to drive the project towards its successful completion. While features define and shape the final product, the different deliverables of the product development process shape the project.

Very often, customers discover mismatches and request changes to the product very late in the development process. These changes are added to the rework created by original work. In order to avoid mismatches, customer requirements should be reflected in specific features of the products and functions of the project. The participation of customers is recommended in points of the design process where characteristics of the project and features of the product are decided. This provides continuous guidance in the satisfaction of customer requirements. In this same line, it is advisable to encourage the inclusion of members in the team capable of detecting faults as well as providing solutions to prevent problems from occurring (Graham, 2000).

Rework and the cost of poor quality

Graham (2000) defines productivity as the creation of work products, and quality as the amount of work products that will not require further reworking. He explains that complex systems often result in rework cycles that represent half of the total work to be performed. Product development projects, by nature, are part of complex systems and therefore rework is not uncommon. The cost of poor quality encompasses the effort and use of resources to carry out corrections derived from the lack of quality in execution.

Cooper (2001) affirms that the amount of rework that a project will experience is largely decided in the early stages, therefore a sharp and early definition of the business case and the outcomes of a project are fundamental to reduce the occurrence of rework. Paradoxically, it is common that most of the time and money spent on projects corresponds to the middle and late stages, mainly due to errors that originated in the early stages as products of omission, poor quality of execution and inappropriate allocation of resources. Cooper points out that the initial steps in the product development process are typically loosely defined and weakly managed, yet they make all the difference between the success and failure of projects.

Delays in the detection and correction of rework can increase development costs dramatically, not to mention its impacts on time and quality. Product development literature points out, as a rule of thumb, that the cost of reworking increases about 10 times per every development phase that passes undetected (Graham, 2000; Freixo and de Toledo, 2004). Graham (2000) explains that the cost increase starts as a chain reaction triggered by defective work, or incorrect information. The chain of events then continues with the erroneous assumption that the existing engineering work is correct, propagating the effects of rework further down to other dependent tasks. It is important to signal rework and deal with it as early as possible to prevent the propagation of rework and its detrimental effects on cost, time and quality.

Rework discovered but not reported is as harmful to the project as undiscovered rework. Cooper (2001) suggests the elimination of *shoot the messenger* policies in order to facilitate the reporting of rework as early as possible. The number of *engineering changes* and the *ratio of early engineering changes over total engineering changes* foster the early detection of rework in the development process and avoid questioning the project quality based only on the amount of recognized engineering changes. A project may receive a good performance score when the majority of faults are detected early in the project, not only if few faults are reported.

Besides the effects on cost, de Toledo and Souza (2005) state that rework impacts the quality of the outcomes of the project, and to some extent its success, since the resources intended for completion of the work, as contemplated in the original scope of the project, should be used to perform work out of the scope as well. Furthermore, rework has a negative impact on project lead-time because the additional work results in an overload of human resources. These authors indicate that ignoring the capability and quantity of the human resources involved in the project at early development phases, increases rework afterwards.

Echeveste, et al. (2005) advise the implementation of controls to reduce the incurrence of rework thus mitigating the costs of poor quality. The implementation of checklists between different phases is a form of controlling the product development process and integrating different parties to fulfill functionality and quality requirements. The checklists are verified at different points during the evolution of the project to validate that the project has reached specific milestones whose ultimate purpose is to conduct the project to its successful completion. Metrics, taken in real time, help to verify that the outcomes from projects are in line with the requirements and scope originally defined for the project, or to make adjustments during the execution of the project. Controlling the project in real time reduces the cost of rework associated with premmature decisions.

Booker, et al. (2001) declare that the use of quality tools and techniques influences the reduction of errors. Their use in early phases of product development projects contributes to a reduction in design changes and thus rework. Furthermore, they state that improving the communication between parties can reduce the effects of rework. This can be achieved by having information available at critical stages so that the project team can take informed decisions.

To reduce rework, Cooper (2001) recommends emphasizing the comprehensiveness and quality of deliverables in projects, rather than passing project milestones at all costs. He argues that often, when quality is emphasized, the project is completed in a timely manner. Moreover, acknowledging the existence of rework, and planning ahead prepares the project team to react faster and more appropriately upon the occurrence of rework.

2.1.3 Project Lead-time

Lead-time is one of the most mentioned metrics of performance in product development literature (Echeveste, et al., 2005; de Toledo and Souza, 2005; Borsato, et al., 2007; Jonsson, 2008). The time invested in a product development project from the conception of a product to its launch is known as time-to-market. According to Jonsson (2008) time-to-market has a large impact on the innovation capacity of a firm since a short product development time can provide a time advantage in the market with respect to a competitor’s products. Conversely, a large product development time may result in delays, and the launch of a product that is no longer attractive to the market.

Cooper (2001) considers short lead-time as an interim goal and profitability as the ultimate goal of a firm. Instead of defining time to market as a metric of the execution and performance of projects, he suggests the use of time to profit instead. This measurement of time considers the time line of a project from its initiation to the point in which it recovers its costs and collects profits. He supports this with the fact that some of the efforts to reduce lead-time result in considerable cost increases. In other words, those efforts bring a product to the market soon but fail in obtaining profit. The latter may be accentuated by launching a product that has serious quality and reliability failures or that does not address customer need, which damages the customer confidence in the firm and may imply substantial warranty costs. Cutting corners in product development projects may result in short-term timesavings that may return as rework in the future.

Rosenthal and Tatikonda (1992) analyze the case of seven product development projects in different firms. Among their conclusions, they state that setting clear time targets facilitates the time management of projects. However, time was not always the first priority in the cases presented in the article; often cost and functionality were considered as more important. The actual time required to introduce a new product is only one measure of performance in product development projects and must be considered in the context of potential tradeoffs with cost and quality of the outcomes. Therefore it is fundamental to determine what are acceptable and realistic aims in terms of time to avoid compromises that result in detriments to the final product and its success. Time targets should reflect a reasonable understanding of the execution of projects. It is likely that cycle time reductions will not result in cost and quality compromises if they are produced by reducing nonproductive time and increasing the overlap with which tasks are performed (Rosenthal and Tatikonda, 1992).

Time has a relative priority that varies across product development projects. Cooper (2001) explains that the sense of urgency varies greatly across the organization; therefore project managers must be aware of the relative priority of time. Typically, the marketing department and management are the functions with a higher sense of urgency while technical departments tend to have a long-term orientation. Rosenthal and Tatikonda (1992) point out that the relative urgency of the project, and planning and managing the project with the reduction of time variance in mind are elements of equal importance in the time management of projects.

Rosenthal and Tatikonda (1992) conclude that time targets are affected by external and internal forces acting on the firm. Among the external forces, the introduction of regulations and deadlines for compliance with those regulations have a large impact on projects. Date of trade shows, customer time requirements, and the launch of competitors' products are some other external time constrains that set deadlines for the project. Forces that are internal to the firm are typically related to managerial and technical capabilities, planning skills, production capacity, milestones defined in the strategic plan, availability of technology for commercial application, and definition of the introduction dates by upper management. Beyond the internal and external forces that define time targets, de Toledo and Souza (2005) indicate that there are factors affecting the duration of the activities related to product development projects. Those factors with larger impact on project lead-time include experience of the team, availability of technological resources, integration of functions, simultaneous execution of activities, and rework.

Conditions that help to reduce lead-time

In addition to meeting customer requirements through the characteristics, quality and cost of outputs, the time in which the customer can have access to the product is also important for the success or failure of a product. Therefore the deliverables of the project must be scheduled to meet the launch date of the product. According to studies, poor timing of introduction is responsible of 8% of project failures (Cooper, 2001). Poor timing may imply moving too slowly and missing an opportunity window, or moving forward too fast without defining clearly the customer requirements, plan and products. Rosenthal and Tatikonda (1992) suggest that management needs to be more precise in the definition of quality, cost and customer satisfaction parameters during the early phases of product development projects in order to reduce the project lead-time without compromising the quality and functionality of the final product.

Booker, et al. (2001) indicate that rework represents an opportunity for reducing lead-time by 30%. Furthermore, they indicate that two thirds of technical modifications can be avoided if communication is improved. Therefore having agile and updated communication systems result in lead-time reductions through the prevention of rework. In general, any condition that prevents the occurrence of rework also helps to reduce lead-time.

As mentioned earlier, speed in project delivery or short lead-time is a powerful advantage that reduces the likelihood of facing different market conditions once the product is launched compared with those in play at the project's inception. It also means that the time to obtain profit is shorter. Nevertheless reducing the lead-time of a project should not compromise the achievement of quality and cost goals of the project (Cooper, 2001). In addition, Cooper states that defining an unrealistic schedule for the project creates frustration and tension among the members of the project team. As time objectives are not met, functional teams tend to blame each other for not delivering in time, which deteriorates the team effectiveness and breaks down trust.

According to Cooper (2001), with parallel processing the activity in a project is more intense and more work is completed in the same elapsed time. For instance, Cooper explains, if three or four activities are done simultaneously by different members of the project team, the resulting reduction of project lead-time also prevents tasks from being overlooked and reduces the occurrence of compromises in the quality of execution. Furthermore, Cooper argues that under parallel processing, the activities are designed to feed each other, causing the entire product development process to be cross-functional and multidisciplinary.

Cooper (2001) suggest five principles to reduce time-to-profit and, in consequence, lead-time in product development projects: Do it right the first time by emphasizing the quality of execution, work on the definition of the product and project early in the development phase, organize and empower a cross-functional project team, foster the parallel execution of activities when it is appropriate, and prioritize projects to focus resources and people on projects that are truly important for the firm.

Cooper (2001) also suggests following the plan and respecting the milestones once the plan of the project is set. He supports this with examples in which project managers have shown dedication to the plan and monitored activities in order to comply with the milestones in a quality-focused and timely fashion. He suggests that it is more desirable to devote resources to meet a milestone than missing the date of the milestone since milestones' objective is to meet the final goals of the project. This should be done with a focus on quality and meeting a milestone shall not supercede meeting quality requirements.

Although contingencies may not figure as part of the initial scope of the project, defining a contingency plan helps greatly to mitigate the effect of delays in the occurrence of an unforeseen event. Sometimes contingencies in projects are experienced by overlooking realities and limitations, or by an optimistic estimation of the learning cycle of new technologies. In this regard, Rosenthal and Tatikonda (1992) noted that some firms reduce the risk of time variability in projects by limiting the use of novel technology in projects. Nevertheless, this principle may depend greatly on the nature of the firm and the phase of change of their particular industrial sector.

Cooper (2001) argues that although it is desirable to keep rework to a minimum, if schedule and resources are not reserved for rework, rework will compromise the progress and success of the project, it would result in quality and morale problems, and may distress the coordination with partners and customers.

2.2 Standardization of the performance measurement

Projects may have different duration, budget and scope. Therefore it is necessary to define a way of breaking down the complexity and variation of projects into elements that are common to all projects. The latter allows for the analysis of different projects under similar parameters and metrics. Tollgate models are a means of homogenizing the management of product development projects by separating a project into phases that characterize the evolution of a project from the identification of the needs that drive the project to the delivery of project outcomes.

Some of the indicators can be measured directly while others cannot. Furthermore, some of the indicators can be measured in real time, while the project is in progress, and others can be measured only when the project is completed. These differences create a need for defining a common ground for projects in order to measure performance according to the same criteria and at similar time intervals.

Projects should be initiated with a plan of what is to be done. If the different activities, deliverables or work packages are not defined, it will be difficult to know when the project has been completed. The definition of a Statement of Work and Work Breakdown Structure will determine what the goals of the project are and how they will be achieved. The Work Breakdown Structure subdivides the major parts of a project into more manageable components. These components have their own objectives and contribute to the project's goals. The division of a project into components can be done per work package or deliverable, each of them requiring of one or more activities for their completion (PMI, 2004).

Once a project has been broken down into components linked to activities, the resources to complete each component can be estimated. This is known as the Activity Resource Estimating in the PMI literature (2004). The estimation of resources required for each component can be done through the different methods explained in section 2.1.1; nevertheless an objective and structured way of estimating cost per activity is recommended to increase the transparency of this process and to facilitate its traceability.

Deliverables have different weight in the completion of a project, Herrmann, et al. (2004) suggest the use of the QFD to identify the actual weighting factors associated with outcomes, or deliverables of the project. It is advisable to involve an interdisciplinary team to evaluate, from different perspectives, the weight of deliverables in achieving the completion of the project. Herman, et al. affirm that if a product development project is to be successful it is necessary to determine the different weights of deliverables as close as reality as possible.

2.2.1 Toll gate models

A tollgate model, as defined by Cooper (2001), is a stage-gate process to manage, accelerate and improve the product development endeavors. The definition of the succession of stages and gates is a road map to streamline the entire product development process. To enhance the effectiveness of their own tollgate model, different firms integrate best practices, lessons learned, and success factors that are specific to their market and context. The definition of a tollgate model is not a one off event, the evolution towards more sophisticated models is characteristic of leading firms according to Cooper.

One of the main goals of a tollgate system is to guaranty the quality of execution in product development projects and the success of their products. In a way, quality of execution in product development projects builds in quality in the final outcomes of the process. Cooper (2001) argues that, as opposed to manufacturing processes, product development processes are characterized by poor quality of execution due to the omission of requirements and lack of focus on completeness. Tollgate models divide projects into stages and help to identify when to consider early engineering changes before incurring in major expenditures.

Since the resources available for a firm are limited, a lack of focus could slow down the development of important projects on behalf of other projects that are not relevant to the business strategy of the firm. For that reason, a tollgate model must be capable of evaluating the viability of projects at early stages of the product development process. Similar to quality checks in a manufacturing assembly line, the gates in a tollgate model are used to guide the process and to evaluate the merit, progress and quality of the project. Gates also provide the opportunity to have *pass/fail* decision points to cancel projects and focus resources on projects that are more valuable for the portfolio (Cooper, 2001).

Cooper (2001) emphasizes that the gates of a tollgate model should be designed to prevent projects from moving to further stages if critical activities and deliverables have not been completed. He also defines that gates should be capable of signaling a *cancel* decision when a project is no longer aligned with the business strategy of the firm, or when it faces insuperable hurdles. Such hurdles could be embodied by serious design failures, unreasonable budget overrun, schedule delays, or lack of technical and technological capabilities. The gates also determine the upcoming milestones, tasks and the timeframe and budgets to accomplish them.

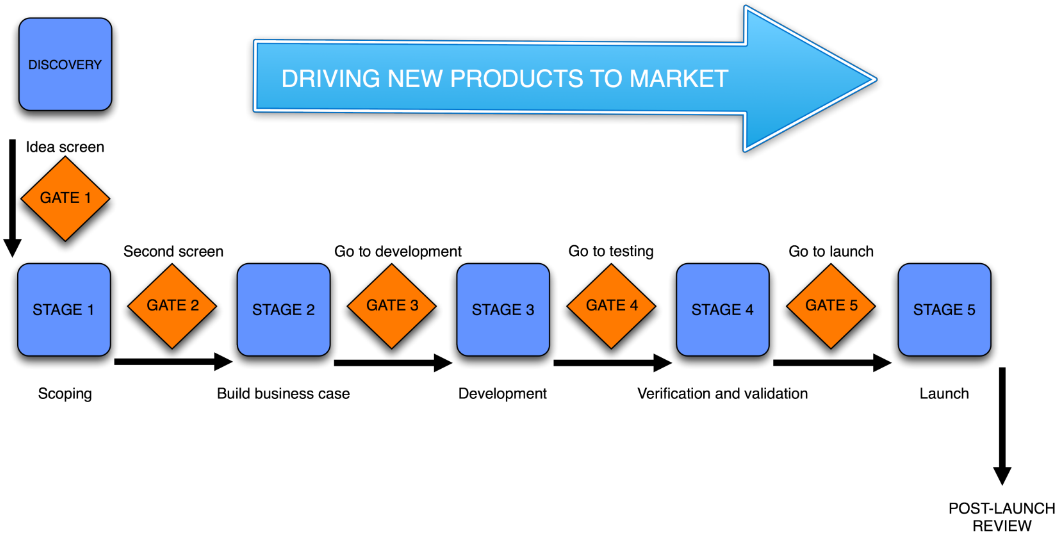

Figure 2.4 Stage-Gate model (Cooper, 2001)

The Stage-Gate model for product development projects depicted in Figure 2.4 divides a project into a series of stages that increase in cost progressively (Cooper, 2001). Expenditures for early stages are kept low and are allowed to increase as uncertainty is reduced, for that reason the process is an incremental commitment process. Each cross-functional stage is designed to gather information needed to bring the project to the next gate or decision point and to reduce uncertainty (see Table 2.1). Each stage encompasses a set of parallel activities undertaken by people from different functional areas within the firm.

Cooper (2001) defines an additional stage called strategy formulation, an essential activity that is left out of the Stage-Gate flow shown in Figure 2.4 because it superimposes on the model and is a prerequisite to an effective Stage-Gate process. This stage defines the orientation of the outcomes of the project with the business strategy of the firm and should be revisited during the different gates of the project.

Phase	Name	Description
Beginning	**Discovery**	During this phase opportunities are explored and ideas are generated.
Gate 1	**Idea screen**	The first decision to commit resources to the project is taken after *must meet*, *should meet* and *cancel* criteria are verified. Strategic alignment, project feasibility, market attractiveness, and alignment with company policies are typical parameters to evaluate.
Stage 1	**Scoping**	A preliminary scope of the project is defined. Preliminary market and technical assessments of the project are also carried out. Market assessments are typically based on quick research, consultations with focus groups and key users. Technical assessments usually involve approach to the problem, manufacturability, regulations compliance, and time and costs estimates.
Gate 2	**Second screen**	A more rigorous screen than Gate 1, this gate is a re-evaluation of Gate 1 with the information obtained in Stage 1. The same *must meet*, *should meet*, and *cancel* criteria of Gate 1 are applied.
Stage 2	**Building the business case**	This stage constitutes a cross-functional effort, and although it is a critical stage, weak handling is not uncommon. In this stage a detailed investigation greatly defines the project and verifies its attractiveness before heavy spending. The products or outcomes of the project are defined based on the customer's needs and preferences identified in market research. Then they are translated into a product concept, features, requirements, and specifications that are technically and economically feasible. Competitive analyses and concept testing could be part of this stage too. Business and financial analyses are carried out to justify the project. The business case is then built with the justification, product definition and a detailed project plan.
Gate 3	**Go to development**	This is the last filter at which a project can be cancelled or postponed before incurring in major spending during the development stage. Passing this gate implies the sign off of the project and its outcomes. A meticulous review of the activities carried out in Stage 2 is performed. Quality of execution of those activities and positive results from the financial analysis are necessary for the project to move forward. After this gate commitment to the product definition and the project plan are ensured and the project team is designated.
Stage 3	**Development**	This stage comprises the implementation of the project plan and development of products. It is characterized by iterative activities that impact the final product, its launch date and production requirements. For long projects, partial milestones and reviews are incorporated in the project plan. Although technical work is emphasized other functions also intervene in shaping the final product. A financial analysis is prepared, and regulation and patent issues are settled.
Gate 4	**Go to testing**	Quality of the development work and consistency with the product and project plan are verified. The progress, attractiveness of the product and economical viability are revisited. Test and validation plans to be carried out during the next stage are approved for implementation.
Stage 4	**Testing and validation**	In this stage the project is evaluated in terms of its economic resources, customer acceptance, and the results of product and production testing. Activities like in-house testing, field trials, pilot production, market trials, and refinement of the business analysis are carried out.
Gate 5	**Go to launch**	This is the final gate before market launch and full production. This is also the final point at which the project can be cancelled. This gate focuses on the quality of the activities completed in the previous stage and their results. Some of the most relevant criteria for passing this gate are financial return, and appropriateness of plans for marketing, production and operations.
Stage 5	**Launch**	Production, operations, launch, and marketing plans are implemented.

Table 2.1 Phases of the Stage-Gate model - information from Cooper (2001)

Decision gates are distributed at different intervals during the execution of the product development project. Their purpose is to control the evolution of the project and to maintain its alignment with the strategic objectives of the sponsoring organization. Gates are usually assisted by senior managers from different functions, who control the resources required to perform the next stage of the project. The decision gates contain criteria to evaluate the project. The severity of the criteria varies from *must meet,* which define factors that are absolutely necessary to fulfill, to *should meet*, which defines desirable factors. *Must meet* criteria is used to define whether or not a project is apt to continue, *should meet* criteria is used to prioritize projects. Cooper (2001) defines that a set of required *deliverables* must be brought to the decision points and should be visible, standard, and decided at the output of the previous gate. In this fashion, management's expectations for project teams are made very clear through the definition of deliverables.

2.2.2 Earned Value Analysis to evaluate performance

The Project Management Institute (PMI, 2004) defines project performance in terms of deviations with respect to planned values and ratios. From the PMI perspective, the measurement of performance is the quantification of the variances that will occur during the development of a project and the comparison of planned and actual values. The earned value analysis (EVA) is a common tool used in projects to measure the magnitude of the progress and variance from the baseline defined in the project plan.

As explained by Bergquist and Carlsson (2005), EV management has the advantage of being simple to aggregate and presents information in a short and simple way, presenting both technical and economic progress together.

The EVA measures the performance of projects and helps to monitor their progress as they move forward. It integrates the project scope, cost of resources, and schedule measurements into indexes that help to assess project performance. If used for reporting, the EVA can express the progress of unfinished activities as a percentage. In order to facilitate traceability of the periodic progress reports, consistency between organizational components is needed. The cost and schedule variance, CV and SV respectively, are the most commonly used measures. The extent of deviation, reflected by the CV and SV values, tend to decrease as the project approaches its completion due to the compensating effect of more work being accomplished (PMI, 2004).

$$\mathrm{CV} = \mathrm{EV} - \mathrm{AC} \qquad \text{Equation 2.1}$$

$$\mathrm{SV} = \mathrm{EV} - \mathrm{PV} \qquad \text{Equation 2.2}$$

Where CV is the cost variance, SV is the schedule variance, EV is the earned value or the work actually performed, AC is the actual value, and PV is the planed value or budget of the project.

Cost and Schedule Performance Indexes can be used as performance indicators for the cost and schedule of any project. The Schedule Performance Index is used to predict the completion date.

$$CPI = \frac{EV}{AC}$$ If $CPI < 1.0$ cost overruns the estimates. Equation 2.3

$$SPI = \frac{EV}{PV}$$ Equation 2.4

Levine (2002) points out that parts of the earned value analysis (EVA) can be used as needed when their capabilities are more practical and useful. EVA can also be employed in projects even when the actual cost figures are not collected and when a project experiences a change in scope. EVA can be used for any type of project in any industry as well. It is a technique to measure the work accomplished, and it is a helpful tool to monitor projects and take decisions during the execution of the project. It is also useful for preventing delays and overspending from suddenly surfacing.

Levine (2002) proposes a set of principles to facilitate the calculation of the completion percentage and earned value of the project. The first principle is the use of weighting factors that define the grade of completion after certain activities are executed. The second is the use of milestones; when tasks are complex or a series of different steps are needed, a fixed percentage of completion is assigned after the achievement of a milestone. A milestone is achieved when activities and work packages are delivered. The third principle is to use of the 0-100% rule for completion of tasks; a task is considered as 0% completed until it is finished. Although this principle produces a lower earned value than actual, it motivates the task owner to complete the task.

The division of a project into work packages should be done so that tasks can be associated with a project deliverable. This can constitute a basic unit to track the progress of the project. Every task has its own weight depending on its budgeted cost or duration. Levine (2002) and Herrmann, et al. (2004) recommend the division of the projects and the use of weighting factors in cases where detailed budget and costs per activities cannot be obtained. However, the use of weighting factors may also provide a systematic basis for allocating weight and budget to work packages or deliverables during the planning stage of projects.

Levine (2002) describes an example in which it is not necessary to have an accurate record of costs for a project; instead, an estimation of the weight of different work packages in the completion of the project is required. This principle can be used downstream in the structure of activities within different work packages. Then the weight factor assigned to each work package can be taken as their particular budget within the total project budget. Even when there is a lack of clarity or resolution in the definition of the project schedule, estimations can be made based on the achievement of work packages or the completion of deliverables. The earned value in this case should be substituted by a completion percentage of each work package.

The completion percentage of the project and the total budget of the project are necessary to calculate the earned value of the project. In other words, the earned value of the project, in monetary terms, depends directly on the budget and the estimation of the completion percentage. It is necessary to produce an accurate estimation of the completion percentage to calculate a realistic project earned value based on the budget of the project.

2.3 Allocating weight to deliverables

ABC and feature costing are suggested as suitable and accurate costing techniques to define the cost of products. For product development projects, it is a way of defining the cost of activities and deliverables of the project. Bergquist and Carlsson (2005) state that if the process is well defined, then the cost control should result from a cost breakdown structure built from activities. However, they maintain that if the process of the project is not very well known but the goals and deliverables are, the cost control should result from a cost breakdown structure built from deliverables rather than from activities. The lack of a cost breakdown structure results in problems when tracking the origins of cost deviations from the budget. The project manager could notice that the project is overspending but not why (Bergquist and Carlsson, 2005).

The method explained in Appendix I should be used in calculating the weighting factors of project deliverables. Each deliverable is allocated a specific weight that is relative to the totality of the project. The weighting factors are expressed as a percentage of the project's completion. The weight of each deliverable considers the interrelation of that particular deliverable and the rest of the deliverables and the relation of the deliverable and the requirements defined for the project. The greater the interrelations with other deliverables and the greater the relations with project requirements, the larger the weight of the deliverable in the completion of the project. In this regard, more weight is allocated to those deliverables that have interdependencies with subsequent deliverables. This supports the commitment of resources to deliverables that require more detailed work, since more rework may result from the lack of quality in the completion of that particular deliverable. Similarly, more weight is allocated to deliverables that address more customer requirements in order to incorporate the voice of the customer in the process of allocating resources and to give more visibility to the customer requirements in the product development process.

2.4 Considerations in the design of measurement systems

The relevance of a measurement system resides in its ability to be used in the decision making process. According to the CMMI (2006), conclusions drawn without previous measurement and analysis are only opinions. Without measurements it is not possible to define the current state of a process, and therefore it is uncertain to know if improvements have been achieved after the implementation of changes. Measurements must be meaningful and repeatable. Moreover, measurements should have a purpose and must be analyzed in order to understand the behavior of the process under study, since data is of little help if it is not understood.

The CMMI (2006) recommends designing the measurement system before the actual measurements are taken. The methods for collecting, storing and reporting data constitute the measurement system. The presentation of results, which is also part of the design of measurement systems, must be clear for the audience to whom the results are addressed. The design of the measurement system should be aligned with specific goals and activities that pursue the incorporation of measurements into other processes. The cost of obtaining measurements should not be higher than the benefits of measuring. In this regard, the CMMI recommends constraining the measurements to existing resources and processes to prevent having resource intensive measurements.

It is expected that a close control of resources and prioritization of measurements be in place at the beginning of the implementation of a measurement system. For this reason, it is strongly recommended to identify existing sources of data generated from current work products, processes and transactions. However, it is likely that the measurement system may change as a product of the evolution of measurement objectives. New opportunities and changes in information needs may lead to the creation of measurements for which data is needed but not available. Besides this, the complexity of data collection and analysis can increase as the scope of the measuring system broadens (CMMI, 2006).

Typical sources of data are project plans, existing tools to monitor projects, interviews, and business plans. In addition to the measurements obtained directly from data, other derived measurements can be calculated as rates from other direct measurements. Examples of commonly used derived measurements are the earned value, cost and schedule performance indexes, defect density, reliability assessments, and quality metrics.

A measurement system can be used to gauge the final state of work and to monitor the performance of a project. In this case the measurements of real variables and performance are compared to the established plans and objectives. Then corrective actions can be taken if needed. The application of a measurement system can escalate from being project focused to being organization focused, according to the CMMI (2006). In such cases the definition of responsibilities for data generation, retrieval and storage is fundamental to consolidating the commitments for maintaining the measurement system. The CMMI strongly recommends documenting the measurement objectives and the actual measurements, because a clear definition of objectives communicates the purpose of the measurement more effectively and because documentation facilitates traceability.

During the development of measurement systems, it is advisable to identify stakeholders and review the initial results with them. This will prevent future misalignments and enable feedback loops to improve the measurement system.

2.5 Framework of indicators to measure performance

From the literature presented in this chapter, 8 indicators were selected to measure performance of product development projects. The purpose of selecting different indicators is to appraise the performance of projects from different perspectives.

Figure 2.5 presents the indicators suggested in the literature review. Rework greatly affects the cost, duration and quality of projects. Although this research does not focus on rework, two indicators that are associated to rework and project performance were selected.

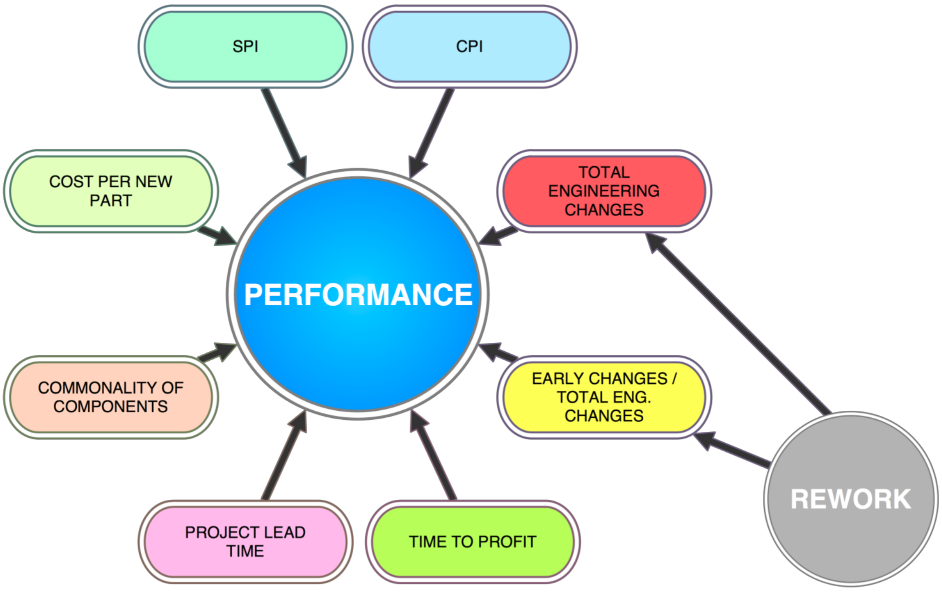

Figure 2.5 Theoretical framework indicators

The project's prime costs represent the direct materials and direct labor invested in the completion of projects. According to product development and project management literature, prior to the start of a project, the prime cost can be estimated by adding together the costs of the activities needed to complete the project (Maylor, 2005; Filomena, et al., 2005; Ben-Arieh and Qian, 2003). Once the project is in progress, the prime cost can be registered and monitored using accounting records and timesheets, and direct materials can be monitored from invoices (Maylor, 2005). The *cost performance index* appraises the performance of projects and portfolio using the project's budget, costs and earned value. In a similar fashion, the *schedule performance index* is proposed as a performance indicator to estimate time deviations from the plan based on the achievements of the project (PMI, 2004).

Projects that are different in scope and nature most likely require different amounts of resources to be completed in a timely fashion with high quality results. Therefore the comparison of two projects with different scopes may not be significant. If the project's prime cost is divided over the products of the project, or new part numbers in the case of product development projects, then a more detailed measurement of performance can be obtained. Projects do not represent an economic gain for a firm, but new parts do. Therefore, *cost per new part* was selected as a performance indicator.

Commonality of components represents the effort of focusing the resources of a firm on those product development projects with larger impact on the organization. As explained in section 2.1.1, the effects of commonality affect the overall cost of projects and products, in addition to the impacts on the operation of the organization. Therefore this indicator is used in the performance appraisal of the portfolio.

Project lead-time is selected as an indicator of project performance because it measures the duration of projects and forms part of time to profit. The division of project lead-time into partial lead-time of activities, work packages or deliverables increases the accuracy in which the duration of activities is estimated during planning through refinement cycles and the use of a historical baseline. *Time to profit* measures the time in which a project starts to collect profit and could be used to measure the performance of projects once they are launched to the market. Although this indicator is not suitable for measuring performance during the execution of projects, it can be used to assess the success of a project. Both indicators are complementary in the assessment of project performance. While project lead-time measures the project in real time, time to profit measures the success, or failure, of a project in the long run.

Rework is a broad subject that affects performance of product development projects. From the literature review two indicators related to rework were identified. Occurrence of *engineering changes* is a direct measurement of the formal signaling of rework. *Engineering changes* represent the beginning of a rework cycle to correct work that was not done properly. Although this indicator does not address the informal signaling of rework, measuring informal signaling of rework may be extremely difficult to measure and therefore not suitable to study. Measuring the occurrence of *engineering changes* alone may discourage reporting *engineering changes* and may not be significant if projects with different characteristics are considered. To cope with this drawback, measuring the performance of product development projects as the ratio of *early engineering changes over total engineering changes* may encourage the early signaling of work that needs to be corrected and provide a better understanding of the distribution of rework in different projects at the same time.

3 Methodology of the study

In Chapter 2, different indicators used to measure the performance of product development projects were reviewed. Their selection is based on recommendations from literature and their ability of addressing general cases. Beyond the selection of indicators suggested in the literature, it is useful to test their applicability in a real-world context in order to identify the implications of their use. A case study was used to test the applicability of the different indicators defined in the theoretical framework. This chapter describes the method followed during the case study and explains the implications of its use.

3.1 Method

Figure 3.1 summarizes the structure of the research method employed in this study. The initial approach to the problem of measuring performance in product development projects was to review the results from a previous study in which four indicators were identified as viable measurements of performance for product development projects. The results of that study are contained in section 4.1. A literature review followed that first approach to identify different indicators of performance and continued throughout the rest of the study. The reviewed literature for this thesis comprises books and articles from specialized fields like project management, product development, logistics, marketing, and quality management. As Yin (2004) advises, literature reviews and revisiting the results of previous studies are means to develop more insightful research questions.

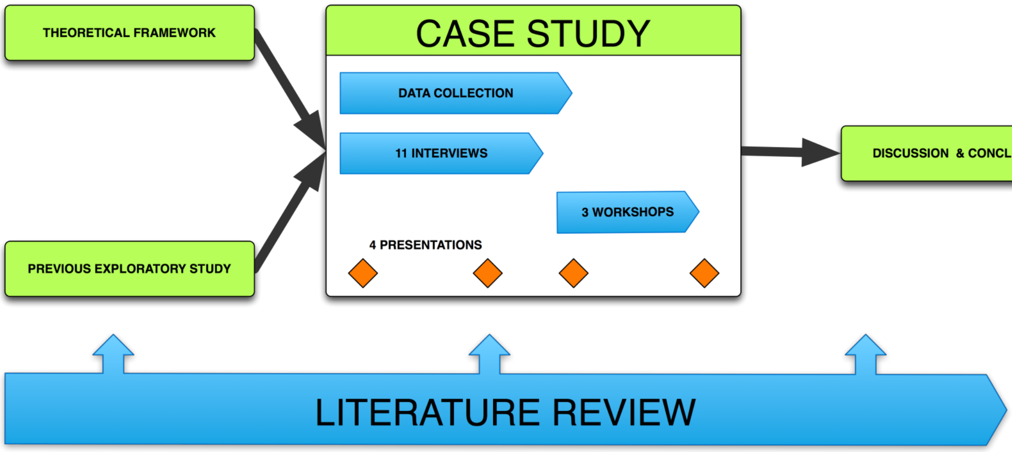

Figure 3.1 Structure of the research method

The selection of content from books is based on several of the courses from the master's programme in International Project Management. The articles were selected to acquire deeper knowledge in specific topics. They were obtained from searches in electronic databases using key words such as *product development performance*, *performance indicators in projects*, *QFD in projects*, among others. Several articles were pre-selected based on the content of their abstracts, and then specific parts of the articles were selected for more thorough review, after a full evaluatation of the pre-selected articles.

The literature review resulted in a theoretical framework that contains different indicators used in product development projects that are relevant for this thesis. The applicability of the indicators that assemble the theoretical framework was tested in a case study, as a result of which a smaller subset of indicators was selected. This further selection is supported by the literature review, the findings from the exploratory study, the relevance of each indicator for the organization, and the availability of data.

In words of Yin (2004), the case study method has been increasingly used in research and allows investigators to retain holistic and meaningful characteristics from real life events. Case studies, Yin explains, can have three different purposes, to explore, describe or explain. The purpose of the case study presented in the next chapter is to explore what indicators could be used to measure performance in product development projects, and to explain the implications of their use.

Yin (2004) defines a case study as an empirical investigation of a contemporary phenomenon in a real context. He recommends the use of case studies when the boundaries between the phenomenon and the context are not very clear and therefore the context conditions also form part of the research scope. In the case of this thesis, the context represents the conditions found in the organization where the performance indicators of the theoretical framework were tested for applicability.

The indicators selected in the theoretical framework were tested in a single case study with multiple units of analysis. There are two reasons for the selection of a single case. The first reason is that the firm is representative of an industrial sector, which develops transport-related products and services. Yin (2004) argues that the selection of a single case study is justified by the selection of a representative case and therefore the selection is acceptable for research. The second reason stems from the difficulty of getting access to more than one company to conduct research, since the data related to product development performance constitutes proprietary information of the firm. The case study is intended to evaluate the applicability of indicators that address performance from different perspectives and involve inputs from different areas of the firm. For that reason the case study will consider multiple units in the analysis.

The case study, as well as the historical baseline was presented to three different groups of managers and decision makers in the organization. Their comments and suggestions were considered and are incorporated in the study. The final group of managers focused on the applicability of the indicators in the operation of the firm.

3.1.1 Quantitative data

Maylor (2005) states that timesheets are one of the preferred ways of registering in which activities individuals spent their time. The archival records used for data collection concern project costs and budget per month, project completion date, new production part numbers launched at the completion of each project, total part numbers in production divided by brand, and engineering changes per week.

The indicators under analysis are related to the performance of the product development activities, and they assess the performance of the organization quantitatively. The data used for assembling the historical baseline of the different indicators was collected from databases that are used for administrative purposes and are kept consistantly updated. The databases of the different administrative tools are fed with information generated while the work is performed or on a monthly basis.

The margin of error in the databases and administrative tools is not considered in the scope of this thesis. However it is expected that the databases and administrative tools do not contain major inaccuracies. The main source of inaccuracies associated with the costs and budget of the project resides in the interface with the users, since they may, or may not, report their labor to the correct project account. Currently the system is set up to report on a weekly basis, which may induce inaccuracies during the reporting process, however, there is an initiative to move towards a daily reporting system, the latter may reduce the inaccuracies related to reporting in the future.

For the case study, the data was retrieved by one of the controllers, which reduced the risk of introducing inacuracies into the data, as may have occurred if the data had been retrieved either directly or through another intermediary. These same databases and procedures used to build the historical baseline for the different indicators can also be used to regularly monitor the indicators.

3.1.2 Qualitative data

Eleven interviews were carried out to identify sources of information and to shape performance indicators. In many cases, the interviews helped to identify additional respondents, who were then also interviewed. The initial respondents were selected with the help of the thesis sponsor at Specialized Vehicles Inc. based on their involvement in the exploratory study prior to this thesis and due to their knowledge of specific areas of the product development process. Respondents from different areas related to product development were chosen to consider the measurement of performance of product development projects from different perspectives. The interviews were face-to-face, semi-structured and based on open questions. The main advantage of face-to-face interviews mentioned by Sekaran (2000) is that the researcher can adapt questions as necessary, clarify doubts, make sure that the responses are properly understood, and pickup non-verbal cues from the respondent. Sekaran suggests the use of unstructured interviews to cause some preliminary issues to surface, which allow the researcher to select the areas that need deeper investigation.

The duration of each interview was approximately 1 hour. Depending on the respondent, the focus of the different interviews varied from data collection details to understanding the relevance of certain indicators in the product development process. The first two interviews, of a group manager and a quality manager, defined the scope of the project and helped to clarify details of the previous study. The next 5 interviews identified sources of information and the format of the different data to be used for the study. This cluster of interviews involved representatives from the quality and finance departments, as well as from global process and strategy management, and systems engineering. The subsequent 4 interviews focused on management process of projects. This final cluster of interviews comprised the participation of representatives from the areas concerned with the definition of the stage-gate process in the company, project control, requirement management, and project planning and quality assurance management.

In addition to the interviews, three one-hour workshops were held to define the main driving requirements and the main deliverables in product development projects. The interactions among different project deliverables and between project deliverables and main driving requirements were also studied during the workshops. The three workshops resulted in the establishment of a set of weighting factors for each deliverable. A representative from the area of the company that defines, manages and balances project requirements was present during the workshops, as well as one representative from the area concerned with the definition of the stage-gate process in the firm; a moderator facilitated the dialog between them. In this fashion, the workshops allowed to reach common agreement on the material being discussed and the outcomes.

3.1.3 Implications of the method

Yin (2004) explains that very few case studies conclude exactly as planned; in many cases unexpected leads are detected, or new research areas are identified. The researcher should keep in mind the original research purpose but should also be willing to adapt the plan in the event of unforeseen circumstances. Yin advises balancing adaptability with rigor to cope with upcoming events and to prevent rigidity in the study.

Different implications of the method may affect the results of the research. Some provisions were taken in order to reduce the misinterpretation of data and results, as well as to prevent the retrieval of erroneous figures for the analysis. The data collected during the case study was obtained from databases that are maintained up to date. Different areas of the firm depend on these databases and therefore different parties may detect inaccuracies promptly. Yin (2004) considers interviews as verbal reports that are subject of bias, poor recall or articulation. Therefore it is reasonable to corroborate the data obtained in the interviews with other sources of information. For the case study, other interviews and internal documents were used to corroborate the results.

Yin (2004) indicates that one of the principal arguments against the case study as a research method is that it provides little basis for scientific generalization, especially in the case of single case studies. Yin also states that case studies, similarly to experiments, are generalizable to theoretical propositions and not to populations, therefore the purpose of the study is to expand and generalize theories and not to generalize the behavior of a population. In this regard, a single case study does not represent a sample and therefore the generalizations resulting from the case study are analytical generalizations and not statistical generalizations.

Yin (2004) points out that not even documents are free from bias; therefore the content of documents should be corroborated and augmented with evidence from other sources. Yin explains that documents are written with specific purposes and for specific audiences that may, in most cases, be different from those concerning the case study. Documentary evidence is a reflection of the communication between parties aiming at achieving different objectives, for this reason a broad selection of documents may provide a more complete perspective and may prevent being misled by documentary information. For this case study, documentation of the findings from the previous study and additional literature from articles and books were used to supports the selection of some of the performance indicators after the case study was carried out. It is arguable that the results from the study that was completed prior to the case study may bias the results of the case study. However, the use of literature from various fields to confirm the selection of indicators and support their use from different perspectives reduces the bias that the previous study may cause.

Yin (2004) argues that one of the major challenges that researches face when using a case study is the bias of using the case study to substantiate a preconceived position. He suggest that a way of testing if such bias exists in the results of the case study is to report the preliminary findings to critical colleagues, who in turn will offer alternative explanations and sources of data collection. In this case study, different people involved in managing projects, defining requirements, establishing project protocols, and ensuring quality were interviewed to obtain feedback during the study and to identify sources of information to define the indicators. In addition to this, four presentations were held at different points during the evolution of the case study. Their purpose was to review the progress of the case study and to obtain feedback from different parties. The different comments that resulted from the presentations are incorporated in the study. Presenting the progress of the case study allowed the customization of the indicators and also that the indicators were verified for correctness and relevance for the organization. The presentation to different panels of managers and decision makers of the firm reduced the risk of bias of the results since the findings and ways of measuring the indicators were evaluated by a third party.

4 Case Study

Currently there is a need of measuring performance of product development projects at Specialized Vehicles Inc. to know the impact of different initiatives and improvements in the execution of projects, to evaluate and monitor the current projects and portfolio, and to communicate the progress of projects. This chapter presents the results of the exploratory study and a description of the ensuing case study. The case study presented in section 4.2 was used to tests the application of the indicators presented at the end of chapter 2. The selection of some indicators is also supported by the findings of the exploratory study.

Specialized Vehicles Inc. is part of a business unit of a transnational company and it is responsible for product development, vehicle development and engineering of the different brands within the business unit. Specialized Vehicles Inc. adds value to their final products through functions related to the different components, assemblies and systems that constitute all the vehicle versions that the business unit produces. Chassis and cabin design, electric and electronic systems and mechanical systems are part of such functions.

4.1 A previously conducted study

An exploratory study, carried out by the quality manager in October 2009, had the purpose of identifying possible indicators to measure product development performance at Specialized Vehicles Inc. In that study the performance of product development efforts was expressed as a measurement of the efficiency in producing outputs and effectiveness in achieving goals of projects. Figure 4.1, taken from the activity model proposed by O'Donnell and Duffy (2002), depicts the elements that shape project activities. Efficiency of product development projects was defined as the ratio of output per input of resources or information. Similarly, effectiveness was defined as the ratio of output per goal, considering that the purpose of the output of an activity is to satisfy the goal set for that activity.

Figure 4.1 Interaction between an activity and elements of product development (O'Donnell and Duffy, 2002)

The study proposes the measurement of four indicators to assess the performance of product development projects from different perspectives: *project lead-time, number of common parts, product development cost per new part,* and *part numbers in production.*

The study concluded that *lead-time* estimates the time to market and strengthens the function of time planning as a steering instrument for projects. Although classifying the different projects into subgroups of projects with common scope provides more detailed information, identifying projects with common scope is complex. The main disadvantage detected in the study was that the calculation of an average lead-time does not consider any categorization of projects regarding their scope.

In practical terms, the only parts that represent an income for the firm are production parts and therefore they are the only ones bearing the product development cost. Due to this reason the study proposed monitoring the *number of part numbers in production* as well. *Cost per new part* was described in the study as a clear indication of the inputs and outputs of the project since cost accounts the labor invested in projects and new parts are a natural result of product development projects. Furthermore cost per new part is currently a decision criterion for go/no-go decision during project sign-off and at different points during the execution of projects. According to the study, the main disadvantage of this indicator is the slow reaction to reflect the effects of implementing operational improvements. Another disadvantage of this indicator is that the effects of developing hardware common to different applications are not reflected in the indicator. However, monitoring this indicator signals the shift of average cost per new part over time.

Commonality of part numbers was identified as a factor that affects the performance of product development projects but whose effect on the cost per new part is not easy to quantify. Due to the latter it was suggested to monitor *number of common parts* separately.

4.2 Testing the findings of the theoretical framework

The objective of the case study was to explore the applicability of the different indicators selected in the theoretical framework. One part of assessing the applicability of different indicators is to define a baseline for each indicator using historical data. Besides addressing the performance of projects from the cots, time, or quality perspective, the applicability of the different indicators selected for the case study depends on the availability of information, or the ability of collecting it in a simple manner. The cost of obtaining data for the indicators should not be higher than the benefits, for that reason the CMMI (2006) strongly recommends that measurements should be initially constrained to existing resources and processes.

As other firms, whose core business is the development of new products, Specialized Vehicles Inc. has a stage-gate model that represents their product development process (Chao and Ishii, 2005). The model, besides defining the different stages and verification points that a product development project undergoes, defines a set of standard deliverables and documents that will be used to manage the project and to ensure that the project is executed in a quality fashion. Furthermore, the different deliverables and documents that are generated during the evolution of the project are important parts of the project's record. During the execution of a project, different requirements and deliverables are defined. During the initial phases of projects the main requirements are defined and balanced, then they are translated and passed down to other children projects. A department performs these functions, which are based on the negotiation and common agreement between the stakeholders and the solution providers of the project. The definition of requirements and their importance is documented and updated throughout the duration of the project but mainly during the initial. Depending on the project level, it may address requirements that are commercial, strategic or technical.

It was observed that the majority of the outcomes from Product Development are deliverables that enable components to be produced or assembled, and systems to be integrated. Nevertheless, those outcomes are not always tangible and therefore difficult to valuate. Besides of the subjectivity inherent to assigning value to intangible outcomes, the elapsed time to produce those outcomes varies. The lifespan of product development projects depend greatly on the complexity of the products and their associated applications, and on the resources assigned to them.

Currently different parties involved in projects integrate both requirements and deliverables to product development projects. Although the management of requirements and deliverables is done in a standard way, the connection between the two of them is not very visible. One of the risks derived from the lack of visibility in the connection of requirements and deliverables of projects, especially in projects that address technical solutions, is the deviation of the outcomes of the project from the customer requirements. The partial deliverables of projects are reviewed at tollgates to determine whether or not the work and progress of a project are conducted in a quality fashion and as planned. By connecting project deliverables with the project requirements, the visibility of requirements throughout the project is assured.

After the case study, the 7 indicators depicted in Figure 4.2 were selected to measure performance of product development projects. Four of the indicators were supported by the findings of the exploratory study and 2 of the indicators of the theoretical framework were not studied but has potential of becoming viable performance indicators since they address quality of execution in projects and there is enough information to assemble a baseline with historical data.

The indicators selected after the case study assess the performance of projects and the portfolio. *Cost performance index, cost per new part, project lead-time, total engineering changes,* and *ratio of early engineering changes over total engineering changes* assess the performance at project and portfolio level. *Part numbers in production* and *commonality of part numbers* assess the performance at portfolio level.

In general, it is possible to retrieve historical information related to projects, except for *project lead-time*, and the different indicators can be monitored in a quarterly basis. The rationale of selecting quarterly measurements is that they involve less administrative work since the measurement is taken 4 times a year instead of 12, and because quarterly measurements have more resolution and are more reactive to changes than yearly measurements.

During the case study the *project lead-time* was not analyzed because, currently, there is an initiative to assemble the baseline for *project lead-time*. That initiative was originated in January 2010 and is undertaken by another department. The way in which this baseline is constructed is based on time reporting and close schedule monitoring. In addition to defining a baseline for *project lead-time*, there is another initiative to enhance the accuracy of time reporting by introducing measurements of work hours related to a project on a daily basis. These two initiatives will facilitate knowing how much time was spent in specific deliverables of the project. Timesheets, according to Maylor (2005), are one of the preferred ways of registering in which activities individuals spent time on an hourly or on a daily basis and could be used to accurately measure *project lead-time*.

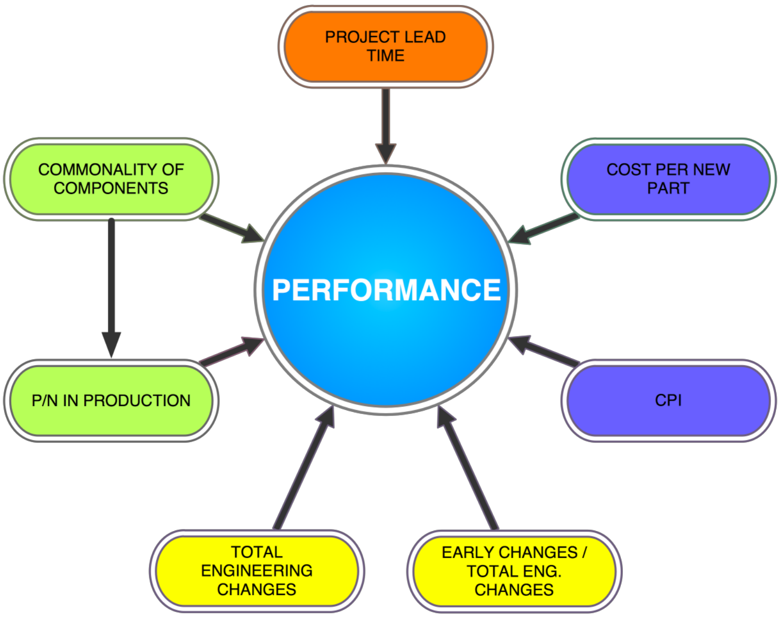

Figure 4.2 Indicators analyzed in the case study

4.3 Selection of indicators based on the case study

Cost performance index

Cost performance index is an indicator for projects suggested by the PMI (2004). This indicator measures the performance of projects in terms of the use of resources and allows continuous monitoring during the execution of the project. Its calculation is not complicated once the weighting factors per deliverable, activities or work packages are estimated. This indicator expresses how efficiently resources are spent in a project in order to achieve the planned outcomes. In this regard, the cost performance index expresses performance as a ratio of the actual work achieved over the costs incurred to produce it.

Herrmann, et al. (2004) suggest the use of the QFD to identify the actual weighting factors associated to deliverables of the project. QFD is a tool aimed at satisfying the customer by linking their demands with design targets and major quality assurance points. For this research, the weighting factors were calculated considering the interdependencies among deliverables and how the project deliverables address particular project requirements. For this case study, the tool described in section 2.3 was employed to calculate the weighting factors of deliverables and to express them as a percentage of project completion. The resulting weighting factors per deliverable indicated that, the accomplishment of early phases of product development projects represent a major portion of the completion of the entire project. It was observed that larger weighting factors are assigned to deliverables in the early phases. As early as concept choice, in stage 2 of the stage-gate model, the deliverables already represented more than 50% of the project's completion. The latter means that approximately half of the dependencies between deliverables and the deliverables that will fulfill the project requirements are addressed between the beginning of the project and concept choice.

Project's prime cost and budget are two variables that are continuously monitored and from which detailed information is available. The measurement of indicators cost per new part and total cost of project was based on a sample of 108 projects, which started after January 2004 and whose products were launched no later than December 2009. The EV of the projects was calculated with the weight per deliverable and the total budget of the projects in order to express the weight of deliverables in monetary terms. The EVA was employed to monitor the progress of projects and to evaluate their performance using the *cost performance index*. The actual prime costs of projects and the deployment of budget throughout the project were retrieved from the same database from which the total budget of the project was obtained. The prime cost of projects was compared to the project's EV in order to assess the project performance of ongoing projects.

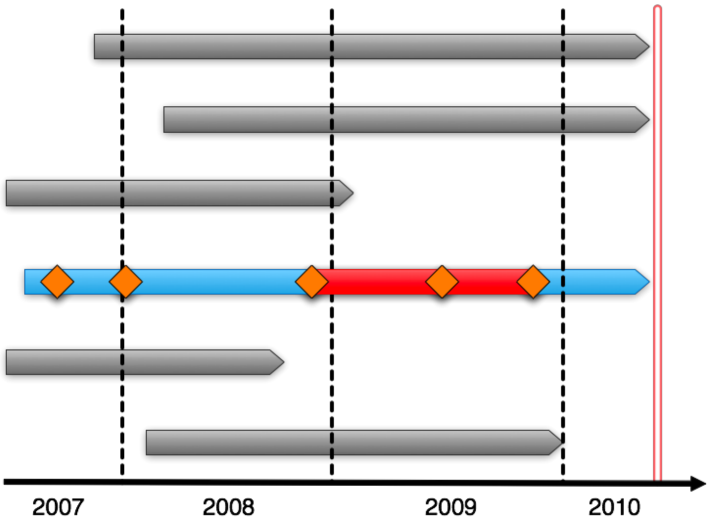

Figure 4.3 Representation of the earned value of one project within the portfolio

Figure 4.3 represents the projects that constitute the portfolio of projects. Beyond the calculation of the *cost performance index*, the cost and earned value of a project can be followed up in detail on a yearly basis. With the division of the project in deliverables it is possible to account the value earned by a project in one year. Taking the diagram as an example, the project under analysis is represented in colors. During the execution of the project, different deliverables are completed and orange rhomboids represent their completion date. To estimate the project's earned value during 2009, for instance, the earned value of the two deliverables that were completed during 2009 is considered, regardless if one of them started in 2008. As Levine (2002) affirms, although this principle produces a lower earned value than the actual, it motivates the owner to complete the deliverable. In a similar manner, the *cost performance index* can be calculated with the budget and actual costs of the two deliverables completed in 2009. The addition of the earned value of all the deliverables completed in 2009 constitutes the earned value of the portfolio. The cost performance index of the entire portfolio can be calculated with the yearly earned value of the portfolio and the addition of the costs of the deliverables completed in the same period.

Cost per new part

Cost per new part is calculated as the cost of the product development project divided by the amount of production part numbers generated by the project. Since part numbers in production are the only ones that represent a future source of income for the firm, they are the only ones bearing the product development costs and therefore they are the ones employed in the calculation of this indicator. It is important to clarify that the amount of part numbers in production corresponds to the specific design parts used for production and not to the production volume.

The sample of projects was divided in two groups according to the nature of the projects. Furthermore, it was observed that the cost per new part in the two groups was different, which further supports the division in two groups. An Anderson-Darling normality test was applied to verify that the cost per new part in both groups was normally distributed. A one-way Analysis of Variance was used to evaluate the difference in cost per new part of both groups. Because the execution of the different projects spans over several years, the costs were adjusted to reflect the effects of inflation. Due to the spread of the projects over different years and the variation in the density of projects completed along one year, it was agreed after a group presentation that the mean cost per new part and its standard deviation would be calculated based on a moving range of 8 consecutive quarters. Moreover, monitoring the cost per new part based on a moving range allows following up this indicator over time and dilutes the effects of dramatic shifts in cost per new parts in specific quarters. This indicator could be monitored quarterly in the future and a further division of projects in subgroups could result in more representative mean cost per new part for the subdivisions.

Figure 4.4 is the proposal of the representation of this indicator. The graph displays two axes and two scales. The horizontal axis represents time and the other axis the variables of the two scales. In one scale, the red line represents the mean values and the blue lines the upper and lower deviations from the mean *cost per new part* of the different periods. Individual mean value and deviations are calculated with the *cost per new part* of the projects completed within the 8-quarter period. In the other scale, bars represent the number of new production parts released by the projects that were completed within the 8-quarter period. The combination of these two axes allows monitoring the evolution of the index and shed light of the effects of the amount of new parts over the mean *cost per new part*.

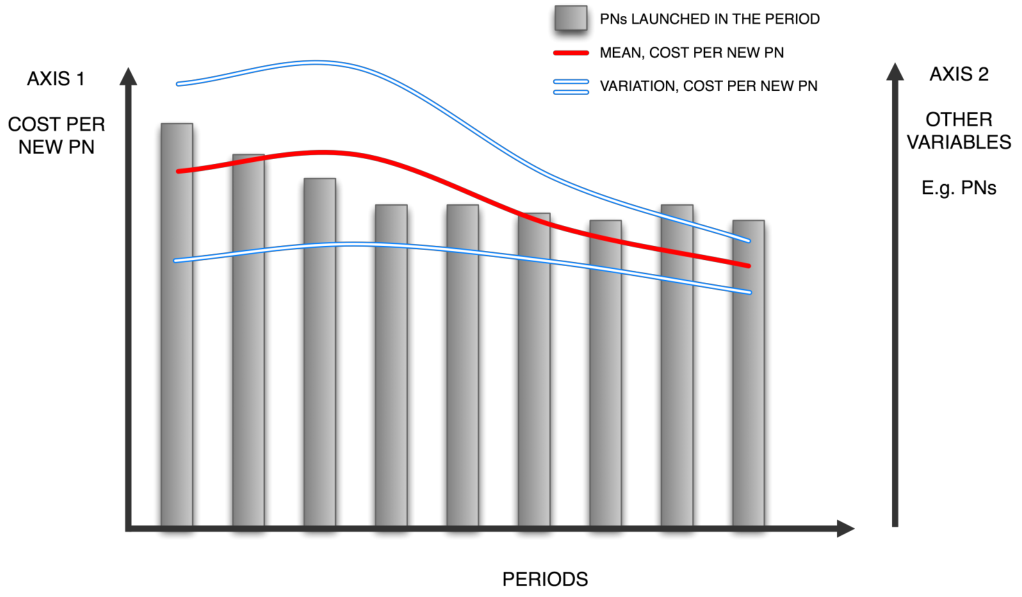

Figure 4.4 Proposed graphical representation of the indicator rolling cost per new part

Project lead-time

Project Lead-time measures the total elapsed time of the project, from *Discovery* to *Launch* (see Figure 2.4). It also measures the time to market of new products. It is desirable that the lead-time is broken down to work packages and/or project deliverables to have a more detailed time tracking of the project and to have historical information that could be used to estimate the duration of the completion of deliverables during the planning phase of the project. Besides that, if work packages are allocated a specific part of the budget, it is possible to track the progress and performance of the project using the EVA.

Commonality of components and total amount of part numbers in production

Commonality of components is the measurement, in terms of percentage, of the shared part numbers among different brands. By having common parts between brands, the firm reduces the effort of developing different hardware for products that belong to different brands. According to Jans, et al. (2008), having common hardware typically results in development and production cost savings. It is uncommon that firms have enough resources to carry out all the projects that seem beneficial for them. Hence it is usual to spread resources over many projects and face competition for the resources within the firm, which may threaten the survival of the projects that are truly important for the organization (Maylor, 2005). If too many projects are undertaken, the firm risks creating bottlenecks around key resources, which also unbalances the utilization of resources in general.

The *total amount of part numbers in production* measures the amount of the different components and assemblies to generate end products. Additionally, this indicator reflects the effects of *commonality of part numbers in production* and represents the part numbers that resulted from all the product development projects.

For the indicators *commonality of part numbers* and *total part numbers in production*, all parts were included regardless of their originating projects. It was defined for this case study that common parts are those shared by at least two different brands. For other purposes, the application of a common part can also be shared by two or more end products. These indicators measure the performance of the portfolio of projects over time and not the performance of a specific project. The historical information of this indicator is represented per year and during the year of measurement it is possible to obtain quarterly values. Both indicators are measured in combination since commonality of components complements the measurement of the amount of part numbers in production. Although these two indicators are monitored on a quarterly basis, not all the part numbers of the different brands are registered in the system when the new parts are launched. However, there is an initiative to integrate other brands to the system in order to obtain more accurate information on a quarterly basis. Parts that are retired from production are also removed from the measurement.

Figure 4.5 represents the proposal of the representation of these two indicators. The graph displays two axes and two scales. The horizontal axis represents time and the vertical axis the other variables to measure. In one scale, the red line represents the stacked values of the *part numbers in production* released during the period and the bars represent the amount of part numbers in production by brand, including common parts. In the other scale, the yellow line represents the percentage of *commonality of components.*

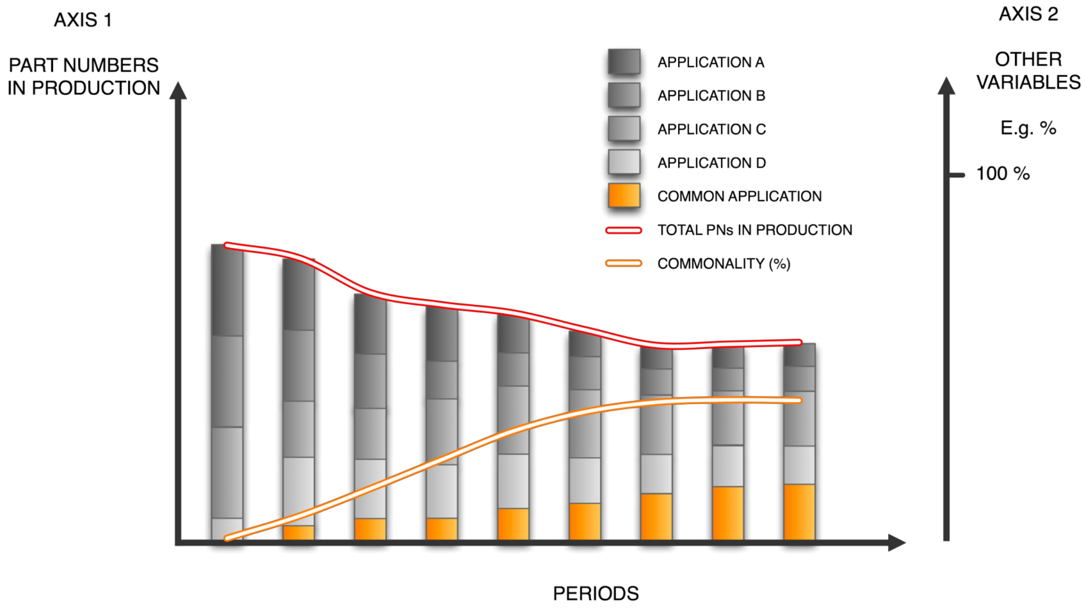

Figure 4.5 Proposal of graphical representation of the indicators part numbers in production and commonality of part numbers

Total engineering changes and ratio of early engineering changes over total engineering changes

De Toledo and Souza (2005) indicate that it is desirable to promote airing, testing and early detection of failures to prevent rework. There is evidence that measuring the amount of modifications to the original work has been used before as an indicator to measure quality in projects (Borsato, et al., 2007). For this reason, engineering changes are appropriate measurements of quality in projects. Engineering changes should be made in the initial phases because alterations are more expensive if introduced later (Freixo and de Toledo, 2004). Therefore measuring the ratio of *early engineering changes per total engineering changes* was selected as another indicator for the study. This indicator represents a way of measuring quality of execution in projects; a high ratio means that less rework cycles happened towards the end of the project and that the attention was centered in detecting and solving issues at the beginning of the project. Conversely, if the ratio is low it means that the rework cycles were initiated in late phases of the project. The root causes of either high or low ratios could be studied and lessons could be learnt in order to improve the quality of execution of future projects. Currently there is data that allow measuring the proposed ratio but the retrieval of data should be done project by project. In order to obtain a baseline that considers the 108 projects in the sample, a significant investment of time is required. The retrieval of data for multiple projects would decrease the time invested to assemble the baseline for this indicator.

Figure 4.6 represents the proposal for measuring the engineering changes during the execution of projects. The graph displays two axes and two scales. The horizontal axis represents time and the vertical axis the other variables to measure. The number of engineering changes per period is displayed in red on one scale and the cumulative cost of the project is displayed in blue on the other scale. The dashed line in the middle represents the concept decision, which indicates the time limit to detect early engineering changes.

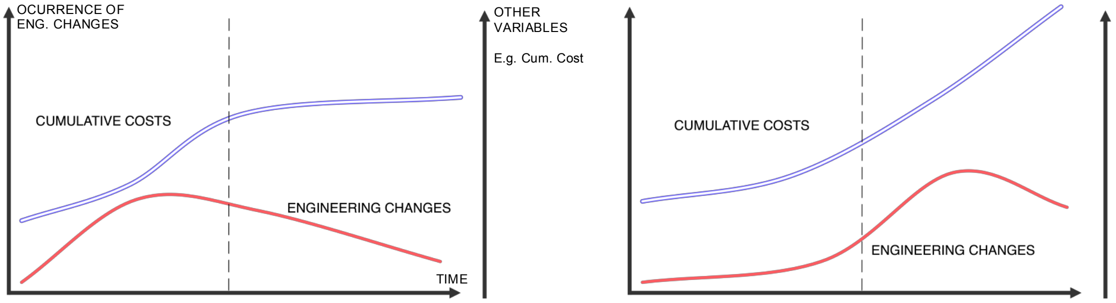

Figure 4.6 Graphical representation of the indicators related to engineering changes

In this case two graphs were used to represent two different results from the measurement of the indicator. On the left, a desirable case shows that a higher ratio of *early engineering changes over total engineering changes* causes the cost of the project to stabilize towards the end of the project. On the right, a less desirable case shows that a lower ratio of *early engineering changes over total engineering changes* causes the cost of the project to ramp up, resulting in a higher total cost for the project. Although this measurement results more revealing once the project is completed, monitoring the occurrence of engineering changes may increase the attention on quality of execution while the project is in progress.

4.4 Limitations and Implications

None of the studied indicators appraise the performance of projects entirely. The approach to measure performance in projects must be addressed from different perspectives and therefore different indicators shall be combined. The later pursues a holistic performance appraisal and tries to avoid partial assessments that may bias the decision making process.

As explained before, some of the indicators used in the case study measure performance only at a portfolio level. Although this may be perceived as a limitation of the indicators to assess performance at project level, these indicators provide a complementary appraisal of other factors that influence the performance of product development projects. In this regard, part numbers in production and commonality of part numbers do not address one particular constrain of projects but help to visualize the results of initiatives to develop common part numbers, which in the long run will impact directly the cost and lead-time of generating new products. It is arguable that the development of common parts should be reflected in the cost per new part since the development process itself is more complicated due to a larger number of constraints and conditions to which the project must adjust. However, during the case study, no way of including the effects of developing common new part number was identified. Instead, the commonality of part numbers was measured independently

Cost per new part is a performance indicator that reflects the investment that a firm undertakes to develop new hardware and end products. The way in which the current baseline was assembled divides projects in two groups according to their nature, and although this division proved to be useful in the definition of the average cost per new part, it is possible that further divisions can lead to more accurate measurements of cost per new parts for groups of components that share similarities. Given the limited number of projects that are completed per quarter, it is unlikely that a further division could result in enough data to monitor this indicator in a quarterly basis. However, it is possible to build a historical reference for particular types of projects in this way if a more detailed categorization of projects is applied. One possible approach to the categorization of projects is to divide each of the two groups into two smaller groups according to the cost per new part of the project. However, this possibility was not explored and it does not correspond to any other characteristic of the project but to the prime cost and the amount of new part numbers produced by the project. This situation causes that projects that produce different types of components and systems could be together with other projects solely on the basis of the cost per new part and not on the nature of the project or their outcomes.

The CMMI (2006) methodology strongly recommends that the design of a measurement system shall be initially constrained to existing resources and processes to avoid unnecessary expenses. Therefore the measurement of performance indicators is tailored to the sources of information available at Specialized Vehicles Inc. Under this premise, the applicability of the different indicators selected for the case study is determined to some extent by the availability of data and conditions specific to the context of Specialized Vehicles Inc. Nevertheless, these conditions may also be valid for other organizations devoted to product development.

The calculation of weighting factors per deliverable focuses on deliverables at early stages of product development projects, which emphasizes the importance of early preparation and quality of execution in the prevention of rework cycles.

The calculation of the weighting factors per project deliverable can be used as precursor of an ABC system in the firm. It is possible to calculate the average cost per deliverable with the prime costs of the projects and the weighting factors of main deliverables. The cost per deliverable can be refined once a more detailed record of cost is developed. The creation of a baseline in this particular manner has the limitation of not reflecting the costs of deliverables according to the products and features to develop, type of hardware, or other special product characteristics. However, the estimations of cost of projects could start to be assembled with approximated cost per deliverable instead of a general estimation of the project's total prime costs. Since this represents a precursor of an ABC system, it is possible to refine and it is expected that more accurate estimations of cost per activity will be produced in the future. On the long run, having and ABC system enables the refinement of the budget estimation for projects which also makes the process of allocating budget to projects a more systematic and transparent process.

Bergquist and Carlsson (2005) argue that there is a general perception among professionals in Swedish companies that the amount of information generated and aggregated for reporting at upper levels results overwhelming. Moreover, they indicate that a common reason of conflicts between line organizations and project organizations is the lack of information and understanding between them. Therefore it is advisable to define the information requirements based on the amount of information for reporting. In this regard, the results of the performance indicators should be brief and clear enough to convey the information without the aggregation of more information. This also allows that the same information could be shared vertically and horizontally through the organization without the need of re-interpretation.

4.4.1 Completeness

Metrics should be relevant, focused on important aspects, balanced, responsive in time, and elegant (Borsato, et al, 2007). he indicators selected after the case study address performance from the perspective of cost, time and quality. They are simple to obtain, and their graphical representation summarizes the information in an intuitive way. Furthermore, two of the indicators address the portfolio performance considering the impact on cost and lead-time in projects.

The intention of including indicators that evaluate performance from different perspectives is to have a holistic appraisal of the execution of projects. Although a single variable to measure performance may be seen as a straightforward appraisal, it proved not to be suitable in the case of projects due to the complexity of the endeavor, and the variety of outcomes and context conditions that characterize product development projects. It is precisely due to the interaction between constraints in projects that performance measurements cannot be addressed by focusing only on one constraint. If the gains and compromises in performance related to the different constraints are to be understood, different indicators need to be measured.

5 Discussion of the results

The results presented herein should not be used to predict future performance of projects at early phases, but to establish the principles for monitoring the evolution of performance in projects. Further reduction of variability in the process of managing projects is needed prior forecasting future performance. Predictability of results in projects is achieved by the combination of implementing refinement cycles in the estimation of resources, improving quality of execution, and defining and following standard procedures to conduct projects. Additional to this first warning, it is important to consider the different reactions within the organization produced by the introduction performance measurements. Individuals, knowing that they are being measured, may bias their behavior. The purpose of the indicators proposed in the framework is to foster positive attitudes and to use principles for objective appraisal of project performance.

From the case study presented in the previous chapter it is concluded that 7 of the 8 indicators defined in the theoretical framework proved to be applicable in the assessment of performance of product development projects. From the 7 indicators selected after the case study, 2 of them are potentially applicable in the assessment of performance of product development projects at Specialized Vehicles Inc. It is important to mention that these two indicators, number of *total engineering changes* and ratio of *early engineering changes over total engineering changes*, measure quality of execution and therefore it is strongly recommended that a way to facilitate the retrieval of data be put in place. The main obstacle to apply this indicator is the possibility of assembling the baseline of the indicator with historical data. Although the historical data exists, retrieving the information project by project makes the process of building the baseline cumbersome and susceptible to errors.

Cost per new part was proven to be an indicator easy to obtain that helps to visualize the resources that the firm invests in developing new components. The baseline that was assembled for this indicator depends on databases that are maintained frequently; therefore coordination between the administrators of those databases is needed in order to create a baseline for this indicator that is easy to build, reliable and up to date. *Project lead-time*, *total part numbers in production* and *commonality of part numbers* are already being measured by the firm. *Total part numbers in production* and *commonality of part numbers* are used in conjunction; their baseline is already established as a key performance indicator and it is monitored continuously.

Even when the market performance of a product is not as desirable as expected, it could represent a learning opportunity that contributes to the success of other products. From the examples presented by Rosenthal and Tatikonda (1992) it is evident that obtaining market and technological success is possible even when the time target is not met.

Pursuing certain goals that seem possitive for the firm may also have downsizes. Regarding commonality, the increased use of common components has also disadvantages, especially when then same component is used within a family of products where the component is sub utilized. In other words, the utilization of components designed for high performance in products with lower performance makes the component expensive for its application. Moreover, the advantages in production that represent developing common components are moved to the producing unit and are not necessarily reflected on the unit that developed the component. In the case presented by Jans, et al. (2008), the commonality savings related to economies of scale in production were minimal. The reason was that procurement costs constituted a large part of the unit production costs and were not affected by an increase of volume. Furthermore, in the same case, the costs related to the complexity of final products were despicable because the parts that integrated the final products were not many and therefore the integration of parts was not complex.

The combination of the QFD and EVA represents a systematic way of estimating the weight of deliverables in the completion of a project. If the weighting factors per deliverable are used in combination with the budget of the project, they may lead to the estimation of activity costs in product development projects. Refinement cycles and learning cycles related to the project execution enable the possibility to produce more accurate activity cost estimates over time. In this case, it is advisable to conduct a classification of projects according to their scope, application or developed hardware to build a more detailed baseline that could be used for future activity costing. During the presentations, managers and decision makers of the firm recognized the use of EVA for project management as a valuable tool. Although it is arguable how it can be applied to different projects and to different hierarchies in the management of projects and the portfolio, the principles for its application are the same for all cases. Although the application of QFD and EVA to monitor the entire project was questioned, it was agreed that its application is appropriate for the early phases of product development projects, where close monitoring of activities foster the detection of early engineering changes and the prevention of rework in later stages of the project.

One of the shortcomings in evaluating the performance of projects using EVA is that the estimation of earned value is based on budget; therefore inaccuracies in the determination of budget may produce a good or bad performance of the project. In terms of time, EVA estimates how efficient the organization is to deliver as planned, and consuming the allocated budget. However it does not assess if the budget allocated to a project was appropriate in the first place. Improvement cycles are needed to reach more accurate budget allocation in projects. Another shortcoming of the EVA is that the estimation of the schedule variance comes from cost and earned value figures. Sivathanu-Pillai, et al. (2002) indicate that from the EVA perspective, being behind the schedule means that it requires a certain amount of cost to get back to schedule. This may not be true, especially in cases in which resources were not estimated correctly or were not committed and secured, or when conditions in the context of projects changed.

Bergquist and Carlsson (2005) identified two main areas in which EV management should focus in order to becoming a more reliable and mature method for project control and estimation of performance. The first one concerns the integration and unification of project planning and control, since a control process cannot be better than the plan on which it is based. They explain that it is not uncommon that the individuals in charge of planning a project have nothing to do with controlling it. The second one concerns the definition of clearer project goals, processes and limitations as a result of optimizing and structuring the pre-study before the project is started. They state that having a low level of detail of the WBS and consequently a nondetailed or non-existing cost breakdown structure limits the accuracy of any cost control system.

Developing a costing model appropriate for each case is a complex task, mostly because the sources of costs vary greatly within simultaneous engineering environments. Freixo and de Toledo (2004) support the latter with a study in which it was found that people constantly use a combination of logic, common sense, education, experience, and judgment to produce an estimate of relevant costs keeping precision and time in mind. Therefore, the resulting costing model is a combination of a series of tacit knowledge difficult to understand by non-specialists. Developing an ABC system reduces ambiguities, improves traceability, and makes of the costing model a standard and transparent tool that could be used for reporting and forecasting.

The use of a framework to estimate project and portfolio performance, and the systematic allocation of resources to deliverables and activities are other elements that support the firm in its journey towards maturity. The proposal of a framework to allocate resources and to measure performance foster the use of objective principles to estimate budget and to monitor how the budget is being used to produce valuable outcomes for the firm.

The framework to allocate part of the budget to deliverables is a precursor of an ABC system. During the case study the budget per deliverable was estimated from the total budget and how deliverables address customer requirements. In the long run, the process may be reversed to estimate the total budget of projects based on the amount of resources to complete the deliverables for those particular projects. ABC is a suitable way to start building a more systematized costing model since projects can be divided into smaller and more concrete parts. The revision of costs per activities and their iterative refinement would produce realistic estimates on the long run (Maylor, 2005). In this regard, the complexity of developing a costing model is tackled down by defining principles for cost estimation in projects that can be refined and adjusted progressively.

Cooper (2001) states that project managers face the dilemma of compressing the cycle time from idea to launch and improving the effectiveness of product development. Cooper suggests that the best way of addressing both goals through having a more thorough and long-term approach in which the failure rate of projects is reduced by concentrating on properly assembling the business case, and by improving the quality of execution and reducing the occurrence of rework cycles. (Freixo and de Toledo, 2004) support the definition of a thorough business case, if the costs associated are not estimated there is a risk of releasing fully compliant product, at the right timing, but at a price set too high for the market.

6 Conclusions

The purpose of this thesis was to define a framework to measure performance of product development projects. This purpose was fulfilled from the theoretical point of view with the selection of indicators suggested in literature from the fields of project management, product development, quality management, logistics, and marketing. The applicability of the theoretical framework, comprised by the initial selection of indicators, was tested in a real context through a case study. Two research questions were formulated at the beginning of this thesis to concentrate in the measurement of performance from different perspectives.

What indicators are suggested in the literature for measuring performance of product development projects?

The answer to this question is supported by the content of the literature review conducted during the thesis. Eight indicators suggested in the literature measure performance of product development projects from different perspectives (see

Figure 2.5). The combined use of those indicators provides a holistic appraisal of performance; the way in which the indicators can be combined depends on particularities of the organization in which they will be applied. The following lines summarize the indicators suggested in literature; more detailed information of each indicator is contained in section 2.5.

Related to the performance of projects in term of their duration, three indicators were suggested in the literature. Project lead-time measures the duration of the life cycle of projects, from their initiation to completion. Time to profit measures the time that a project takes before generating profit, or the time that takes for the organization to recover the investment in a particular product development project. Schedule Performance Index is a measurement of the magnitude of schedule variations in projects. In general, having shorter lead-time and time to profit is desirable, nevertheless reducing these indexes shall be a reflection of improvements in quality of execution and process enhancements. Having none or small variations from the planned schedule is a positive sign, therefore it is desirable having values of Schedule Performance Index above or close to 1; values below 1 indicate that the project is behind the schedule.

Quality is addressed by two indicators in the theoretical framework that are associated to rework as well. Rework is a broad area that impacts project performance and it is worth devoting an independent study to measuring it and understanding its effects in detail. Although rework was not studied directly, the two indicators that measure performance from the quality perspective also address rework indirectly. Total engineering changes measure the amount of corrections, and therefore rework cycles, that were formally reported in projects. The ratio of early engineering changes over total engineering changes measures the portion of changes formally reported that were detected early in the development process. A good performance in projects is characterized by a number of engineering changes that decreases over time and/or the occurrence of the majority of them early in the development process.

Performance of projects with respect to cost is addressed directly by two indicators. Cost Performance Index measures how efficiently the budget is used to move forward in projects. Cost per new part measures the resources required to develop new parts. Although there are several conditions that determine the amount of resources needed to generate a new part, the initial approach is to consider the prime costs of projects since it represents the direct costs incurred and may also be the major ones. A favorable performance in projects implies having a Cost Performance Index equal to or greater than 1, and costs per new parts that decrease over time.

Finally, commonality of components measures the percentage of components generated by projects that can be used in different applications or end products. Having an increasing number of component commonality may represent advantages in project performance from different perspectives. An increased commonality of components focuses resources in the development of parts with a broader application, which reduce the cost and lead-time to develop end products, not to mention other advantages that can be translated into benefits for the organization. Some of the effects of commonality of components can also be seen in the total amount of part numbers in production. On the long run, it is desirable to see an increase of the ratio of common parts over total part numbers in production. The firm is responsible of balancing the ratio to obtain a greater advantage in the application of common components to generate end products.

Which of the indicators suggested in the literature can be measured at Specialized Vehicles Inc. and how?

The answer to this second question is supported by the results of the case study. Six of the eight indicators suggested in the literature were selected after the case study along with another indicator that was identified during the case study (see

Figure 4.2).Their applicability was tested in a real context and depended on two conditions. First, that the indicators were relevant for the organization, and second, that it was possible to assemble a baseline with historical data. Two of them only measure performance at portfolio level and five of the indicators measure performance at project and portfolio level.

Cost per new part, cost performance index, lead-time, total engineering changes, and ratio of early engineering changes over total engineering changes are suitable to measure the performance of individual projects. However, it is necessary to compare the performance of individual projects against a baseline. That baseline is built with the performance indicators for all the projects that integrate the portfolio. It was observed that introducing a rolling measurement of the indicators enable the firm to monitor the evolution of the different indicators. Since the context and the way in which projects are managed impact their performance, it is useful to have metrics that evolve as the context that surrounds projects changes.

Commonality of components measures performance from the portfolio perspective. To have a more detailed view of the effects of commonality over the product development activity it is necessary to study the natural outcomes from product development projects: part numbers in production. Is for this reason that part numbers in production was also selected as one of the indicators after the completion of the case study. Although these two indicators address performance from the portfolio perspective, it should not be taken as a limitation, since they complement the performance assessment of the portfolio provided by the other five indicators.

As a general conclusion, the definition of a framework to measure performance proved to be beneficial for visualizing objectively how projects are being executed. Measuring performance in projects, more than an end, is a means to become a more mature firm; one that allocates and uses resources in the most favorable way, and whose decision making process relies on objective facts.

Although the EVA does not seem to be suitable to capture accurately the value generated at the end of product development projects, it can be used to manage projects and to represent the economic achievement of the project during its execution. The accuracy of estimating performance through the EVA is linked to the precision of estimating the project budget, therefore refinement cycles are recommended to enhance the precision of budget estimation. The EVA measures how efficiently the budget is consumed and if the organization is delivering as planned. Bergquist and Carlsson (2005) declare that the combined use of work breakdown structure and cost breakdown structure, and the control and evaluation of projects, are the foundations for learning from one project to the next one and producing more accurate future estimates. Maylor (2005) suggest the application of a systematic revision-refinement cycle to produce realistic cost estimates on the long run. Although the EVA does not measure how efficient is the organization in creating value or how appropriately the budget was estimated, it constitute a first approach to measure and controlling how the organization uses its resources. Therefore it is still a very valuable tool.

> *Measurement is the first step that leads to control and eventually to improvement. If you cannot measure something, you cannot understand it. If you cannot understand it, you cannot control it. If you cannot control it, you cannot improve it.*
>
> James Harrington (Kaydos, 1998, pp. 3)

Levine (2001) affirms that there will be always ways in which people can deceive a system. However, the efforts of facilitating the calculation of percentage of completion, or making its falsification more difficult, are aimed at moving the source of earned value data closer to the administrative system, which makes the method to calculate weighting factors per deliverable a more robust way of calculation of earned value of projects.

Lastly, Cooper (2001) affirms that the dilemma of compressing the cycle time of product development and improving the performance of product development is better achieved through reducing failure rates and rework, and improving quality of execution. The appraisal of performance of product development projects depends of different interpretations of performance that vary across the organization. A benchmarking of 161 firms identified the 3 top success drivers for new product performance: a high quality product development process, a defined new product strategy, and an adequate commitment of resources (Cooper, 2001). Although the performance measurements presented herein address different aspects of the product development process, they are the reflection of how projects are being managed, and how quality of execution has been deployed across the activities that integrate projects. It is for this reason that the strategy to achieve the long term survival and success of a firm must be built over the foundations of improving quality and reducing waste, the positive effects will follow. Measuring performance sets the background that will allow a firm to estimate resources to be used in future projects. Also, it is the basis for evaluating projects and communicating their merits when resources need to be secured.

6.1 Research lines connected to this study.

Due to the scope of this thesis some research areas were not covered but they may still constitute a valuable source of information for Specialized Vehicles Inc. and for project management in general. Along the development of this thesis, some areas of research were identified. They are related to obtaining more accurate measurements, exploring other areas of project management, or reinforcing the measurement of performance of product development projects. For instance, rework cycles in product development projects was identified as a factor that greatly affects performance of projects, therefore it is advisable to extend the study of project performance on that line. Scope changes also affect the performance of projects and therefore their effects could be studied as a factor affecting the performance of projects.

The ratio of surviving parts over total development parts is another factor that was identified as an element that influences performance in product development projects. This indicator could be used to evaluate the effectiveness of the definition of requirements at early phases of the product development process that will not result in major modifications or discontinuation of parts. Analysis of the behavior of changes and the ratio of surviving parts over total development parts can constitute another measurement of performance and it is worth to be considered as subject for future study.

Earned value in projects as revenue enabler is another idea that was identified during the initial phases of this thesis. The intention is to identify the commercial value of deliverables in projects based on the future demand of the products that are generated from the project. Although this is not directly related to product development performance, it can help to build an ABC system that enable the allocation of value to project deliverables and the further evaluation of the project performance on cost over commercial value and not over budget.

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Appendix I – Weighting factors of product development deliverables

Introduction

The model presented herein is inspired in the House of Quality. The purpose of the model is to assign weight to the different deliverables. This model addresses the fulfillment of customer requirements through the activities carried out during the project. The information contained in this document is related to the spreadsheet HoQ_Product_Dev.xls

Functionality

The model is designed for calculating weighting factors per deliverable. For this initial version, the maximum number of deliverables to use is limited to 30, and the maximum number of customer requirements is limited to 5. Fewer deliverables and customer requirements can be used as well.

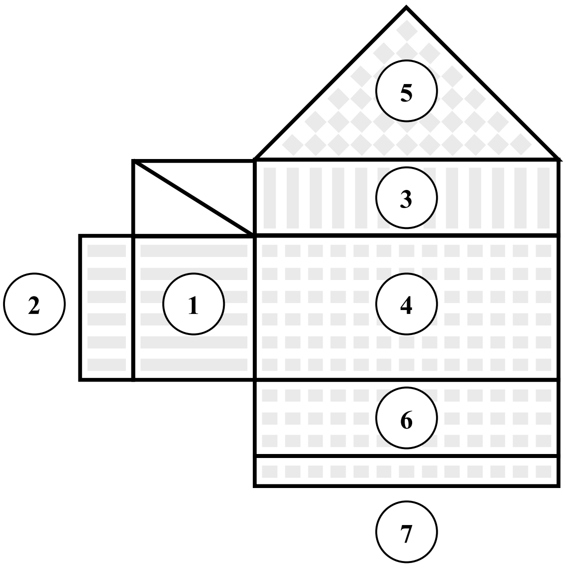
The weight per deliverable is expressed as a decimal fraction of the total weight of the deliverables under consideration. The total weight after the completion of all deliverables must be equal to 1,0. The cumulative weight per deliverable, up to the current stage of the project, is used as a factor to estimate the earned value of the project up to that point in time. Then, the earned value is used to calculate the cost and schedule variances of the project, and the Cost Performance and Schedule Performance indexes.

Use

The operation of the toll is based on the direct input of data from the user and the execution of macros. The areas of the tool that require input from the user are *customer requirements*, *weight per customer requirement*, *deliverables* and *relations among deliverables*. Those areas are depicted as 1, 2, 3, and 5 respectively in

Figure 0.1.

The *customer requirement* cells are comprised by an editable cell that should contain a description of the requirement under consideration and a check box. The *deliverable* cells are comprised by an editable section that should contain the name of the deliverable and a switch button. The cells that contain the *relations among deliverables* are scrolling list with the options a, b, c, and <empty>.



Nomenclature

1 Customer requirements

2 Weight per customer requirement

3 Deliverables

4 relations between customer requirements and deliverables

5 relations among deliverables

6 partial indexes per deliverable

Figure 0.1 Schematic representation of the tool

First, fill in the names of *customer requirements* and *deliverables* simply by clicking on the cell and typing the names. Each customer requirement is the assigned weight as a percentage. The addition of all the requirements under consideration must add up to 100%.

Then select the relevance of the relations among deliverables by clicking on the cells and selecting from the options in the scrolling list. The cell that contains the relevance of the relation among two deliverables corresponds to the intersection of the header numbers of the deliverables (numbers in purple above each deliverable in Figure 0.2). An empty cell indicates that the two deliverables are not related or dependent. A cell marked as *c* indicates that there is a weak relation or dependency between the deliverables. A cell marked as *b* indicates that a medium relation or dependency exists between two deliverables. A cell marked as *a* indicates that two deliverables are strongly related to each other or that there is a strong dependency between them.

The next step is to indicate how each deliverable addresses the different customer requirements. This step is performed by deliverable. Click over the switch button of deliverable and then click on the check box of the requirements that are addressed by that particular deliverable. More than one requirement may be checked per deliverable.

The final step of the process to calculate the weight per deliverable is to click on the button labeled Calculate the effects of interactions on the upper left corner of the tool.

To erase all the cells containing the relations among deliverables click on the button labeled as *Reset Interactions TGI:TGI.* To erase the selection of deliverables that address the different customer requirements click on the button labeled as *Reset Interactions REQ:TGI.*

Logic behind the tool

This section contains the formulas used to calculate the different indexes used to calculate the weight per deliverable. The names of the different variables are in accordance to Figure 0.2.

Index$_p$ is the average of the fractions that represent the dependencies or relations that one particular deliverable has with the rest of the deliverables. Empty cells are considered in the calculation of the average. For instance, the relations and dependencies of deliverable 5 (marked in yellow in Figure 2) produce the following *Index*$_p$:

$$Index_P = \frac{\sum_{i=1}^{n-1} a_i}{n-1}$$

$$Index_P = \frac{1 + 0{,}5 + 0 + 0 + 0{,}5 + 0{,}5 + 1}{8-1} = 0{,}5$$

Q_i is the addition of the weights of all customer requirements that are addresses by a particular deliverable. In the example, the Q_i index for deliverable 5 is calculated as follows:

$$Q_i = \sum_{i=1}^{q} W_i$$

$$Q = 0 + 0{,}3 + 0 + 0{,}05 + 0{,}05 = 0{,}4$$

Index$_T$ is the product of the *Index*$_p$ and Q. In the example, the *Index*$_T$ for deliverable 5 is calculated as follows:

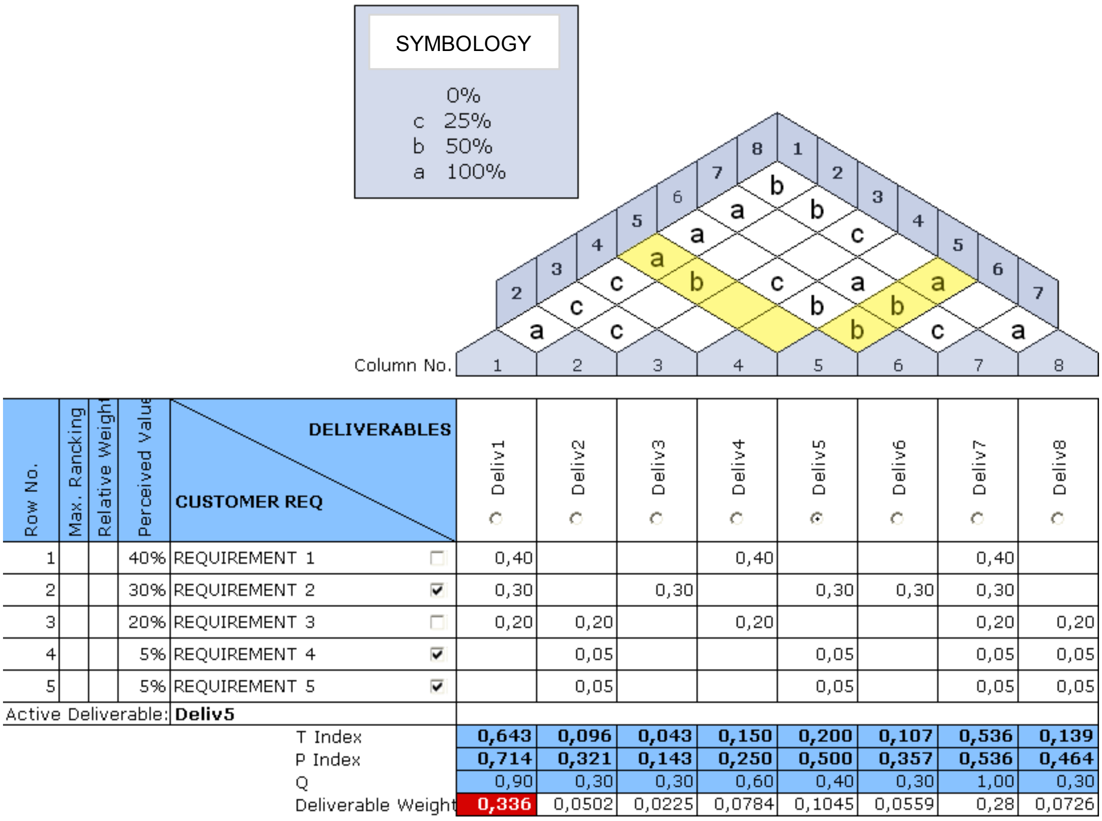
$$Index_T = Index_P Q$$

$$Index_T = (0{,}5)(0{,}4) = 0{,}2$$

The weight per deliverable, V_i, is the normalized value of *Index*$_T$ for a particular deliverable. It is calculated as the *Index*$_T$ of the deliverable divided by the sum of the *Index*$_T$ of all deliverables. The weight of deliverable 5 in Figure 2 is calculated as follows:

$$V_i = \frac{Index_T}{\sum_{i=1}^{n} Index_{T_i}}$$

$$V_i = \frac{0{,}2}{0{,}643 + 0{,}096 + 0{,}043 + 0{,}15 + 0{,}2 + 0{,}107 + 0{,}536 + 0{,}139} = 0{,}1045$$ or 10,45% of the completion of the project



SYMBOLOGY

0%
c 25%
b 50%
a 100%

Row No.	Max. Ranking	Relative Weight	Perceived Value	DELIVERABLES / CUSTOMER REQ	Deliv1 ○	Deliv2 ○	Deliv3 ○	Deliv4 ○	Deliv5 ●	Deliv6 ○	Deliv7 ○	Deliv8 ○
1			40%	REQUIREMENT 1 ☐	0,40			0,40			0,40	
2			30%	REQUIREMENT 2 ☑	0,30		0,30		0,30	0,30	0,30	
3			20%	REQUIREMENT 3 ☐	0,20	0,20		0,20			0,20	0,20
4			5%	REQUIREMENT 4 ☑		0,05			0,05		0,05	0,05
5			5%	REQUIREMENT 5 ☑		0,05			0,05		0,05	0,05
Active Deliverable:				**Deliv5**								
				T Index	**0,643**	**0,096**	**0,043**	**0,150**	**0,200**	**0,107**	**0,536**	**0,139**
				P Index	**0,714**	**0,321**	**0,143**	**0,250**	**0,500**	**0,357**	**0,536**	**0,464**
				Q	0,90	0,30	0,30	0,60	0,40	0,30	1,00	0,30
				Deliverable Weight	**0,336**	0,0502	0,0225	0,0784	0,1045	0,0559	0,28	0,0726

Figure 0.2 House of Quality Tool for product development projects