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Multidimensional project control system

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MULTIDIMENSIONAL PROJECT CONTROL SYSTEM

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Abstract

Project control systems often fail to support management in achieving their global project goals. This thesis proposes a Multidimensional Project Control System (MPCS) as an approach for quantifying deviations from the planning phase to the execution phase with respect to the global project control specification (GPCS). The projects' current state must be translated into yield terms, which are expressed as a gap vector that represents the multidimensional deviation from the global project control specification. The MPCS methodology allows the project manager to determine: integrated project status; where problems exist in the project; when and where to take corrective action; and how to measure improvement. However, implementing the MPCS methodology does not require extra data collation. MPCS deals with the control of a single project and defines the project performances in comparison with the plan. The progression of several projects in parallel is a common situation in organizations, therefore a comparison of the various project performances is required. It is proposed that a comparison process be performed using the data envelope analysis (DEA) approach. The reference points for examining the performances of different projects and the directions of improvement for the projects are not necessarily found on the efficiency frontier. An algorithm is developed for applying multi-project system control having a relatively large number of inputs and outputs while maintaining the validity of the DEA methodology. The DEA output allows the diagnosis of those found on the efficiency frontier and those that need improvement.

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Nomenclature

ACWP - Actual Cost of Work Performed -ACWP has been replaced by AC (Actual Cost) in some standards.

APMBoK - Association of Project Management Body of Knowledge.

BCWP - Budgeted Cost of Work Performed - BCWP has been replaced by EV in some standards.

BCWS - Budgeted Cost of Work Scheduled -BCWS has been replaced by PV (Planned Value) in some standards.

BOM – Bill of Material.

CBS – Cost Breakdown Structure

BoK - Body of Knowledge.

CTC – Cost to Complete.

CI - Cost Index.

CP – Control Point

CWP- Control Work Package.

DEA - Data Envelope Analysis.

DMU - Decision Making Unit.

EV - Earned Value.

GP - Gap Performance.

GPCS - Global Project Control Specifications.

LOB – Line of Balance.

MRP –Material Requirement Planning

PMBoK - Project Management Body of Knowledge.

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Chapter 1: Introduction to the Thesis

1.1 Introduction

"A project" is defined by Project Management Body of Knowledge (PMBoK) (2000) as "a temporary endeavor undertaken, to create a unique product or service". Temporary means that every project has a definite beginning and a definite end. Unique means that the product or service is different in some distinguishing way from all similar products or services. Typically, projects utilise a control system, which monitors the difference or gap between the planning variables and the actual performed results.

Project control systems indicate the direction of change in preliminary planning variables compared with actual performance. Figure 1 illustrates the gap between planned and actual values of a given variable. Narrowing this gap may be accomplished by one of the following alternatives:

(a) Define corrective actions to achieve the desired results according to the original plan (moving from B to A in figure 1); or (b) Define adjusting activities, changing planned variables to actual performed results (moving from A to B in Figure 1).

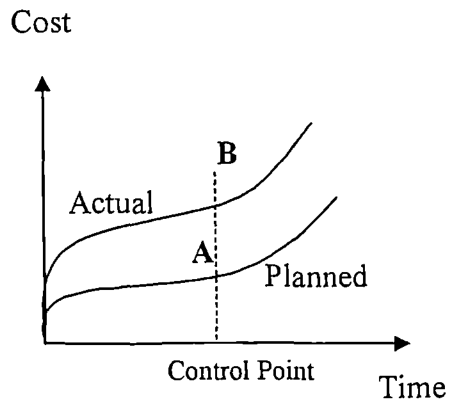

Figure 1. The gap between planned and actual values of a given variable

Shtub et al.(1996) suggest that the design of a project control system is an important part of the project management effort. A control system is based on a set of project goals and their relative importance. For each goal, at least one performance measure is required. There is overall agreement between project management researchers, (Lock (1989) Nicholas (1994), Mantel et al. (2001), Candle et al. (2001)), and project management practitioners that each project should strive to achieve the following objectives:

(a) be on time,

(b) be within its cost budgets,

(c) satisfy customer technical or performance standards.

Objective (c) combines and encompasses various dimensional measures from different disciplines, e.g. quality, operational, technical, etc.

1.2 Aim of the Research

To devise a rational project control methodology and suitable tools to allow an approach for quantifying deviations from the planning phase to the execution phase, hence to ensure that the predefined project planning and design is successfully executed during the project execution phase.

1.3 Objectives of the research

The following objectives were formulated for the research:

1. To evaluate the current state-of-the-art project control methods and practices used.
2. To develop a project management methodology, that will provide information to management so that successful performance can be achieved according to the plan.
3. To develop a project control methodology to obtain a successful performance according to the plan.
4. To develop a framework, tools and techniques so that all the project's dimensions will be integratively maintained.
5. To devise a framework, tools and technique in order to compare multiple projects operating in an organization.

Chapter 2: Literature Review

2.1 Introduction

"A project" is defined by the PMBoK (2000) as "a temporary endeavor undertaken, to create a unique product or service." Temporary means that every project has a definite beginning and a definite end. Unique means that the product or service is different in some distinguishing way from all similar products or services. As the world is changing there is a need for updating the methods, tools, and techniques of the way projects are managed. The field of project management has been developing in recent years. These project characteristics have been found to cause a managerial problem mainly because of a lack of an established, structured, learning process such as that within flow production.

As the world is changing there is a need for updating the methods, tools, and techniques of the way projects are managed. One of the main phenomena is the shortening of the product life cycle. The operations management meaning of this process is moving from high volume production toward project management. World wide there is a growing understanding of the need for a managerial tool within the project management field. For example, Schimmoller (2001) stated the need for updated project management tools in power plant projects because of these projects' complexity. Otherwise, project management will suffer losses in cost and time. Many studies have been made to develop tools, concepts, and methodologies. For example, Denker et al. (2001) introduced the concept of information dependency structure. This concept aims to minimize interaction during the project life cycle. The technique transforms descriptive maps (constraints) into prescriptive maps (project scheduling) using the dependency structure matrix (DSM). Hardie (2001) introduced a recursive model based on a Markov Chain. According to the author, the aim of a project manager should be to minimize revision probabilities, even if a specific activity takes much longer than was originally planned. Moving on to the next activity is not necessarily a sign of genuine progress if the preceding activity has not been successfully performed. Rather, at the end of each activity it is necessary to examine how well the activity was performed and to estimate from the remaining dependent activities the probability that revision will be necessary. If these revisions probabilities are high or even moderate, then further work must be done on the activity in order to reduce these revision probabilities.

Another way of tackling project management problems is to adopt tools from other disciplines and try to use them in a project environment. For example, Hides et al. (2000) stated that there is a connection between total quality management (TQM) principles and project management. Adopting TQM principles improves project performance as regards good leadership, better customer service, error prevention and employee development. Also, Laszio (1999) demonstrated the feasibility and practicality of applying a quality management approach to project management. The model uses the criteria of the Canada Award for Excellence, the internationally recognized Quality Award programme. Cicmil (1997) put the notion of Total Quality Management into a project management perspective. Conroy et al. (1997) developed a knowledge base system to support multi-disciplinary engineering design projects. The system applied intelligent decision making knowledge based support processes to the selection of appropriate project management systems. It is sometimes difficult to use the same methods in another environment such as Bauch et al. (2001) who described the development and application of a statistical project control tool for engineering projects using statistical process control (SPC) principles. The model had a significant limitation; in order for a useable chart to be developed, appropriate and consistent historical parameter data must have already existed. This may contradict the PMBoK definition of a project. Therefore it is important to delimit the project types to those to which the model may be applied.

Global changes influenced not only the classic operations environment producing products and services, but also the project environment where problems were identified. Berggren et al. (2001) discussed trends in infrastructure projects. Three problems have been identified: the problem of coordination; the problem of absent customer; and the problem of learning. A conceptual framework was offered in order to assist management to solve these problems. Pinto (2001) explored the connection between the project manager and organization politics. A good understanding of the organization politics associated with a particular project is necessary for managing the project properly. Halman (2002) et al. carried out a survey within one of the worlds' largest companies. The survey findings revealed clear differences in perception between project owners and project managers. These differences not only referred to the project content but also to the expectations of their mutual roles during the start-up project.

As the world is changing toward managing more and more products within the project management domain, the project management field is also changing in order to cope.

a. Bodies of Knowledge

An interesting way of coping with the increasing demand for project management solutions was the development of Bodies of Knowledge (BoK), that summarized the main and important knowledge in the area of project management, by two professional associations: the Association of Project Management (APM) and the Project Management Institute (PMI). These BoK are unique phenomena within the industrial engineering and management area. For example, in the field of operations research there is no BoK. Morris (2001) conducted a review regarding the existing project management bodies of knowledge. Morris (2001) indicated the need for BoK and continually updating the BoK. The researcher surveyed Israeli defense projects and challenged the BoK assumption that all projects are similar and "one size fits all". Shenhar (2001) classified the surveyed projects into 4 categories. Each category had to be managed a little differently in order to be successfully managed. Evaristo et al. (1999) had taken the same attitude and developed a classification of project management types based on the number of projects and sites involved. The existence of distributed projects, their importance, and expected future predominance was described.

It is important to emphasize that the main argument against the BoK methodology is the complexity of projects. Williams (1999) stated the need for defining project complexity in order to cope with the evolution of projects. On the other hand Tatikonda et al. (2000) supported the BoK assumption of project similarity. Tatikonda et al. (2000) investigated project management methods used during the execution phase of new product development. The findings were that companies can indeed balance firmness and flexibility in product development projects. Another result is that companies can manage a variety of projects using broadly similar project execution methods.

The APMBoK (2000) suggested a strategic approach regarding management of projects. Also, Lampel (2001) studied the core competencies of project execution within an engineering – construction – procurement environment. Three types of strategies were developed: (a) focusing, i.e. company driven; (b) switching, i.e., opportunity driven; and (c) combining.

Project management professional associations developed the bodies of knowledge to standardize project processes and procedures. There is a debate on the implementation efficiency but the amount of BoK implementation is increasing.

Both APMBK and PMBoK do not tackle the control issues within an integrative framework. The control methodologies used are: the EV methodology; and one dimension control tools such as scope change control, quality control, etc. Therefore, there is a gap of supporting the integration of these dimensions within both BoK.

b. Using project management's tools, method and techniques within different environments.

Project management methods are starting to be used in environments which have never before used project management methodology.

Lo et al. (2000) introduced standard project planning tools into SMEs ISO 9000 implementation projects. Côtè et al. (2000) introduced standard project planning tools into a hospital environment.

Ling et al. (2002) presented a case study of a 621 million US dollars power plant in East Asia. It demonstrated how a large and complex project in the area of power plants can be successfully implemented. The project encountered several problems for example: no smoothing progression; inaccuracy of project information; excessive changes orders; ineffective communication; misalignment of client's expectations. An important lesson learned in order to achieve project's success is strictly performed use of control procedures by the project stakeholders.

These papers strengthen the observation that project management methodologies, tools, and techniques are being used more and more in different environments.

c. Risk management

Risk management is one of the main research areas in today's project management domain. The main difference between the PMBoK 2000 edition versus the 1996 edition was the former's development of an enriched risk management model. Much research was performed during the last few years on risk management. One study was performed by Floricel et al. (2001). They studied 60 large scale projects. The results showed that building a strategic system for dealing with anticipated risks was the preferred approach for dealing with turbulence in large scale engineering projects. Tummala et al. (1996) described a risk management model methodology and implementation. Another study, performed by Miller et al. (2001), proposed that managing and controlling risk reduces project failure probability. A managing and controlling risk methodology, based on 60 large engineering projects, was developed. The methodology describes six layers of mechanisms used by the managers for coping with risks. Many companies that implement the BoK methodology implement risk management as a part of it. Other companies implement only risk management. Elkington et al. (2002) carried out a survey in order to examine project risk management practice in the British utility sector. The findings were that there is a strong link between the amount of risk management undertaken in a project and the level of project success. More successful projects used more risk management. Also, the earlier that risk management was used in a project, the more successful it was.

The importance of risk management and of using accepted quantitative tools and techniques to support it has become apparent world wide. For example, Schmit et al. (2001) described a systematic process that identifies risk in software projects. The process was developed using the Delphi study that took place in the USA, Finland and Hong Kong. Another example is a study performed by Lorance et al. (2001). They discussed techniques for the analysis and presentation of all possible resource requirements and outcomes. Datta et al. (2001) stated that the success of project completion within budgeted time, cost, and perceived parameters depends to a great extent on the early identification of immediate risks to the project. A risk management matrix was used as a supporting tool to achieve project aims. Adopting another tool was suggested by Chait (2000) who stated the importance of a knowledge management system regarding managing projects and their risk. A success story of implementing a risk management methodology was described by Dey (2001). This researcher developed and implemented a risk management model in a cross country petroleum pipeline construction project in India. The model was a decision support system based on analytic hierarchy process (AHP) and decision tree analysis (DTA).

Risk management has many psychological ingredients. It is difficult to forecast human behavior. Grundy (2000) described the implementation of strategic behavioral methods and tools in a British Telecomm strategic project.

Risk management also deals with the interaction between all the project stakeholders. Gutierrez et al. (2000) analyzed the relationship between project owners and project subcontractors. They asked whether subcontractors should be managed individually or as an aggregate (pool)? The main conclusion was that as long as the contractors are strongly consistent across the project, pooling is recommended.

Another stakeholder conflict is the contractual relationship between the project and the project contractors. Turner et al. (2001) developed concepts to predict the type of contracts that should be selected for infrastructure projects.

Risk management has become one of the main research issues in project management. Risk management implementation however is a very demanding process that includes the use of quantitative tools and techniques integrated with qualitative methodologies.

d. Theory of constraints (TOC)

Another subject that researchers and practitioners have discussed in the project management literature is the implementation of the theory of constraints (TOC) introduced by Goldrat (1988) and Goldrat (1997). Steyn (2002) introduced the theory of constraints approach for managing resources shared by a number of projects operating in parallel. The author explored the use of TOC principles in project cost management and risk analysis. Rand (2000), Umble et al. (2000), Leach (1999), Sragenhym (2001), and Herroelen et al. (2002) described the theory of constraints - critical chain principles and implementation methodology. The TOC was implemented in many organizations, e.g., Michalski (2000) described TOC implementation within pharmaceutical industry projects.

There is an argument as to how efficient and realistic is the implementation of TOC in projects. Herroelen et al. (2001) described the advantages and disadvantages of implementing critical chain scheduling. The critical chain scheduling methodology of using time buffers (a basic TOC tool used to manage the project) provides a simple tool for project monitoring and realistic due date setting. The danger, however, lies in its oversimplification, i.e. implementing the TOC will lead to real life problems that the TOC tools are not capable of handling. Therefore, it may be problematic implementing the critical chain in a complex project. However, Herroelen et al. (2001) suggested a branch and bound mechanism to improve the final project makespan. The critical chain is starting to be implemented and it will be interesting to follow its further development and integration within traditional methodologies.

2.2 Nature of project control

The APMBoK (2000) has taken a broad view of what is meant by control. Planning, measuring, monitoring and taking corrective action are all usually included in the control cycle. Typically, projects utilise a control system, which monitors the difference or gap between the planning variables and the actual performed results.

Project control systems indicate the direction of change in preliminary planning variables compared with actual performance.

2.3 Importance of project control

The importance of project control is a significant issue. Shtub et al. (1996) stated that the design of a project control system is an important part of the project management effort. Falco et al. (1998) stated that "it is widely recognized that planning and monitoring plays a major role as the cause of project failures. Despite the continuous evolution in the project management field, it appears evident that the traditional approaches still show a lack of appropriate methodologies for project control." Many articles have supported the importance of control in order to achieve the project's aims and objectives. Avison et al. (2001) stated that project performance can be improved if more attention is given to the issue of control. Dey (2000) described the implementation of a concurrent engineering methodology within a cross country petroleum pipeline construction project in India. This study strongly recommended controlling projects through risk management, quality monitoring and an integrated information management system.

Another way of tackling the importance of control is by examining projects' failures in order to find the project control rule. For example, Whittaker (1999) surveyed 1450 companies in the public and private sectors. The findings were that lack of risk management is the most highly ranked factor contributing to project failure. Other contributing factors were the lack of required team skills and control.

During the last decade leading projects in many industries were Enterprise Resource Planning (ERP) implementing projects. Motwani et al. (2002) found that the recommend actions needs to bring troubled ERP projects under control are: (a) redefining or subdividing the project; (b) improving project management through the use of formal tools and techniques; and (c) using a team based approach to solve specific project problems. Their findings emphasize again the importance of project control.

Demirkan et al. (1998) described the importance of a project office managing multiple, interdependent projects. In the case of many projects running in parallel it is important to facilitate organization management with the use of appropriate control systems.

Another important aspect of a project control system is the support of multidimensional objectives. This is supported by Turner et al. (1999). They noted that managers should recognize that organizations are essentially multidimensional. The multidimensional characteristics: (a) hierarchy linked to the senior management; and (b) different models for operational control and senior management; (c) the elements of operational control: (1) managing clients; (2) inputs; (3) processes; and (4) outputs.

Therefore, a proper way of managing a project must refer to factors that lead to success in meeting the whole range of multidimensional objectives. Much research has been conducted in order to examine project success factors. Pinto & Slevin (1987) carried out a survey based on Fortune 1000 companies that examined project success among a sample of these companies. Sánches et al. (2002) surveyed R&D project management in Spanish industry. White et al. (2002) reported the findings of a survey designed to capture the "real world" experiences of people active in project management. The survey took the form of a questionnaire that was sent to 995 project managers. Sudeh et al (2000)'s survey covered approximately one hundred defense projects. Fricke et al. (2000) conducted a survey among organizations with interdepartmental projects. The common denominator resulting from the above-mentioned surveys pointed to a common checklist representing project success factors that include clear goals, management supports, ownership, a control mechanism and communication. A great deal of variation is present among these success factors that do not always employ the same dimensions. For example, clear goal and management supports do not share the same control dimension.

Francis- Elran (1998) took a different angle. She surveyed 86 Israeli construction companies. The findings showed that the success level of a project implementing a specific control method is related to the level of risk as measured by situational factors. In the same geographic region, Odeh (2002) et al. surveyed construction projects in Jordan. The survey objective was to identify major causes of delay in the construction industry. The findings indicated that owner interference, inadequate constructor experience, financing and payments, labor productivity, slow decision making, improper planning and subcontractors are among the top ten most important reasons for delay.

Dvir et al. (2003) surveyed approximately one hundred Israeli defense projects. The findings were that there is a significant positive relationship between the project's success to each of the following : (a) the amount of effort invested in defining the goals of the project; (b) the functional requirement; (c) technical specifications of the project.

Complex projects are performed in the software industry. Jiang et al. (2000) surveyed 86 project managers regarding project effectiveness in the software development industry. The data, in general, indicated good control over risk factors. However, project effectiveness measures revealed that two common risks have a major significant impact: (a) lack of general expertise on the team; and (b) lack of clear role definition for team members. A year later Jiang et al. (2001) surveyed Project Management Institute (PMI) members. The results confirmed the critical role of the project managers in project success, implying that organizations should involve their information system project managers in their projects as early as possible. Senior management should provide infrastructure that allows the project managers to adopt needed methods.

Baccarini (1999) tried to have a better definition of the problem. He developed the logical framework method (LFM) defining project success. LFM was developed to assist in the understanding of two components of project success: management success and product success. These two components must be defined and differentiated in the project in order for the project team to clearly know its objectives.

Reviewing the above mentioned papers leads to a better understanding of the importance of a control system. A control system has an important role in achieving project aims and objectives. A problem that arises here, however, is the multidimensional nature of project aims and objectives.

2.4 Current project control systems

Integrated cost and scheduled control systems were introduced in the USA during the sixties and were mainly used in defense projects. These systems created standards supported by guidelines such as DoD 7000.2. Abba (1997) described the development process of an integrated project control system in the US Department of Defense (DoD). The project control system was implemented in large projects budgeted by the DoD. This control system is also called Earned Value (EV). This classical project control method is used for monitoring two dimensions: time and cost. The project control status is based on the aggregate of these variances. The EV concept is based on the work breakdown structure (WBS) planning tool. The PMBoK (2000) defined WBS: "a work breakdown structure is a deliverable-oriented grouping of project elements that organizes and defines the total scope of the project." Planning a project using WBS structure means hierarchic structuring of a project using its components and subcomponents. A work package, usually at the lowest level of a WBS, includes a set of tasks to be carried out in a predefined organizational unit. In general, work packages are used as the basic elements in the planning and control phases of a project. Berg et al. (2000) reported on the "WBS Practice Standard" team working toward developing a document describing how to use a WBS. The main conclusions were: (a) the project manager should have the flexibility to design the WBS; and (b) the lowest level in the WBS may be connected with dependency links in a dependency diagram.

Figure 2 illustrates the EV methodology. The cost variance (CV) is traditionally defined as the gap between budgeted cost of work performed (BCWP) and the actual cost of work performed (ACWP) i.e., (BCWP – ACWP). The schedule variance (SV) (BCWP –BCWS) is the gap between budgeted cost of work performed and the value of budgeted cost of work scheduled.

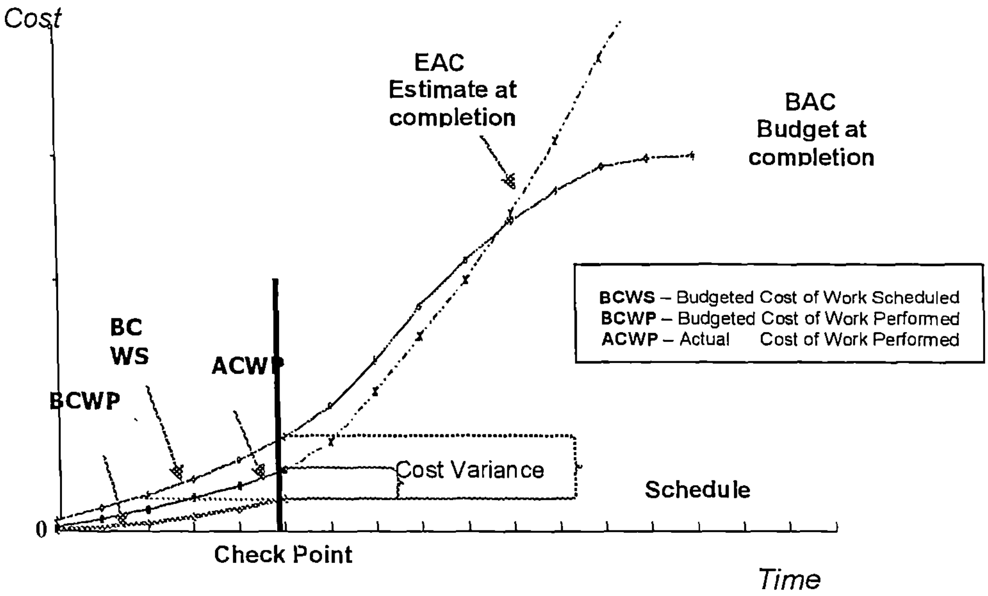

Figure 2. EV data elements

Sipper et al. (1997) described these US Air Force methodology / Earn Value principles that examine work-performed cost versus budgeted cost. Raby

(2000) outlined the foundations of the Earned Value concept and showed how EV is used to measure and monitor projects. Fleming et al. (1999) and Fleming et al. (2000) described the foundations of the methods for Earned Value concept and showed how EV is used to measure and monitor projects. Williams (2003) conducted a thorough literature search regarding the contribution of mathematical modeling to the practice of project management. It was found that the synthesis of project management principles and operational research principles will lead to a new managerial theory. The earned value methodology is cited as a methodology for project control.

Currently, project control systems employ similar principles. Deng et al. (1998) carried out a survey within the Hong Kong construction industry, examining integrated cost/schedule control. Their findings indicated that only a small percentage of construction projects implemented such a methodology. Their article also recommended that the government and private sector use an integrated cost / schedule control system, emphasizing that using an unsatisfactory single performance measure system would not advance the projects' performance.

El-Mashaleh et al. (1999) conducted a survey regarding integrated project control systems in clean-room construction projects. Their conclusions were: (a) a control system constitutes an essential part of the ongoing managerial effort aimed at achieving the project's objectives; (b) an organization employing the project should allocate the proper amount of financial resources in order to establish an effective control system; (c) every project should be hierarchically structured in a work breakdown structure (WBS); and (d) a project control system should monitor all the participants at the work package (WP) level.

From a different perspective, the following studies present Earned Value enrichment. Paquin et al. (2001) offered to add another dimension to the control system. The model constitutes a quality breakdown structure (QBS) to indicate the overall quality objective. This dimension enables the project manager to assess, at any time, the overall quality simply by comparing its earned quality of work planned with the planned quality of work performed. Assessing ongoing quality enables the project manager to identify activities that were not successfully performed. The assessment of those activities initiates corrective action as quality deviations are detected. Another enrichment EV model was introduced by Robinson (1997). The researcher developed a statistical approach that aims to improve the project manager's understanding of the Earned Value results. Using this statistical approach the project manager can know when observed schedule variances are statistically significant. In the case of statistically significant variances, the project manager will be able to take corrective action.

The DoD scheduling guide for program managers (2000) illustrates a control system designed for projects producing more than one product unit. Performance is measured as throughputs at predefined control points. This control system is the Line of Balance (LOB). Arditi et al. (2001) presented the effect of learning on LOB control methodology in a repetitive – unit construction environment using learning curves. Another use of the LOB technique was used by Shtub (1997).

This researcher developed a tool for a project such that its work content can be divided into several subprojects or segments. In this tool the same set of activities is performed on each segment. Line of balance (LOB) measuring indices were implemented within the segments control.

Other control tools are used mainly for controlling specific issues in order to achieve other project aims. One control tool is Project Scope Management, which defines the procedures whereby the project content may be altered. It includes various managing tools designed to control changes. Meredith et al. (2000) mention that these changes are mainly produced by the stakeholders' desires, technology developments, increased knowledge base and changes in project process.

Another control tool is based on project engineering design control systems, which include a series of design reviews (DR) that typically contain predefined control points through a project's life cycle.

Strategic project control is another tool described by Van Veen –Dirk et al.(2002). They suggested a model connecting critical success factors with the balanced scorecard (BSC) in order to achieve strategic control. The BSC is not related to the market. Therefore, the combination of BSC with critical success factors can detect market changes and lead to changes in company strategy.

Another control tool is offered by the theory of constraint. The TOC offers controlling project scheduling by monitoring the time buffers as Steyn (2000) stated.

Another model is described by Costa et al. (1989). The authors introduced a new managerial methodology in order to manage and control projects and jobbing production. The paper described a conceptual model for a control system based on traditional techniques including the importance of integration. This model takes a strategic perspective using "winning criteria" as the goal.

Mayor (2003) described a procedure for controlling suppliers and contractors using "the Five Rights": the right quantity; the right quality; the right price; the right time and place; and the right supplier. Hormozi et al. (1999) indicated the need to define and establish a control system supporting time, cost and performance. They mention that project managers often prioritise projects aims differently. For instance, one manager may prefer to focus on timetable while another manager emphasizes profitability.

Another control system concentrates only on project finance control systems. For example, Akalu (2001) introduced implementation of a finance appraisal called shareholder value analysis (SVA). The SVA tackles the relationship between the market value of debt used to finance the project and the net present value (NPV) of the project. Akalu recommended using SVA measures during the project life cycle at each control point. Abbasi et al. (2001) introduced another project finance control system. The author suggested a new hybrid heuristic that maximizes project net present value. The heuristic is based on a combination of minimum late start and shortest processing time priority rules.

Reviewing the literature regarding current control systems suggested the following: first, the primary project control system is the Earned Value which is implemented world wide. The system integrates cost and scheduling. Second, a less often used control system is the Line of Balance which measures the progress of projects producing more than one product unit. Finally other systems concentrate only on one specific dimension such as cost, design, etc.

2.5 Deficiency of the current project control systems

Both project management researchers and practitioners stated that there are deficiencies using the current project control systems. Kolisch (2001) surveyed an extensive array of research on various aspects of project scheduling. An important conclusion was that the integration of project objectives with resulting models and methods is an important goal that remains to be explored. Another study was conducted by Driva et al. (2001). They carried out a survey of performance evaluation of new product developments in the UK. Without exception, all companies wanted to improve their use of performance measures. This probably meant that the methodologies that these companies were using were not satisfactory.

Bauly (1994) supported this view and described the need for the use of performance measurements within project management. The author suggested a list of preferred metrics. This point of view regarding the deficiency of the current project control systems is supported by a study performed by Tukel et al. (1998). They carried out a survey of project characteristics in diverse industries. The conclusions were that time and cost are important project objectives. However, project quality is also an important project objective. Furthermore, use of quality as a measure for project success is an important factor for the successful implementation of a project. Project quality can also be defined as equal to a proper performance of the project content, i.e., its multidimensional aims and objectives. Kwok et al. (1998) described the total control methodology (TCM) which is based on the scenario that several separate processes usually exist within each product line. Each of these processes should have an individual control plan. The plan must include control instructions for each operator, i.e., control specifications. Kwok et al. (1998) enhanced the basic TCM model by using quality control tools. They emphasized the need for controlling the quality dimension. Another supportive opinion is that of Tukel (2001). The author found that a project manager's primary success measure is the quality of a project. This is supported by empirical generalization. The quality of a project is found to be associated with customer focus, rework reduction, and conformance to the technical specifications. De Toni et al. (2001) surveyed 115 medium and large Italian companies. Among the findings was that although these companies adopted the synthesis of cost and non-cost dimensions, in practice, the cost and non-cost dimension results were kept separate and not within an integrated form.

The above studies indicate that: (a) the control dimensions of time and scheduling are not enough; (b) there is a need for a multidimensional project control system that can measure the project's aims and objectives; and (c) there is a need for an integrative system that can indicate the project's status during the project's life cycle.

2.6 Author's experience

Based on 15 years of consultancy projects in the Israeli production and service industries it is clear that project managers need to have more than two control dimensions, (e.g. quality, operations) to achieve project aims and objectives that go beyond time and cost. This will be supported using 4 representative cases of consultancy jobs in the Israeli industry.

Rozenes (2000) described a consultancy assignment to implement a project management methodology at Tadiran Spectralink LTd. According to Dan and Bradstreet (2003), Tadiran Spectralink Ltd. is a highly specialized producer of advanced wireless communications systems. These systems are available for a variety of airborne platforms and ground installations, including Clear, Anti-Jamming, LPI, Digital, and TDMA systems. Major capabilities include: data link design; Combat and Peacetime Search & Rescue systems; software and hardware development; production integration and testing; after-sales technical support and Integrated Logistics Support. Tadiran Spectralink has a workforce of 150, mainly engineers and skilled technicians. The consultancy assignment main goal was to implement the PMBoK methodology combined with the Critical Chain approach. The process took a year and the final results were satisfactory. The company adopted the methodology and performance improved. The complexity of the Hi-Tech projects demanded knowing the status of multidimensional control measures such as quality, operational, functionality, etc. Implementing traditional control systems did not integrate the different control indices and the managers could not observe the entire picture.

Rozenes (1998) described the implementation of the Earned Value control system at ECI Telecom Ltd IS department. According to Dan and Bradstreet (2003), ECI Telecom Ltd. is a provider of advanced telecommunications solutions. Focused mainly on the metropolitan optical and access markets, ECI enables leading service providers and carriers world wide to maximize their capital investment and reduce operating expenses while providing voice, data, video and multimedia services to their customers. ECI maintains a global sales and customer support network. The consultancy assignment main goal was to implement the EV methodology in the information systems department. Managing complex projects in a dynamic environment is a difficult mission. The problem in implementing the EV control systems was team discipline, i.e., the staff were not willing to report their progress to the management. The main argument was that using the EV system will not indicate the amount of effort that was put into their work and the quality of their work. That meant the staff wanted more indicators pointing toward the quality of performance of the team.

Rozenes (1997) described planning a multi-project control of electrical transformation stations at the Israel Electric Corporation. According to Dan and Bradstreet (2003), the Israel Electric Corporation (IEC) is responsible for generating, transmitting and distributing electricity. It supplies electricity to all parts of Israel including those areas under the control of the Palestinian Authority. The IEC operates under the auspices of the Israel Public Utility Authority (PUA) and is subject to the Electricity Law that regulates licensing, competition, rates and environmental practices. The consultancy assignment main goal was to plan the project according to traditional methodologies. The consultancy project involved planning 80 electrical transformation stations using traditional methodologies. Planning a control system for this project based on the EV system was problematic because the complexity of the project demanded other dimensions and integration among all of the control indicators.

Rozenes (1996) described implementation of a project control system at Israeli Military Industry Corporation factory. Israel Military Industries (IMI) is the first defense equipment manufacturer in Israel, established in 1933 to provide self-defense equipment for the State of Israel. Today, IMI is focusing on its core business - the defense systems market. With over 60 percent of its production destined for world markets, IMI is a recognized supplier to armed forces, law enforcement and security agencies and defense manufacturers on five continents. IMI is the major supplier to the Israel Defense Forces, fulfilling its most important mission - ensuring the safety and security of Israel and its citizens. Over half of IMI's 4,000 employees are engineers, scientists and technical experts. The consultancy assignment main goal was to implement a control methodology in a specific Hi-Tech project using one control dimension - cost. Only one parameter was not enough for controlling the entire project. In this case the management was insistent on this procedure. Again there was a lack of different control indices that did not reflect the complexity of this Hi-Tech project.

2.7 Discussion and Conclusions

This literature review indicates the rapid development of the project management domain. For large projects the Earned Value methodology is the dominant control methodology world wide. Many reports described application or enrichment of the EV system. There is a lack of a broader control picture. Project managers need to have more than two dimensions, e.g., quality, operations, etc, in order to achieve project aims and objectives that go beyond time and cost. This is supported by many researchers aiming to identify project success factors. The main conclusion is that a project tackles many dimensions and the project manager should have a methodology that supports the integration of these dimensions. Controlling the entire array of these success factors defines the need for a multidimensional project control system (MPCS). The MPCS system described by Rozenes et al. (2004) will be presented in the following chapters of this thesis.

Chapter 3: MPCS: Multidimensional Project Control System

3.1 Introduction

Earned Value (EV) is the classical project control method used for monitoring two dimensions: time and cost. Using the EV methodology is sometimes not sufficient, as there are projects where effective monitoring requires more than the two dimensions of cost and time.

Figure 3 illustrates a case where a subassembly in level 1 is broken into 3 work packages in level 2. These work packages carry out purchasing and integration activities.

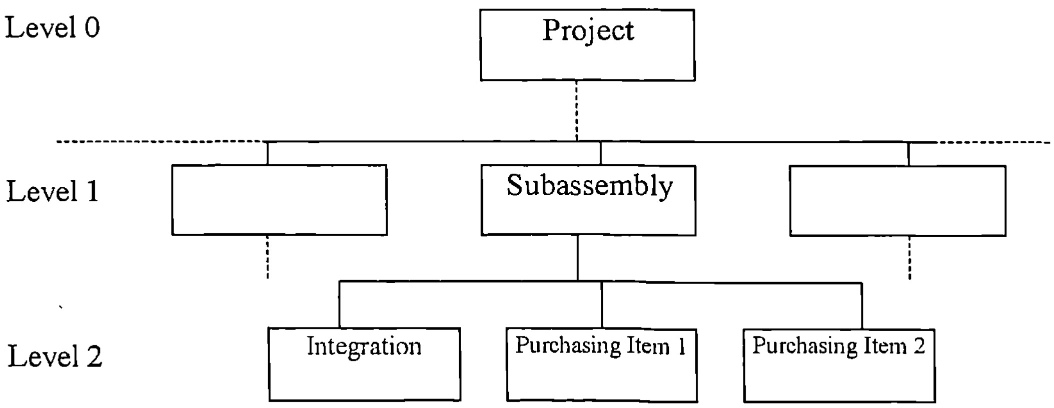

Figure 3. Partial WBS

Table 1 presents typical data derived from employing the EV control methodology on the case illustrated in figure 3. It shows that the control indices, i.e. the cost index (CI) and schedule index (SI), of "Subassembly" are satisfactory (CI=0.99, SI = 0.99).

Table 1. EV Subassembly control status

	$CI = \frac{BCWP}{ACWP}$	$SI = \frac{BCWP}{BCWS}$	*BCWP* (*$K*)	*BCWS* (*$K*)	*ACWP* (*$K*)
Subassembly	*0.99*	*0.99*	*301*	*303*	*305*

However, Table 2 contains a detailed presentation of the subassembly's structure. It presents the value of control indices of all of the subassembly's components. CI and SI values of "Purchasing Item 1" and "Purchasing Item 2" show that they have performed according to the plan i.e., (CI=SI=1). However, the CI and SI values for "Integration" show poor performances i.e., (CI = 0.2, SI = 0.33). The conventional usage of the EV methodology would result in a satisfactory accomplishment of the subassembly (i.e. CI, SI in Table 1). However, it would not be possible to accomplish the subassembly without satisfactorily accomplishing the integration and this would mean that the project's objectives would not be met, i.e., the actual performance of the CI and SI indices are not as good as those indicated by the EV methodology.

Table 2. EV control status

	$CI = \frac{BCWP}{ACWP}$	$SI = \frac{BCWP}{BCWS}$	*BCWP* (*$K*)	*BCWS* (*$K*)	*ACWP* (*$K*)
Subassembly	***0.99***	***0.99***	***301***	***303***	***305***
Purchasing Item 1	1	1	100	100	100
Purchasing Item 2	1	1	200	200	200
Integration	0.2	0.33	1	3	5

The proposed MPCS methodology uses a multidimensional control system which assists in controlling projects. The MPCS is using the Global project control specifications (GPCS). The GPCS determines control specifications by defining control tasks through the project life cycle. Control activities define the measurement processes that should be executed in order to successfully perform the project WBS. The GPCS defines the control dimensions, their details, structure and performance prioritization.

Project management methodologies are used in two phases of the project life cycle: the planning phase and the execution and control phase. Table 3 shows the tools used in the various phases when implementing either the EV methodology or the MPCS methodology. The WBS is the classic method used at the planning stage. However, the GPCS replaces the WBS during the execution and control phases when the MPCS methodology is used in preference to the EV approach.

Table 3. MPCS versus EV

Methodology Phase	*Earn Value EV*	*Multidimensional Project Control System MPCS*
Planning	WBS	WBS
Execution and Control	WBS	GPCS

The differences between the two methodologies (EV and MPCS) are exemplified by using the structures illustrated in figures 4 and 5. Figure 4 illustrates a classical structure of a project using the EV methodology. It shows two types of tasks. Work packages (WP) and control work packages (CWP) determine task content and control content respectively. Note that activities of both phases (planning, control) are present in one structure.

Figure 5 illustrates the MPCS methodology. Figure 5a presents the planning phase and Figure 5b represents the execution and control phase. When implementing the MPCS methodology, each phase has its unique structure.

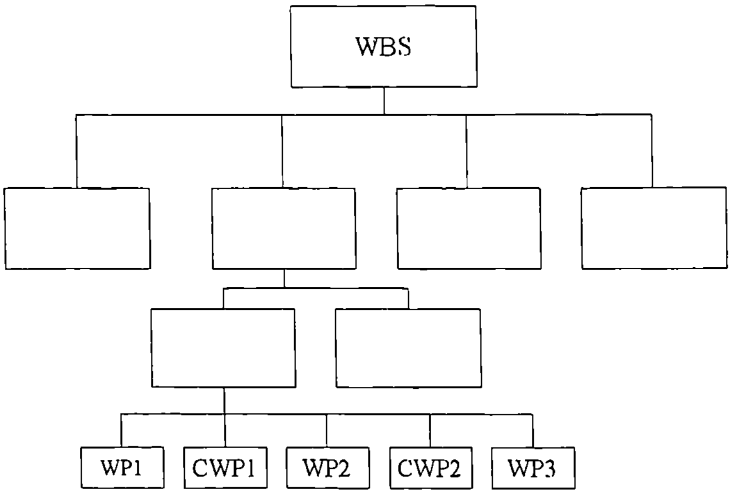

Figure 4 Classic WBS planning

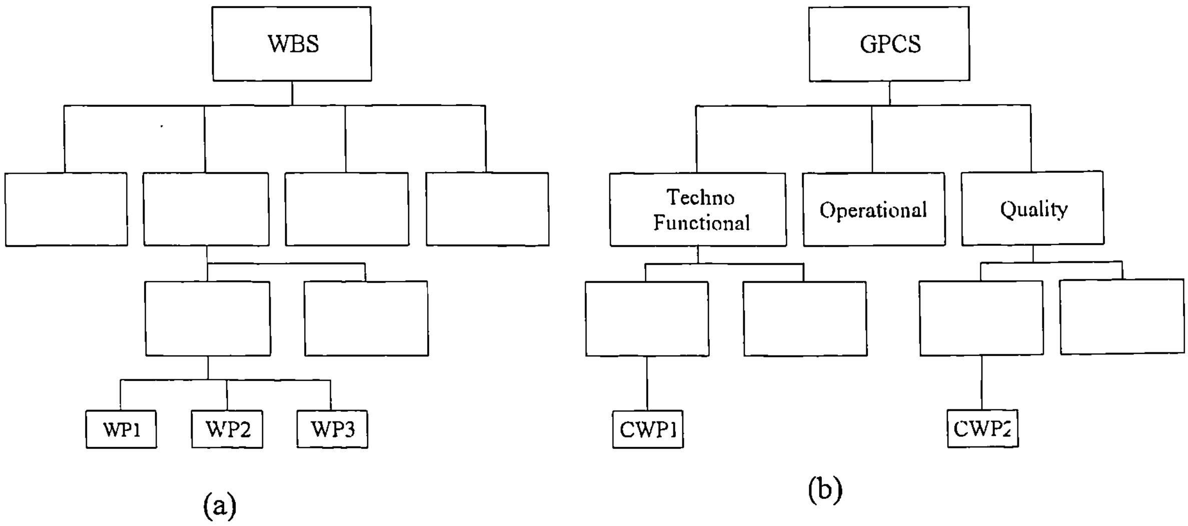

Figure 5 MPCS methodology structure

Figure 6 illustrates a typical GPCS structure (based on Figure 5b). It presents the detailed control activities throughout the execution phase.

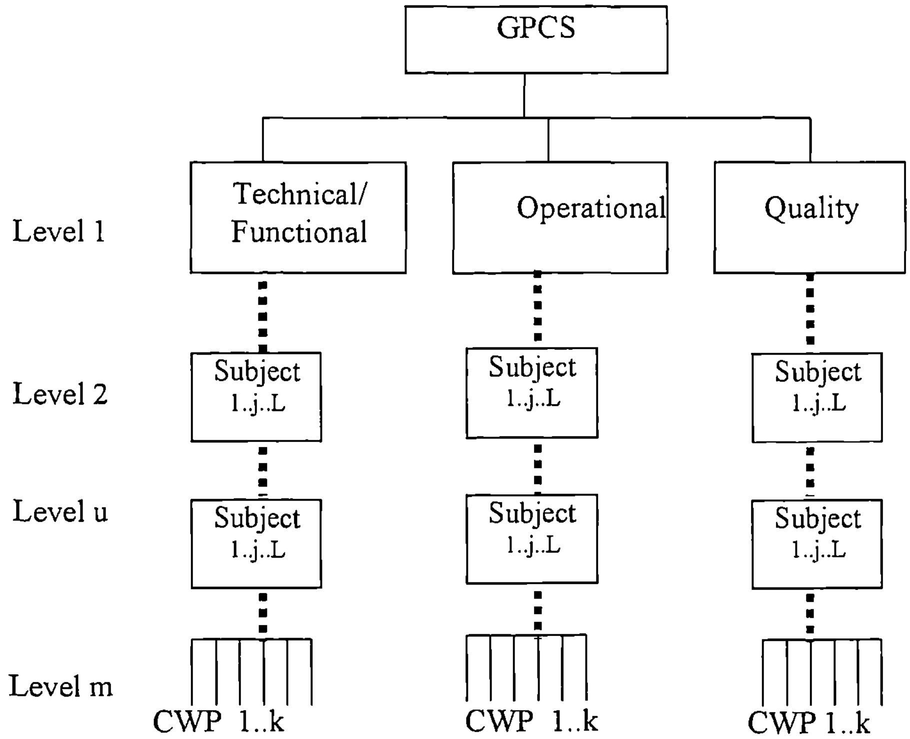

Figure 6 Global Project Control Specifications Structure

Level 1 defines the various control dimensions / categories, noting, there is no limit to the number of dimensions that may be used. Typical categories are quality, operational characteristics etc. The type and number of dimensions depend on the nature of the project. Each category presented in level 1 may have subcategories in level 2 to level m. These subcategories are denoted as subjects. The lowest level of any category defines the related control work package (CWP).

The Technical / Functional category includes technical data needed to produce the project. It may include for example the following topics: functional flow analysis, integrated test planning, data management plans, configuration management plans, system safety, human factors analysis, value engineering studies and life cycle cost analysis.

The Operational category contains project operating systems. It also contains project flow process and priorities determination. It may include for example the following: preliminary requirements, system/cost analysis, effectiveness analysis, synthesis, logistics support analysis, technical performance measurement planning, engineering integration, preliminary manufacturing plans and manpower requirements/personnel analysis.

The Quality category defines project quality requirements and may include the following: requests for contractors ISO 9000 certification, requests for contractors ISO 14000 certification, application of statistical process control , quality cost systems, and quality measures.

The logic of the GPCS methodology creates the need for a measuring method to be used with various categories and various related units of measurement. A useful measuring tool has been the yield concept. Bohn et. al [3] and Badinelli [2] mentioned the important role of yield. Zhang et. al. [21] define different types of yields such as assembly yield and machine yield. Tapiero (2001) and Eliman et al.(2001) used yield as an important measuring tool. Badinelli (2000) stated the important role of yield. It is proposed to utilize the yield concept as the measuring method for project categories. This is discussed below.

3.2 MPCS quantitative measures

The control system aims at minimizing the gap between planning and results. The planning basis in the MPCS system constitutes the GPCS's control specification, as indicated in Figure 6. The GPCS defines control assignments during the course of the project's life. Should there be a gap between planning and performance, a warning is indicated by the system in order to take corrective action. This comparison process is conducted while measuring actual performance using the yield index. The MPCS's output constitutes the category yield's vector presentation for all categories included in the GPCS specifications. Since the GPCS is hierarchically constructed, the yield's computation process is aggregative. Commencing at the lowest level, which is the control work packages level from subject j level up to level 1, which is the category level. The subject level yield (Y_{ij}) computation input is based on performance in the control packages level. The categories yields computation input is based on comparing the subjects' performance to predefined performance levels (CRj). The measure of these levels in the various subjects is defined by the project's management, taking into account that the leading consideration is the required control sensitivity measure. These levels are designed to detect unreasonable digression. A reasonable digression is one in which subject j's performance, in yield terms, is higher than the defined performance level. In case of an unreasonable digression the project's team will be asked to take corrective measures.

a. Subject yield

The various GPCS control packages are defined in the planning stage. The performance of each control package k is tested during the performance stage. If performed is as planned, then $\delta_K = 1$, otherwise, $\delta_K = 0$. An identical weight assigned to each control work package k, out of M control work packages, related to subject j of category i out of L subjects.

$$(1) \quad Y_{ij} = \frac{\sum_{k=1}^{M} \delta_k}{M} \forall ij$$

Where:

$$\delta_k = \begin{cases} 1 & \text{If CWP k is successfully performed} \\ 0 & \text{Others} \end{cases}$$

When the index Y_{ij}, is not equal to 1, it means that there are differences between planning and performance.

b. Category yield

When the subject's yield Y_{ij}, equals or exceeds the threshold value defined by the project administration, then subject's performance is defined as successful, i.e., $\theta_j = 1$. The closer CR_j is to 1, the higher control sensitivity will be, indicating that the project is responding to specification requirements. The GPCS structure includes N categories and each category has L subjects.

Due to the GPCS's structure, the categories are independent of each other. However their importance and contribution to the success of the project's performance are not identical. For example, the subject "configuration management" in a software project is more important than the subject "value engineering studies". Therefore, subject weight is suggested according to its position in the GPCS specification based on King's (1980) algorithm. Using the King's algorithm allows the project management to implement the Pareto concept where few categories contain the majority of the weight. Furthermore, adding more categories to the same GPCS, during the GPCS design, will increase the importance of the first positioned categories. Equation (2) presents the yield computation of category i using King's algorithm.

(2)
$$Y_i = \frac{\sum_{j=1}^{L} \theta_j 2^{L-j}}{\sum_{j=1}^{L} 2^{j-1}} \forall i$$

Where:

$$\theta j = \begin{cases} 1 & \text{If Yij} \geq \text{CRj} \\ 0 & \text{Others} \end{cases}$$

The project management may use other weighting methods if there is a need to weight differently a certain category.

c. Vectorial presentation

Based on the lack of dependence between the GPCS's categories, the control system is formulated as an orthogonal vector system whose axes constitute the various categories. Nicholas [12] and Meredith et.al. [10] performed a similar use of an orthogonal presentation for representing the project's goals. Such a formulation of the control system enables the use of vector analysis's mathematical principles and tools. Employing the results of equation (2), vector $\vec{P}$ can be formulated as the actual performances of the various N categories in yield terms as in equation (3).

$$(3) \qquad \vec{P} = Y_1\hat{i} + Y_2\hat{j} + \cdots + Y_N\hat{n}$$

Where: $\hat{i}, \hat{j}, \ldots \hat{n}$ *are unit vectors.*

Vector, $\vec{P}$, shown in Figure 7, represents a three-dimensional case of actual performance which is not compatible with planning. There is evidence of a gap existing between the planned and actual performance, represented by the $\vec{I}$ vector, where $Y_i = 1 \forall i = 1 \cdots N$.

The smaller the gap, the closer will vector, $\vec{I}$ be to vector, $\vec{P}$.

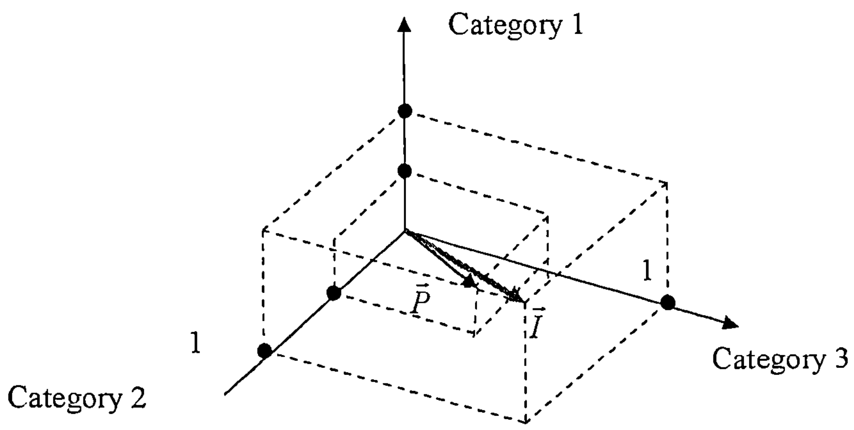

Figure 7 yield vector presentation

(4) $\vec{G} = \vec{I} - \vec{P}$

(5) $\vec{G} = (1 - Y_1)\hat{i} + (1 - Y_2)\hat{j} + \cdots + (1 - Y_N)\hat{n}$

The gap vector ($\vec{G}$) presented in Figure 8 is a managerial tool whose size and direction represent the effort required in taking corrective action, i.e., comparing planned to actual performance. The desired value for this vector is zero.

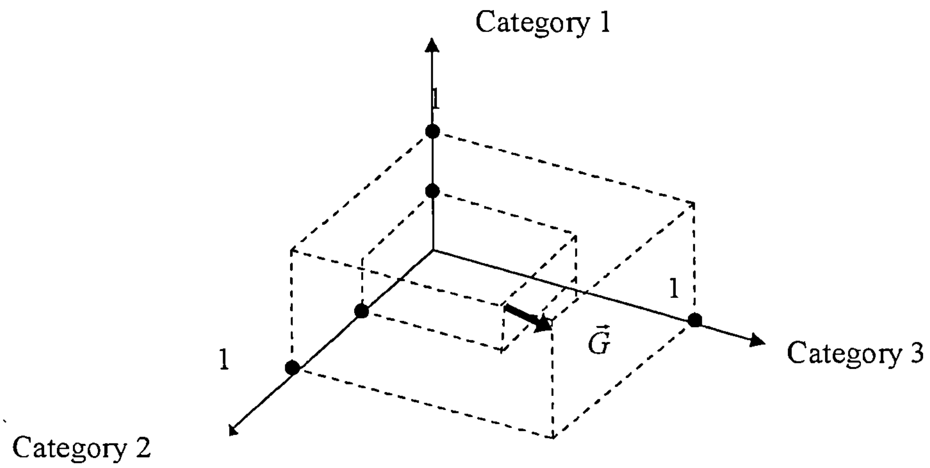

Figure 8 gap vector presentation

The MPCS system defines two types of indices. The first is a performance index Y_i for each dimension/category, and the second is the gap vector $\vec{G}$ which constitutes an inclusive index examining the entire array of the project's performance. The Gap Performance (GP) index presented in equation (6) serves as an additional inclusive index.

$$GP = \frac{|\overline{G}|}{\sqrt{N}} \tag{6}$$

Where: N is the number of dimensions/categories

The Gap Performance (GP) index has a normalized value. The closer this value is to 0, the closer project performances are to planning, i.e., complete and full responsiveness to the requirements presented in the GPCS. The GP index is designed to be used by the manager, comparing the performance of a number of projects with the index representing performance on a 0-1 scale. Thus, planning performance can be compared with project performance within the project life cycle. This index can be easily computed with a spreadsheet so that the manager need not know vectorial analysis to derive these measures.

3.3 Computational example

This example illustrates the application of the MPCS methodology. Let the control system be compatible with the project presented in Figure 3 which was planned and controlled using WBS concepts. The example presents a two-dimensional control of the techno/functional and operational dimensions. The example includes the definition of GPCS control specifications, computation of subject yield, computation of category yield, vectorial presentation of the results of the MPCS methodology and analysis of the results.

The GPCS control specifications are given in Table 4. The specifications are hierarchically constructed and consist of two categories representing the control dimensions. Each category includes a number of subjects that define its contents and each subject includes control work packages. For the sake of simplicity, only the control work packages of subjects 1 and 3 in the techno/functional category are displayed. The dotted points in Table 4 represent the appropriate control packages for each subject and are incorporated in the overall calculations of the respective category yield.

Table 4. GPCS

Category (i)	Subject (j)	Control Work Package (k)
1.Techno/Functional	1. Configuration management	1. Identification block 2. Proposed change description and references 3. Justification 4. Impact statement 5. Alternatives 6. Initial review results and disposition
	2. System safety	⋮
	3. Integration	1. System integration
		2. Subassembly integration
		3. ATP – Automatic testing procedures
	4. Value engineering studies	⋮
	5. Life cycle cost analysis	
2. Operational	1. Preliminary requirements	⋮
	2. System/cost analysis	
	3. Effectiveness analysis	
	4. Logistics support analysis	1. Purchasing control
		⋮

The implementation of the control work packages was examined by means of the control processes defined in the control work packages. When the content of the controlled work is performed according to the plan defined in the work package k, the value $\delta k = 1$ is obtained. A value of $\delta k = 0$ means that the tasks defined in the plan were not executed. Tables 5 and 6 show the performance at a defined control point within the life cycle of the project. Table 5 and 6 show the δk values for "Configuration Management" and " Integration" respectively. However in Table 6 the control package "Subassembly integration" was not performed, while according to the aggregate control indices of the EV methodology described in Table 2, the integration was well performed.

Table 5. Subject 1 - Configuration Management - δk

i	j	k	Control Work Package	δ
1	1	1	Identification block	1
1	1	2	Proposed change description and references	1
1	1	3	Justification	1
1	1	4	Impact statement	0
1	1	5	Alternatives	1
1	1	6	Initial review results and disposition	0

Table 6. Subject 3- Integration - δk definition

i	j	k	Control Work Package	δk
1	3	1	System integration	0
1	3	2	Subassembly integration	0
1	3	3	ATP	1

The CWP performance data constitute the input for computation of the yield for each subject. This computation is based on equation 1. Referring to Table 6, the computation for the yield of subject 1 "Configuration management", is given by:

$$Y_{11} = \frac{\sum_{k=1}^{6} \delta_k}{6} = \frac{4}{6} = 0.67$$

The yield computation of subject 3, "Integration" is:

$$Y_{13} = \frac{\sum_{k=1}^{3} \delta_k}{3} = \frac{1}{3} = 0.33$$

The performance of the subjects calculated in terms of yield is examined against the threshold value defined for each subject. If the actual performance result equals or exceeds the threshold value, then the value $\theta j = 1$ is obtained. If the threshold value is higher, $\theta j = 0$ is obtained. The project management should define the threshold value during the planning phase. The higher the threshold value, the higher is the response sensitivity.

For example, management may decide that the subject Integration is successfully implemented if two out of 3 work projects (67%) are satisfactorily completed, i.e., the threshold value in this instance would be 0.67 (a detailed procedure is presented in chapter 4).

Table 7 presents the subject yield results, including the results of the control work packages which were not presented in Table 4, along with the process for comparison of the subject yield results with their respective threshold values.

Table 7. Yield results

I	j	Subject	*Subject yield Yij*	*Threshold value CRj*	θj
1	1	Configuration management	0.67	0.67	1
1	2	System safety	0.78	0.65	1
1	3	Integration	0.33	0.67	0
1	4	Value engineering studies	0.55	0.60	0
1	5	Life cycle cost analysis	0.95	0.65	1
2	1	Preliminary requirements	0.45	0.50	0
2	2	System/cost analysis	0.25	0.50	0
2	3	Effectiveness analysis	0.69	0.50	1
2	4	Logistics support analysis	0.87	0.50	1

The category yield computation process ascribes importance to the location of the subject within the GPCS specifications – that is, in this project, the subject

"Configuration Management" is given a greater weight than the subject "System Safety" because it is listed first in the hierarchy. Computation of the yield for category 1, "Techno/Functional" which is performed on the basis of binary weighting and based on Equation (2), giving by:

$$Y_1 = \frac{\sum_{j=1}^{5} \theta_j 2^{5-j}}{31} = \frac{25}{31} = 0.81$$

Computation of the yield for category 2 "Operational", is then:

$$Y_2 = \frac{\sum_{j=1}^{4} \theta_j 2^{4-j}}{15} = \frac{3}{15} = 0.2$$

The performance results of the categories may be shown vectorially by means of the GPCS yield vector based on Equation 3,

i.e., $$\vec{P} = 0.81\hat{i} + 0.2\hat{j}$$

The gap vector based on Equation 5 is:

$$\vec{G} = 0.19\hat{i} + 0.8\hat{j}$$

Figure 9 presents a graphic description of the two vectors. It is seen that the GPCS yield vector $\vec{P}$, represents reasonable performance in the Techno/Functional category and inferior performance in the Operational category. The gap vector, $\vec{G}$, represents the direction and strength of the remedial activities that should be undertaken in order for the GPCS performance to become equal to the plan – that is, for $\vec{G}$ to become the a vector that have values of 0 and $\vec{P}$ to become the unit vector $\vec{I}$.

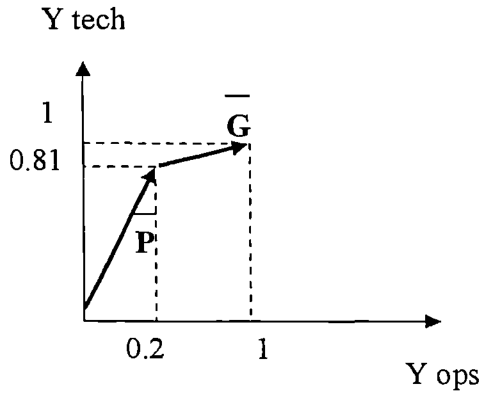

Figure 9 gap vector illustration

The system performance may be presented by means of the Gap Performance index GP, calculated according to Equation 6. This index presents an overall evaluation of the gap existing between plan and performance. The optimal value of this index is 0. Applying appropriate values to Equation 6 the value of GP for the project is:

$$GP = \frac{|\bar{G}|}{\sqrt{2}} = \frac{\sqrt{0.8^2 + 0.19^2}}{\sqrt{2}} = 0.58$$

In order to improve the performance of the project, the project manager must take corrective action to reduce the value of GP or reduce the values of $\bar{G}$. Table 8 summarizes the findings of Tables 4 and 5 and presents the control work packages which have not been properly performed.

Table 8. Control Work Packages that do not satisfy the GPCS demand

i	j	k	**Control Work Package**	δk
1	1	4	Impact statement	0
1	1	6	Initial review results and disposition	0
1	3	1	System integration	0
1	3		Subassembly integration	0

If the corrective activities are undertaken and the control work package "Impact Statement" is properly performed, $\delta\, 4 = 1$ will be obtained and the yield will improve accordingly. However, the previous value of Y_{11} (0.67) was higher than the threshold value required (see Table 7) and thus the category yield will not change.

Combined improvement of two control work packages, "System Integration" and "Subassembly integration" will cause the value of the subject yield Y_{13} to surpass the threshold value (0.75 - see Table 7),

$$Y_{13} = \frac{\sum_{k=1}^{3} \delta_k}{3} = \frac{3}{3} = 1$$

The category yield Y_1 will improve:

$$Y_1 = \frac{\sum_{j=1}^{5} \theta_j 2^{5-j}}{31} = \frac{29}{31} = 0.94$$

Thus, it may be seen that the MPCS methodology draws attention to the problem of integration in the project which by comparison the EV methodology indicates "Integration" as being reasonable results (as in Table 2).

3.5 Conclusions

Typically, project specifications will be hierarchically structured, based on the WBS structure. Controlling a project is a highly complex activity and is currently achieved by using a number of independent systems. The EV methodology, although used internationally, only integrates the cost and the schedule. Hence, other dimensions such as quality, technology, operations etc. are not integrated into the system and consequently must be controlled using other systems.

The EV methodology is based on an integrative calculation of the WBS. Accordingly, there may be situations in which the control indices indicate a reasonable project status, but the actual situation will lead to non-compliance with the project goals.

A new methodology, MPCS, has been presented, which integrates all known dimensions of the project giving appropriate weighting to each. The MPCS uses a control tool, the GPCS, which determines control specifications by defining control tasks through the project life cycle.

The use of MPCS presents the project performance in all of its dimensions of operation. There is no averaging of the various operations; accordingly, the system will be able to draw attention to poor performance in a certain dimension, and the Project Manager will be able to understand the extent of its influence on achieving the project objectives.

The computational example illustrates the advantage of the MPCS methodology over the classic EV methodology. It may be seen that the MPCS system draws attention to problems of integration whose cost is relatively low and whose advantage is relatively high in contrast to the EV system which does not provide such alerts to the senior management level.

The MPCS methodology presents an innovative concept that integrates definition of GPCS control specifications with a computational process that presents the status of each dimension in terms of yield and provides a vectorial representation of the entire system.

Chapter 4: MPCS Multidimensional Project Control System Implementation Methodology

4.1 Introduction

The control system aims at minimizing the gap between planning and results. The planning basis in the MPCS system constitutes the GPCS's control specification as indicated in Figure 6. The GPCS defines control assignments during the course of the project's life cycle. Should there be a gap between planning and performance, a warning is indicated in order to take corrective action. This monitoring process is conducted using the yield index while measuring actual performance.

a. The GPCS Topology

Every GPCS structure may include one or both of the following substructures.

I. Substructure A

Substructure A represents a single subject configuration with Control Work Packages (CWP) only. Substructure A is described in Figure 10. where every subject may contain M Control Work Packages. Level m is the lowest level in the GPCS branch and contains a compilation of control tasks that must be performed in order for the project to achieve its objectives.

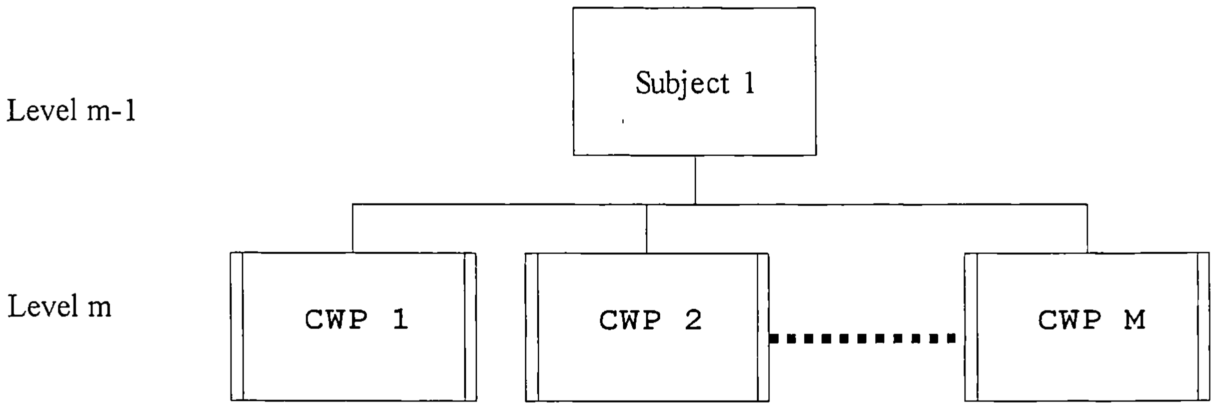

Figure 10. GPCS Substructure A

II. Substructure B

Substructure B represents a single or multi subject configuration with lower level subjects and CWP's. Figure 3 shows an example of a Substructure B. Subject A includes the combination of a subject (e.g., Subject 1) or several subjects with the same level as control work packages (e.g., CW1 and CW2). Subject 1 contains only CWP's therefore it has a Substructure A configuration.

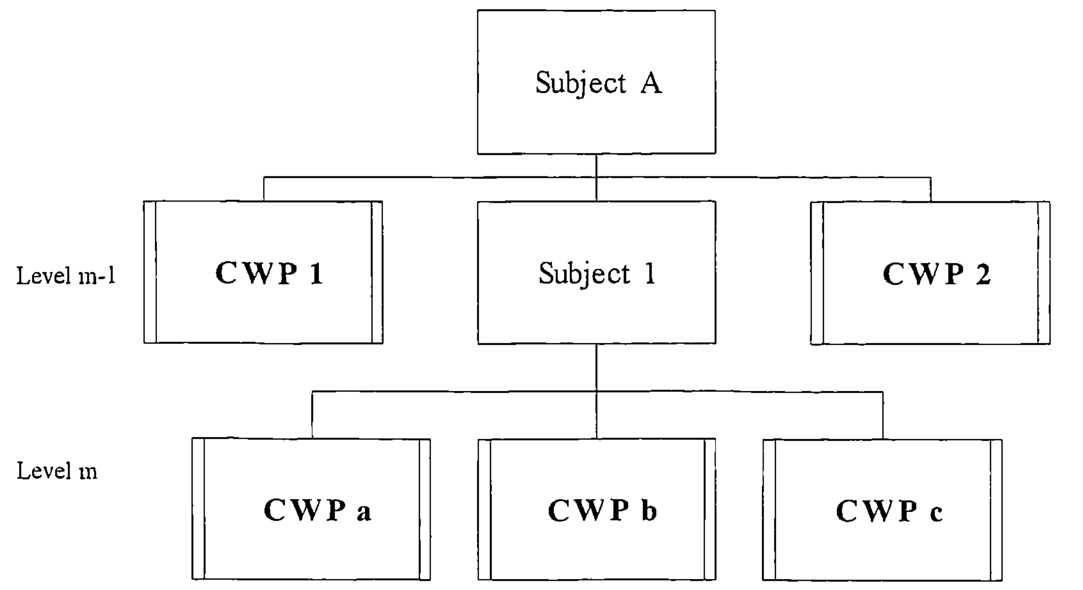

Figure 11. GPCS Substructure B

b. MPCS performance measures

Since the GPCS is hierarchically constructed (see Figure 6) the yield's computation process is aggregative, starting at the lowest level up to the category level. The category yield computation is based on comparing the subjects' performance to predefined performance levels (CRj). These levels (for the various subjects) are defined by the project's management taking into account the required control sensitivity requirements. These levels are designed to detect unreasonable digression. A reasonable digression is one in which subject j's performance, in yield terms, is higher than the defined performance level. In case of an unreasonable digression the project's team will be asked to take corrective action. The process of defining the threshold values (CRj) by the project management is based on the definition of each control work package as a critical CWP or non-critical CWP. A critical CWP is one that must be successfully performed in order to proceed with project execution otherwise the project will not reach its predefined aims and objectives .For example, a threshold value (CRj) of 1 means that every CWP that belongs to subject j must be successfully performed otherwise that project execution will not meet the project objectives. A threshold value (CRj) for a specific subject set at 0.5 means that up to 50% of the CWP related to this specific are being defined as critical CWP. Performing 50% or more of the CWP subject (including the critical CWP) is defined as a "successfully performed" of the subject.

I. Subject Yield

As described earlier, every GPCS can contain both topologies, Substructure A and Substructure B (see Figures 10, 11). In the case of Substructure A, the performance of each control package k is tested during the performance stage. Yield calculation results Y_{ij} is using Equation (1) .Where index Y_{ij} is not equal to 1, it means that there are differences between planning and performance.

In the case of Substructure B, computation includes the yield calculation for all subjects on the same level which are then compared with their respective threshold values (CRj) as defined by the project management. When the threshold value is higher than the yield, then $\delta_k = 0$, and when the subject yield value exceeds the threshold value, then $\delta_k = 1$. Control package values are calculated in the same manner as in Substructure A.

$$(7) \quad Y_{ij} = \frac{\sum_{k=1}^{M} \delta_k}{M} \forall ij$$

Where:

$$\delta_k = \begin{cases} 1 & \text{If } Y_{ij} \geq CR_{nj} \text{ or } CWP_k \text{ is successfully performed} \\ 0 & \text{Otherwise} \end{cases}$$

II. Category yield

When the subject's yield Y_{ij} is equal to, or exceeds the threshold value then the subject's performance is defined as being successfully completed and the auxiliary variable θ_j equals to 1, otherwise $\theta_j = 0$.

The closer CR_j is to 1, the higher the control sensitivity will be, indicating that the project is responding to specification requirements. The GPCS structure includes N categories and each category has L subjects.

Due to the GPCS's structure, the categories are independent of each other. However, their importance and contribution to the success of the project's performance are not identical. Therefore, each subject weight is determined according to its position in the GPCS specification using Equation (2).

III. MPCS managerial indices

The MPCS system defines the following indices: performance index Y_i for each dimension/category i; gap index G_i (i.e., the difference between 1 and Y_i) for each dimension/category i; gap performance index (GP) presented in equation (8) is based on Rozenes et al.(2004).

$$GP = \frac{\sqrt{\sum_{i=1}^{N} G_i^2}}{\sqrt{N}} \qquad (8)$$

Where: N is the number of dimensions/categories

The gap performance GP index has a normalized value. The closer its value to 0, the closer the project performances are to the respective plans, i.e., complete and full responsiveness to the requirements presented in the GPCS. The GP index may be used by the manager to compare the performance of several projects with the index representing performance on a 0-1 scale. Thus, planning performance can be compared with project performance within the project life cycle. This index can be easily computed with a spreadsheet.

4.2 MPCS implementation procedure

The MPCS Implementation methodology incorporates two phases based on the project life cycle; the planning phase and the execution phase, as shown in Figure 12. The planning phase begins with the GPCS definition. Managerial decisions defining the measurement processes are made as well as performance and report procedures and the selection of MPCS threshold values. The execution phase performs yield calculations at every GPCS level with calculations being completed at the highest level in the GPCS structure, i.e. the category. Control indices computations are done by comparing yield results to the predefined MPCS threshold values (CRj). Examination of these control indices determines what corrective actions should be taken. The implementation methodology will be discussed in details using a computational example.

Planning Phase

1. GPCS definition.
2. Defining Measurement Procedures.
3. Defining Execution and Reporting Processes.
4. MPCS Threshold values.

Execution Phase

1. Yield computation.
2. Control indices computation.
3. Control Indices examination.
4. Corrective actions.

Figure 12. MPCS Implementation Methodology

4.3. "Building garden project" – an illustrative example

An example of a garden building project is used for understanding the MPCS implementation. The project combines landscape construction, building techniques and planting flora. The project content is described using a work breakdown structure (WBS) and the project team is described using an organizational breakdown structure (OBS). Figure 13 describes the garden project WBS which defines the total scope of the project. It contains all the tasks needed to build a garden and includes the planning and performance processes involved in establishing an infrastructure to be followed by planting the garden. The WBS is divided into 3 main topics: Planting, Layout Functionality and Infrastructure. Each topic includes work packages that define the exact tasks that should be executed during the project life cycle.

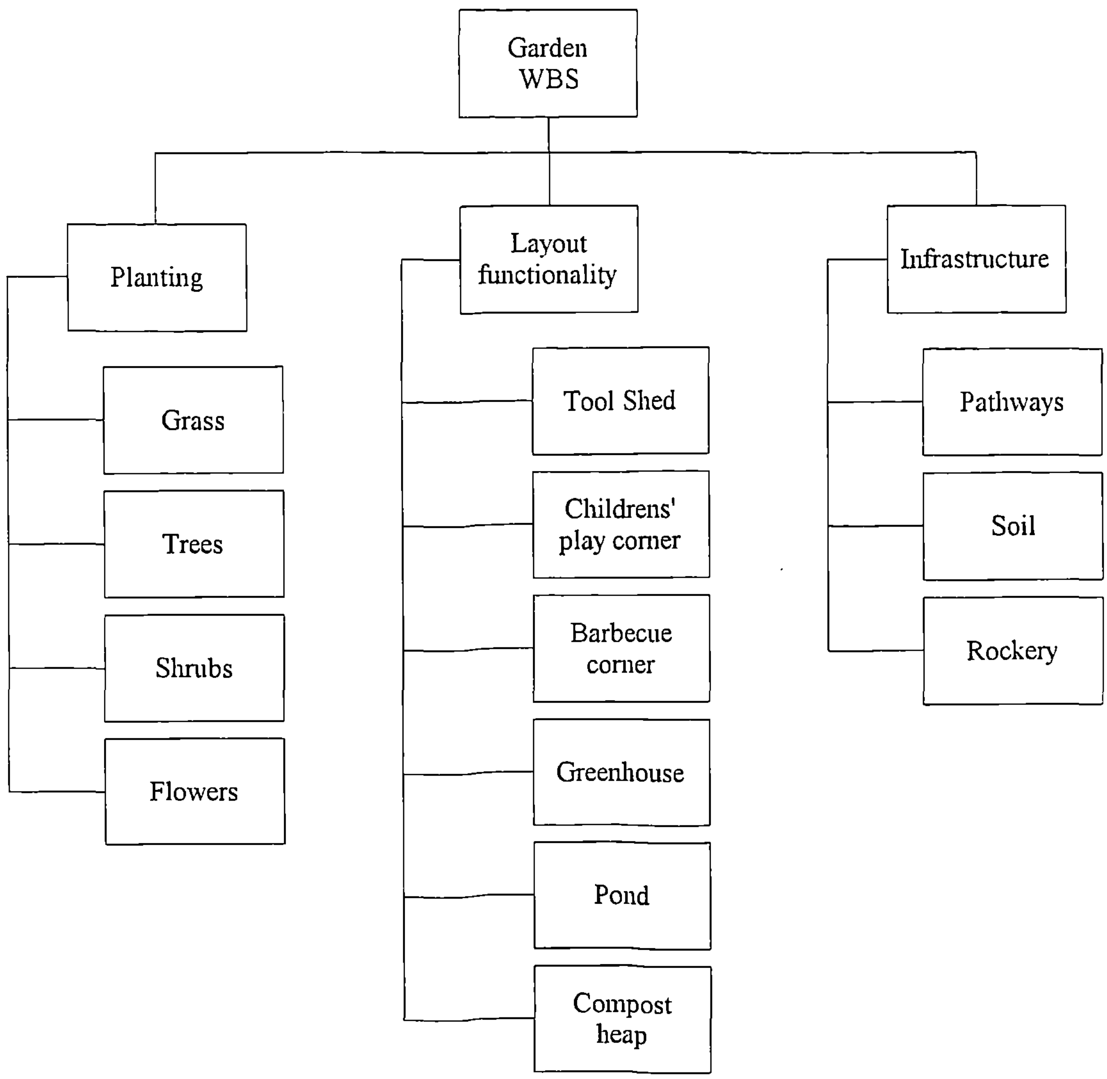

Figure 13. Garden Project WBS

Figure 14 represents the Organization Breakdown Structure (OBS) for the garden building project. It contains the traditional project structure and includes the main Human Resources functions such as: Garden Operations responsible for both the garden infrastructure and flora, Purchasing, Control and Landscape Design which covers design and engineering. The garden project management is assumed to include the project manager, the landscape design manager and the garden operations manager (encircled by shade in Figure 14).

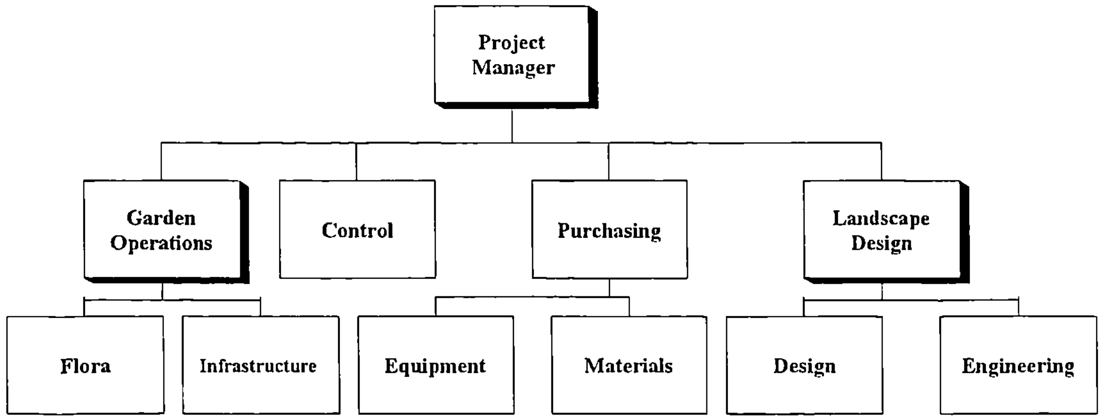

Figure 14. Garden Project Organizational Breakdown Structure

4.4 The implementation methodology

The implementation process of the MPCS contains two phases based on a typical project life cycle: the planning phase and the execution phase (see Figure 12).

a. The planning phase

This phase includes the definition of the project control system. Following is the composition of this phase:

I. GPCS structure definition

Defining the GPCS structure includes the entire array of the required control activities needed during the life cycle of the project. Figure 15 represents the GPCS control specifications for the garden building project. The GPCS control specifications includes three categories which comprise the control dimensions: Design, Operations, and Quality. The GPCS structure contains a combination of subjects and control work packages on various hierarchical levels. For example, the design category includes two subjects (Infrastructure, Planting) and one control work package (Concept verification).

The garden building project GPCS includes all the control activities that should be executed in order to successfully perform the project WBS. For example, successfully performing the WBS Infrastructure should result in successful performance of both Design Infrastructure and Operations Infrastructure subjects at the GPCS level 2.

It can be seen that the garden project GPCS structure (see Figure 15) differs from the garden project WBS (see Figure 13). The aim of the WBS design is to activate the project in a rational way in order to establish the bases of the Cost Breakdown Structure (CBS). The aim of the GPCS design is to control the project, therefore the GPCS categories represent the main control dimensions that are needed. For example, the garden project WBS (see Figure 13) includes Planting at level 1, and Planting includes the work packages Shrubs and Trees. These work packages include a definition of type, quantity, location and nature of planting. Controlling these work packages have two dimensions, Design and Operations.

At the Design category the GPCS control work packages Shrubs and Trees defines a comparison process between the design made by the Landscape Design team (see Figure 14) and the design done as is customary in the field of landscaping, for example comparing to existing standards and regulation. At the Operations category the CWP Planting defines the control process of the garden operations team performance for all the Planting components during the execution phase.

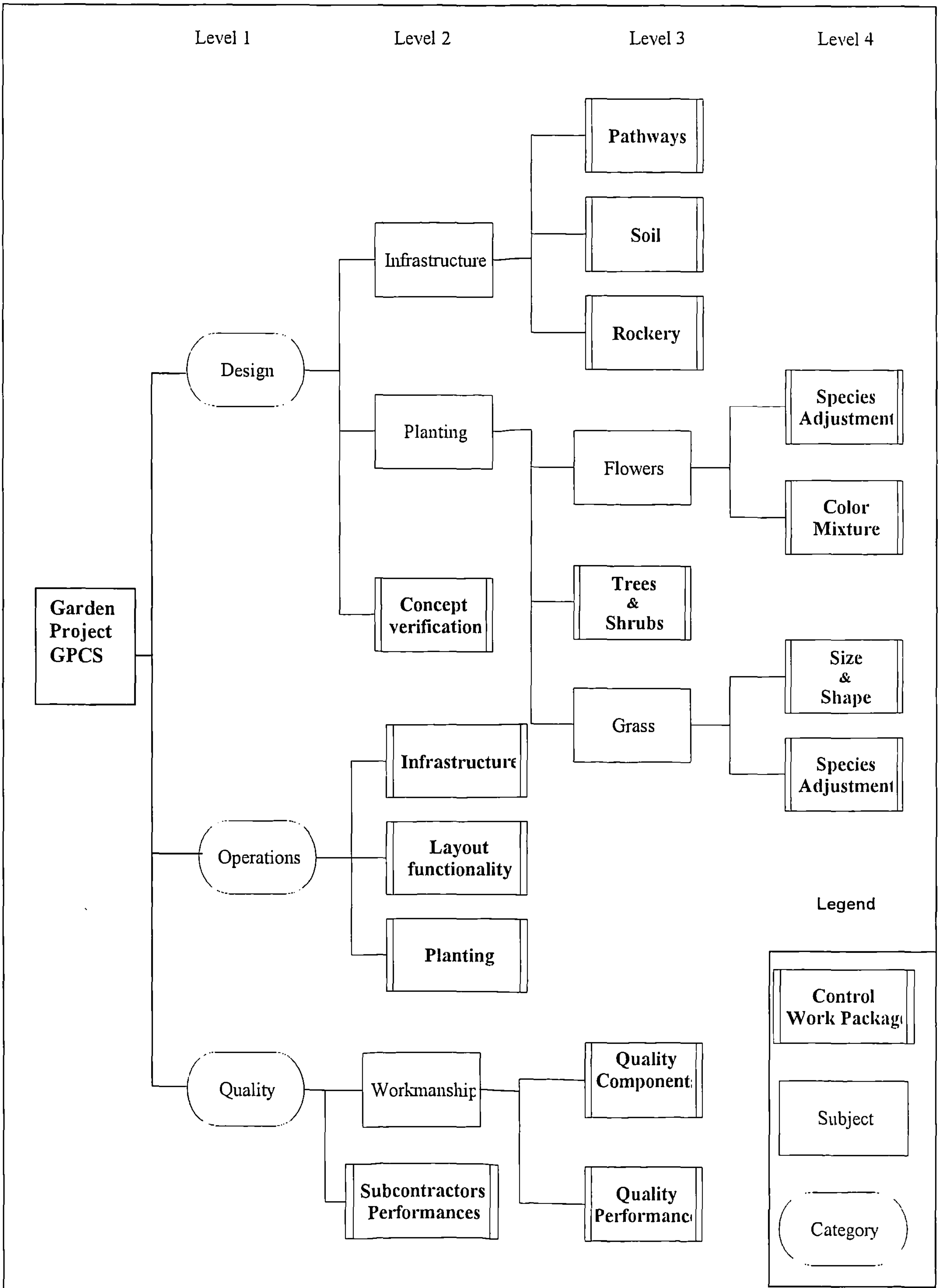

Figure 15. Garden Project GPCS

II. Measurement procedures

Each control work package defines the measurement processes for evaluating the project's performance. For instance, the control work package Trees & Shrubs is defined in Figure 15 level 3 and includes a procedural definition on how the measurement should be executed. For example, does 'color' define the mixture of color that has the best emotional impact? and so on.

For example, the CWP Subcontractors Performances holds a measurement procedure of how to measure the quality of the garden fence performed by a subcontractor, e.g. the fence's strength, color etc.

A CWP performed according to the specifications is indicated by $\delta_K = 1$, otherwise $\delta_K = 0$.

III. Execution and reporting procedures

Based on the project's OBS (see Figure 14), each organizational unit is responsible for execution of each specific control work package. Table 1 presents a report matrix of the various control work packages in the project. The Table defines those involved in the project reports (i.e., the X's). A report of a CWP includes the output of the process (δ_K) and a concise description of the required corrective actions. A report of any subject or category will include a quantitative index which will be computed employing Yield terms.

Table 9. Report matrix

Level	Description	Classification	Project manager	Garden Operations	Landscape Design
1	Design	Category	X	-	X
2	Infrastructure	Subject	X	-	X
2	Concept verification	CWP	X	X	X
2	Planting	Subject	X	-	X

IV. MPCS threshold values

Project management (e.g. project manager, landscape design and garden operations) defines the threshold values in the MPCS system.

Each subject in the GPCS has a predefined threshold value (CRj) which indicates a satisfactory performance of the project state.

The project management defines each control work package as a critical CWP or non-critical CWP.

A critical CWP is one while successfully performed enables the project execution to proceed, otherwise the project will not reach it predefined aims and objectives.

The garden project threshold values are presented in Table 10. In the GPCS garden project shown in Figure 15, the subject Infrastructure incorporates 3 control work packages: Pathways, Soil and Rockery. Project management defined CWP Soil as a critical CWP. It means that the CWP Soil must be successfully performed. Further, project management decided that in order to carry out the garden project either CWP Pathway or CWP Rockery should be performed successfully. It means that two out of three CWP (Soil critical) should be performed successfully it results with CRj = 2/3 = 0.67.

The subject Planting does not have any critical CWP. The subject Workmanship incorporates 2 CWP both critical, i.e. threshold value is 1. Both subjects Flowers and Grass incorporate 2 CWP and the threshold value is 0.5.

Table 10. Threshold value

Level	Subject	CRj	Number of CWP/ Subjects	Critical CWP
2	Infrastructure	0.67	3	Soil
2	Planting	0.67	3	-
2	Workmanship	1	2	Quality components, Quality performance
3	Flowers	0.5	2	Species adjustment
3	Grass	0.5	2	Species adjustment

b. The execution phase

This phase (see Figure 12) includes measuring, monitoring and taking corrective action. Following is the composition of this phase:

I. Yield computation

Yield Computation includes the calculation of both subjects' yield and categories' yield. These are now considered.

Subject yield calculation

Subject yields are calculated aggregately on the GPCS structure at each control point in the project life cycle. In order to compute this calculation, both Substructures A and B must be assessed.

The GPCS in the Garden project represented in Figure 15 contains both Substructure A and Substructure B. In order to clarify the explanation, only the Design category in the Garden Project is displayed in Figure 16. One component of the Design category is the Infrastructure. This subject is based on the Substructure A of the GPCS and is marked with a dotted line.

The actual results of the execution phase are presented in Figure 16. The notation $\delta_k = 1$ means that a CWP was successfully performed. For example, in level 3 the CWP Pathways was successfully preformed; Figure 16 depicts the MPCS threshold encircled by a dotted line and the actual Yield results.

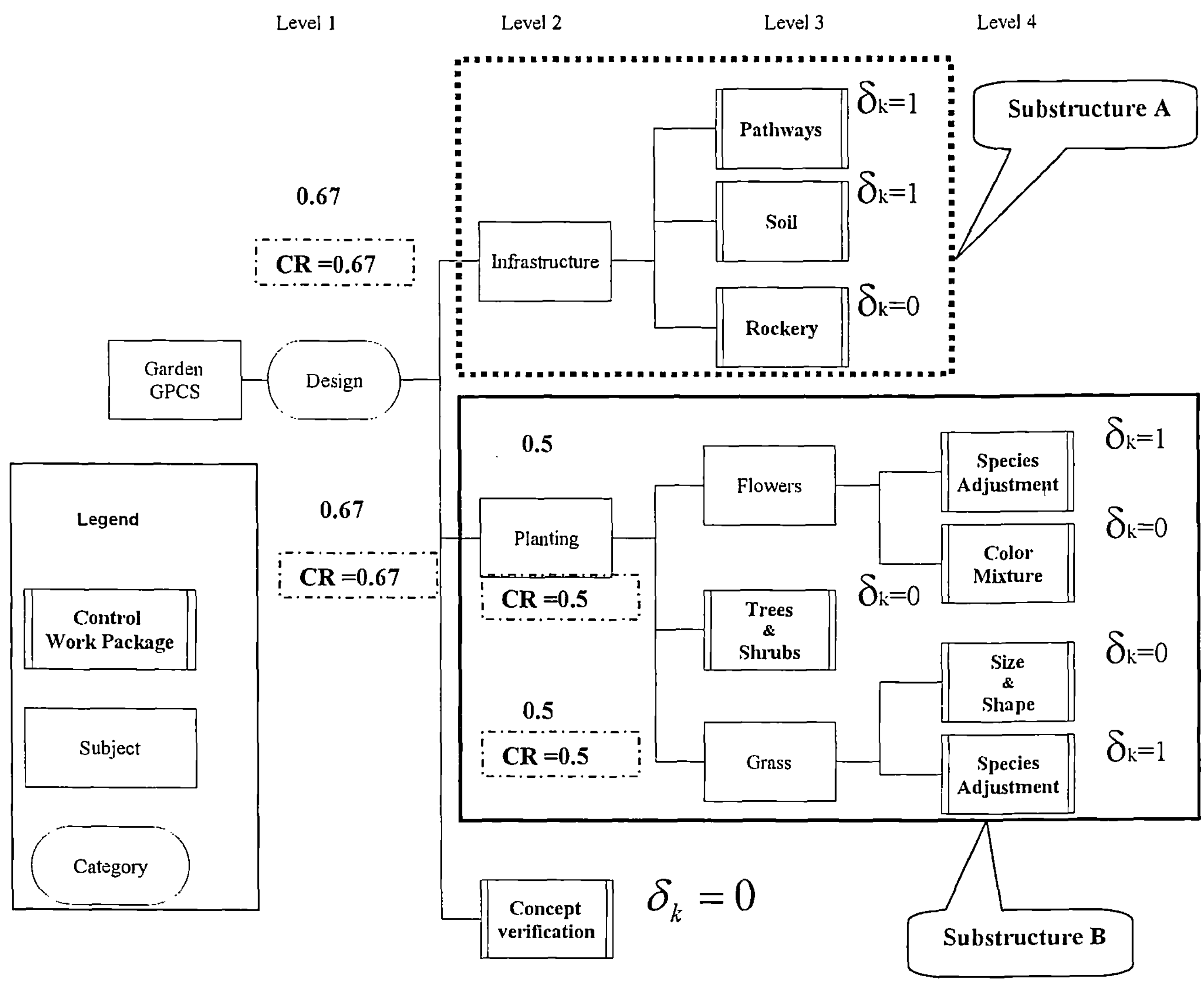

Figure 16. Design Category garden project

Table 12. Planting subject CWP performances

Subject Level	Subject	CWP Level	CWP	Successfully performed	δ_k
2	**Planting**	3	Trees & shrubs	No	0
3	**Flowers**	4	Species adjustment	Yes	1
3	**Flowers**	4	Color mixture	No	0
3	**Grass**	4	Size & shape	No	0
3	**Grass**	4	Species adjustment	Yes	1

The flowers subject is a Substructure A configuration and its yield is calculated as follows:

$$Y_{Flowers} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{1}{2} = 0.5$$

The Flowers subject yield result (0.5) is equal to the Flowers subject threshold value (0.5) presented in Table 10, which means that the project management will consider the Infrastructure subject as being successfully performed.

The Grass subject is a Substructure A configuration and its yield is calculated as follows:

$$Y_{Grass} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{1}{2} = 0.5$$

The Grass subject yield result (0.5) is equal to the Grass subject threshold value (0.5) presented in Table 2, which means that the project management will consider the Infrastructure subject as successfully performed.

These results are shown in Figure 16. Table 13 presents the Planting subject performances. The Planting subject is defined as a Substructure B configuration where the yields for Flowers and Grass were calculated. The subject auxiliary variable value $\theta_j = 1$ indicates a satisfactory performance of the subject according to the threshold predefined value (e.g. the subject Flowers and the subject Grass).

Table 13. Planting subject performances

	CR_j	**Subject yield**	δ_k	θ_j
Flowers (Subject)	0.5	0.5	-	1
Trees & Shrubs (CWP)	-	-	0	-
Grass (Subject)	0.5	0.5	-	1

The yield for the Planting subject was calculated as follows:

$$Y_{Planting} = \frac{\sum_{k=1}^{3} \delta_k}{3} = \frac{2}{3} = 0.67$$

The Planting subject yield result (0.67) is equal to Planting subject threshold value (0.67) presented in Table 10, which means that the project management will consider the Infrastructure subject as being successfully performed.

Category yield calculation

Yield calculation for the Design category depicted in Figure 15 is based on Equation (2) and presented in Table 14.

Table 14. Design category performances

	θ_j	δ_k	**CRj**	**Subject yield**
Infrastructure (subject)	1	-	0.67	0.67
Planting (subject)	1	-	0.67	0.67
Concept verification (CWP)	-	0	-	-

Yield calculation for the design category is as follows:

$$Y_{Design} = \frac{1*4+1*2+0*1}{7} = 0.86$$

GPCS control specifications for the Garden project presented in Figure 15 includes two additional control dimensions, the categories of Operations and Quality. Listed below is the yield calculation for both categories. Table 15 presents the performance data for the Operations category.

Table 15. Operations category performances

CWP	δ_k	**Successfully performed**
Infrastructure	1	Yes
Layout functionality	0	No
Planting	0	No

The yield for the Operations category is calculated as follows:

$$Y_{\text{Operations}} = \frac{1*4+0*2+0*1}{7} = 0.57$$

Performance data for the Quality category is given in Table 16.

Table 16. Quality category performances

Subject Level	Subject	CWP Level	CWP	δ_k	Successfully performed
2	Workmanship	3	Quality Components	0	No
2	Workmanship	3	Quality Performance	0	No
		2	Suppliers performance	1	Yes

The yield calculation for the category includes the yield calculation for the Workmanship subject situated on level 2.

$$Y_{\text{Workmanship}} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{0}{2} = 0$$

The Workmanship subject yield result 0 is lower than Workmanship subject threshold value 1 presented in Table 2, which means that the project management will consider the Infrastructure subject as not successfully performed.

The yield for the Quality category is thus:

$$Y_{\text{Quality}} = \frac{0*2+1*1}{3} = 0.33$$

II. Control indices computation and examination

MPCS control indices computations results (as calculated previously) are: $Y_{Design} = 0.86$, $Y_{Operations} = 0.57$ and $Y_{Quality} = 0.33$. There is a gap between the ideal situation defined by yield values equal to 1 and the Garden project performances. Gap values are calculated as; Design Gap = 0.14, Operations Gap = 0.38, Quality Gap = 0.67. It is noticeable that the Quality performance is poor and corrective actions must be taken.

The Gap Performance (GP) index, presented in equation (4) is a managerial support tool, where the lower this index, the smaller is the gap between planning and performance. Applied to the Garden project, the GP index is:

$$GP = \frac{|\overline{G}|}{\sqrt{3}} = \frac{\sqrt{0.14^2 + 0.43^2 + 0.67^2}}{\sqrt{3}} = 0.465$$

The project performances according to the GP index are low and that corrective actions are required to improve project performance.

III. Corrective actions

In order to improve the performance of the project, the project manager must take corrective actions which will reduce the value of GP. In the garden building project the Quality category holds the largest gap; therefore a corrective action should be taken in order to reduce the gap. Table 17 summarizes the performance results given in Tables 10 through 14 and presents the control work packages that have not been properly performed. Table 17 indicates in which CWP a corrective action will contribute to the yield result. For example, performing a corrective action in CWP Rockery can increase the Infrastructure subject yield result to 1. However the Infrastructure subject threshold value (CRj) is 0.67. Therefore the Design category yield cannot be changed and the corrective action is redundant.

Table 17. Control Work Packages that do not satisfy the GPCS demand ($\delta_k = 0$)

Category	**Subject**	**Yield**	**CWP**
Design	Infrastructure	0.67	Rockery
Design	Planting – Flowers	0.5	Color Mixture
Design	Planting – Grass	0.5	Size & Shape
Design	Planting	0.67	Trees & Shrubs
Design	-	0.86	Concept Verification
Operations	-	0.57	Integration
Operations	-		Planting
Quality	Workmanship	0	Components Quality
Quality	Workmanship	0	Performance Quality

The Quality category shows that the Workmanship subject contains two control packages: Components Quality and Performance Quality. The threshold value determined for this subject was 1, i.e., the two control packages should be accurately performed. The improvement in both the Gap Vector and the GP index will be examined when these packages are satisfactory performed, when both receive the value of $\delta_k = 1$.

Yield calculation for the category will include the yield calculation for Workmanship found on level 2.

$$Y_{\text{Workmanship}} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{2}{2} = 1$$

The Quality category yield would then give:

$$Y_{\text{Quality}} = \frac{1*2+1*1}{3} = 1$$

The updated yield results are $Y_{Design} = 0.86$, $Y_{\text{Operations}} = 0.57$ and $Y_{\text{Quality}} = 1$,

The updated gaps are: Design Gap=0.14, Operations Gap=0.43, Quality Gap=0, and the GP index will be:

$$GP = \frac{|\overline{G}|}{\sqrt{3}} = \frac{\sqrt{0.14^2 + 0.43^2 + 0^2}}{\sqrt{3}} = 0.261$$

There was a 44% improvement in the GP index when the Quality dimension deficit was corrected (previous $Y_{\text{Quality}} = 0.33$ corrected to $Y_{\text{Quality}} = 1$). Corrective actions in other dimensions would not generate as meaningful an improvement. For example, corrective action performance in level 4 (see Figure 15) control packages that belong to the Flowers and Grass subjects, would increase the yield value of the subjects. However, since the original values were greater than the threshold value, δ_k of the subjects, the yield value of the Garden subject remained unchanged, as did all project dimensions. The data presented in Table 17 serves as a managerial report. It points out which CWP needs to be revised. Computerizing the MPCS implementation methodology will include Table 17 as a printout.

4.5 Software support

The implementation of the MPCS system can be supported by software.

Explanation of the software support process uses the Garden project example.

The software support is performed as follows:

a. Project planning

The project planning phase includes two components:

I. <u>WBS planning with MS Project 2002</u>

The WBS planning uses the MS Project 2002 software program via the traditional planning procedures. It includes the traditional WBS (without the CWP), the project logic, the task duration, the project resources availability and cost. The WBS planning is performed using a single file. Figure 17 illustrates the WBS Garden project MS Project 2002 output.

ID		WBS	Task Name	Duration	Aug '03 S S M T
1		1	**Planting**	days 5	
2		1.1	Grass planting	days 3	
3		1.2	Trees planting	days 5	
4		1.3	Shrubs planting	days 4	
5		1.4	Flowers planting	days 2	
6		2	**Layout functionality**	days 4	
7		2.1	Tool shade	days 2	
8		2.2	Childrens' play corner	days 4	
9		2.3	Barbecue corner	days 3	
10		2.4	Greenhouse	days 3	
11		2.5	Pond	days 4	
12		2.6	Compost heap	days 2	
13		3	**Infrastructure**	days 6	
14		3.1	Pathway	days 5	
15		3.2	Soil	days 5	
16		3.3	Rockery	days 6	

Figure 17. WBS Garden project GPCS MS Project 2002 output

II. GPCS planning with MS Project 2002

The GPCS planning uses the MS Project 2002 software program. It is performed using a different file. It uses the MS Project 2002 ability to create a hierarchy structure within the same software platform, i.e. time deployment. The GPCS is deployed and integrated with the WBS. There are GPCS tasks that are predecessors to the WBS activities and vice versa. Figure 18 illustrates the Garden project GPCS MS Project 2002 output.

ID	ⓘ	GPCS	Task Name
1		1	**Design**
2		1.1	**Infrastructure**
3		1.1.1	Pathway
4		1.1.2	Soil
5		1.1.3	Rockery
6		1.2	**Planting**
7		1.2.1	**Flowers**
8		1.2.1.1	Flowers species adjustment control
9		1.2.1.2	Flowers color mixture control
10		1.2.2	Trees and Shrubs planting control
11		1.2.3	**Grass**
12		1.2.3.1	Grass species adjustment control
13		1.2.3.2	Grass size and shape control
14		1.3	Concept verification
15		2	**Operations**
16		2.1	Infrastructure operations control
17		2.2	Layout functionality control
18		2.3	Planting operations control
19		3	**Quality**
20		3.1	**Workmanship**
21		3.1.1	Quality performance
22		3.1.2	Quality components
23		3.2	Subcontractors' performance

Figure 18. Garden project GPCS MS Project 2002 output

III. Transfer MS Project 2002 planning files to Excel files

The WBS and the GPCS planning files were formed with MS Project 2002 in order to be consistent with the common planning tools. Implementing the MPCS system requires transferring the MS Project 2002 files to an Excel file.

Table 1 presents the planning file in an Excel format including the predefined threshold level as mentioned earlier.

Table 18. MPCS planning phase

Name	Level	Type	Threshold Value
Garden project GPCS			
Design	**1**	**Category**	
Infrastructure	2	Subject	0.67
Pathway design control	3	CWP	
Soil design control	3	CWP	
Rockery design control	3	CWP	
Planting	2	Subject	0.67
Flowers	3	Subject	0.50
Flowers species adjustment control	4	CWP	
Flowers color mixture control	4	CWP	
Trees and Shrubs planting control	3	CWP	
Grass	3	Subject	0.50
Grass species adjustment control	4	CWP	
Grass size and shape control	4	CWP	
Concept verification	2	CWP	
Operations	**1**	**Category**	
Infrastructure operations control	2	CWP	
Layout functionality control	2	CWP	
Planting operations control	2	CWP	
Quality	**1**	**Category**	
Workmanship	2	Subject	1.00
Quality performance	3	CWP	
Quality components	3	CWP	
Subcontractors' performance	2	CWP	

b. Project execution

During the project life cycle the project status is examined using predefined control points. At each control point, the yield indices are examined. Table 19 presents the MPCS results at control point No.1 (equal to the results mentioned earlier).

Table 19 . MPCS execution results at control point No. 1

ID	Name	Type	Threshold Value	CWP Performance	Yields Results	GAP
	Garden project GPCS					
1	**Design**	**Category**			**0.86**	**0.14**
2	Infrastructure	Subject	0.67		0.67	
3	Pathway design control	CWP		1		
4	Soil design control	CWP		1		
5	Rockery design control	CWP		0		
7	Planting	Subject	0.67		0.67	
8	Flowers	Subject	0.50		0.50	
9	Flowers species adjustment control	CWP		1		
10	Flowers color mixture control	CWP		0		
11	Trees and Shrubs planting control	CWP		0		
12	Grass	Subject	0.50		0.50	
13	Grass species adjustment control	CWP		1		
14	Grass size and shape control	CWP		0		
6	Concept verification	CWP		0		
15	**Operations**	**Category**			**0.57**	**0.43**
16	Infrastructure operations control	CWP		1		
17	Layout functionality control	CWP		0		
18	Planting operations control	CWP		0		
19	**Quality**	**Category**			**0.33**	**0.67**
20	Workmanship	Subject	1.00		0.00	
21	Quality performance	CWP		0		
22	Quality components	CWP		0		
23	Subcontractors' performance	CWP		1		

GP Index **0.46**

Table 19 shows that the GP index is 0.46 which indicates a problem in the project. Looking at the different categories in the column "GAP" shows that the problem is in the Quality category as it was mentioned earlier. Taking corrective actions in the Quality category led to better GP results. Table 20 shows the execution results at control point No. 2. These results were measured after the performance of the corrective actions.

Table 20 . MPCS execution results at control point No. 2

ID	Name	Type	Threshold Value	CWP Performance	Yields Results	GAP
	Garden project GPCS					
1	**Design**	**Category**			**0.86**	**0.14**
2	Infrastructure	Subject	0.67		0.67	
3	Pathway design control	CWP		1		
4	Soil design control	CWP		1		
5	Rockery design control	CWP		0		
7	Planting	Subject	0.67		0.67	
8	Flowers	Subject	0.50		0.50	
9	Flowers species adjustment control	CWP		1		
10	Flowers color mixture control	CWP		0		
11	Trees and Shrubs planting control	CWP		0		
12	Grass	Subject	0.50		0.50	
13	Grass species adjustment control	CWP		1		
14	Grass size and shape control	CWP		0		
6	Concept verification	CWP		0		
15	**Operations**	**Category**			**0.57**	**0.43**
16	Infrastructure operations control	CWP		1		
17	Layout functionality control	CWP		0		
18	Planting operations control	CWP		0		
19	**Quality**	**Category**			**1.00**	**0.00**
20	Workmanship	Subject	1.00		1.00	
21	Quality performance	CWP		1		
22	Quality components	CWP		1		
23	Subcontractors' performance	CWP		1		

GP Index 0.26

4.6 Discussion and conclusions

A new methodology called the MPCS has been presented which integrates all known dimensions of the project giving appropriate weightings to each. The MPCS uses a control tool, the GPCS, which determines control specifications by defining control tasks through the project life cycle.

The use of MPCS presents the project performance in all of its dimensions of operation. There is no averaging of the various operations. Accordingly, the system will be able to draw attention to poor performance in a certain dimension, and the project manager will be able to understand the extent of its influence on achieving the project objectives.

The MPCS methodology presents an innovative concept that integrates definition of GPCS control specifications with a computational process that presents the status of each dimension in terms of yield.

MPCS is implemented using a procedure based on the GPCS hierarchical structure.

Managing and controlling a project requires data collection from many dimensions. Nowadays the data is collected from the entire project dimensions such as quality, functional, operations, etc. However, this collected data is not integrated properly. Therefore the project manger does not know the implication of divergence within one dimension upon other dimensions. Further more the project manger would not know the influence of the divergence on the project aims and objectives achievements.

Implementing the MPCS methodology does not require extra data collation. The MPCS methodology allows the project manager to determine: integrated project status; where problems exist in the project; when and where to take corrective action; and how to measure improvement.

The presentation of the control system status focuses management's attention to the power and the direction of corrective actions that must be performed in order for performance to be identical to planning.

A computerized system based on MS Project 20002 and MS Excel is supporting the MPCS methodology as a friendly managerial tool.

Regarding the garden project example the MPCS system indicated a quality gap. The CWP Quality performance is usually difficult for cost estimation. In this garden project the monetary value of this CWP is low referring to other CWPs . Therefore, using only the EV methodology will not alert the project manger to the quality problem. The project manager would have not taken the needed corrective actions and the project would suffer from quality deficiencies. Therefore, a reduction of customer satisfaction may occur.

If the garden project example were planned using the conventional EV methodology the original WBS will include both the GPCS and the WBS of the garden project. Hence, there are neither extra activities needed nor extra data collected.

The MPCS methodology introduces an integrative control status during the entire project life cycle.

Chapter 5: Using Data Envelope Analysis (DEA) to compare projects efficiency in a MPCS environment

5.1 Introduction

A Multidimensional Project Control System (MPCS) deals with the control of a single project and defines its performances in comparison with the plan. The progression of several projects in parallel is a common situation in organizations, therefore a comparison of the various project performances is required. It is proposed that a comparison process be performed using the data envelope analysis (DEA) approach. The reference points for examining the performances of different projects and the directions of improvement for the projects are not necessarily found on the efficiency frontier. An algorithm is developed for applying multi-project system control having a relatively large number of inputs and outputs while maintaining the validity of the DEA methodology.

5.2 The data envelope analysis (DEA)

The data envelope analysis (DEA) is a mathematical programming approach which assesses the comparative efficiency of a set of decision making units (DMU).Example of DMUs have been reported as follows:

R&D organizations - Golany et al. (2000) ;telephone offices - Kim et al. (1999) ; credit unions – Pille (2002);conventional fuel plants - Park et al. (2000); manufacturing facilities - Sinuany et al. (2000); universities - McMillan et al. (1998); clinics - Friedman et al. (2000); companies benchmarking - Sinuany et al. (2000) etc. The DEA methodology is performed where the presence of multiple inputs and outputs makes comparison difficult. Charnes et al. (1978) first introduced the DEA concept and many articles have appeared that deal with the various types of implementations (e.g. Banker et al. (1984), Friedman et al. (1997), Post et al (1999) , Cook et al. (1999), Maital et al.(2001), Sarkis (1999) , Thamassoulis (2001)).

The DEA is a non-parametric approach that allows efficiency to be measured without any assumptions regarding the functional form of the production function or the weights for the different inputs and outputs chosen. The DEA defines best practice efficiency frontier that can be used.

Charnes et al. (1978) recognized the difficulty in seeking a common set of weights to determine relative efficiency. They proposed that each DMU should be allowed to adopt a set of weights, which shows it in the most favorable light in comparison to the other DMUs.

They used the following formulation: the efficiency of a decision-making unit (DMU) j incorporated multiple inputs and outputs denoted in equation 9; the efficiency of a DMU j is defined as weighted u_r sum of its S outputs divided by a weighted v_i sum of its m inputs.

(9) $$\max h_0 = \frac{\sum_{r=1}^{S} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

subject to:

$$\frac{\sum_{r=1}^{S} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad j = 1,\ldots n,$$

$$u_r, v_i \geq 0 \qquad r = 1,\ldots, m.$$

5.3 Using DEA methodology to evaluate project performance efficiency

Several projects performed in parallel and at varying stages of their respective life cycles occur fairly frequently in industry. The MPCS methodology is designed for the multi-dimensional control of single projects and it is not suitable for the control of several projects in parallel. However, the comparative process for the performances of several projects each controlled by the MPCS system can be accomplished through the use of the DEA methodology. Each project presents its performance at specific control points through the yield indices of the MPCS methodology while the DEA enables the examination of performances of each project based on these indices. Furthermore, the two control methods, the EV and MPCS method, can be used in independently for each project.

Operating several projects in parallel using the MPCS methodology requires GPCS standardization similar to the WBS standardization. The standardization means that the two higher levels in the GPCS structure are identical in each project that is managed and controlled in the organization. The creation of this standardization also contributes to the improvement of the organizational learning process whilst creating a comparative tool for projects in progress and those that took place in the past. Using the GPCS standardization enables the DEA comparison process.

In the MPCS methodology the outputs represent the totality of dimensions by which the project is measured. The outputs are the yield calculations of the different categories. Their number derives from the control system planning process that uses GPCS. In the EV method the system outputs are the control indices of the earned value that present the schedule deviation and cost deviation. This combination will usually make the characteristic systematical project controlled by the two methods include many outputs.

The DEA evaluation is constrained by the total number of inputs and outputs. In general, the following rule of thumb (see Friedman et al. 1998 and Jenkins 2003)) is used: the sum of input and outputs types should not exceed one third of the number of decision-making units (DMU). There are cases that the total number of projects executing in parallel are relatively small. However, the number of inputs and outputs are relatively high because of these projects nature. Therefore there is a need for a reducing inputs and outputs methodology.

A 3-stage methodology was developed, which adjusts the total number of outputs and inputs to meet the rule of thumb while also representing the necessary information.

Stage 1: Inputs / Outputs Definition

When implementing the DEA in conjunction with the MPCS methodology, it is essential to create a standardized frame for project control on all projects involved in a given organization.

This procedure allows uniformity of reporting on all projects in the organization to enable comparison to be made.

Inputs definition

The input data characterize the different projects of the organization and generally includes the following:

Cost

The total cost of the project is derived from the total costs of the cost breakdown structure (CBS) of the project. The cost as an input variable represents the budgetary importance of the project in the process of comparing different projects.

Work content

The total hours allocated for the project including the planning stage. This input represents the investment of resources required for the project. A large gap between the Work Content cost and the total project cost represents an indication for the characteristics of the project, for example the existing purchase percentage in the project.

Level of monitoring

Control and follow up level required for performing the project. The higher the complexity of the project is the higher the value given on a scale of 0-10. Therefore this number indicates the complexity of a project is complicated comparing with all the other projects of the organization.

Level of uncertainty

The level of uncertainty existing in the project is measured on a scale of 0-10. The higher the value, the higher the uncertainty level is. In high tech projects this number indicates the level of using advanced technology.

Output definition

The project control system combines the EV system with the MPCS system, therefore the outputs of the system include the total output of both systems. The EV outputs are Schedule Index (SI) and also Cost Index (CI). These outputs are relative and will therefore have the same numerical level as the MPCS system outputs used for comparison between the systems. The MPCS outputs are defined at the planning stage through the GPCS and result from the Yield of each GPCS category. These outputs are Yield category1, Yield category 2 up to Yield category n.

Stage 2: Grouping algorithm

When only a few projects are in progress, a problem occurs when the definition of outputs and inputs at stage 1 leads to a relatively large number of inputs and outputs. In order to maintain the rule of thumb for such a case the number of outputs and inputs should be reduced while maintaining their information. The algorithm consolidates the different inputs and different outputs to a reduced number to meet the rule of thumb. The 3-step algorithm contains the following:

a. Inputs correlations and outputs correlations computation.

Stage 'a' includes the examination of correlation between the different inputs and outputs. The correlation results are presented in the following matrixes:

Matrix [RI ij] contains input correlations. It presents the correlation ratio between input j and i. Matrix [RO ij] contains outputs correlations. It presents the correlation ratio between output i and output j.

b. Grouping process

The grouping process leads to the creation of inputs and outputs groups. When the similarity level among these groups is high, it is possible to consolidate them in order to perform comparison without significant loss of information.

Heragu (1997) describes a similarity coefficient (SC) algorithm that is used as a grouping process.

The calculation of the similarity coefficient is based on the results of correlation calculations that were calculated at the previous stage. In order to create suitable statistic reliability, each correlation result that is lower or equal to 0.8 is defined as being insufficient, therefore the value of the similarity coefficient is defined as 0.

SCOij is the output similarity coefficient for output pair ij as expressed in equation 10.

(10) $$SCO_{ij} = \begin{cases} 0 & \text{If } RO_{ij} \leq 0.8 \\ RO_{ij} & \text{Otherwise} \end{cases} \qquad \forall ij$$

Each case where $RO_{ij} \geq 0.8$, reduces at least one output.

The similarity among the different inputs is examined in a similar way. SCIij is the input similarity coefficient for input pair ij as expressed in equation 11.

(11) $$SCI_{ij} = \begin{cases} 0 & \text{If } RI_{ij} \leq 0.8 \\ RI_{ij} & \text{Otherwise} \end{cases} \qquad \forall ij$$

Using the SC algorithm results in inputs and of outputs groups with similar characteristics.

c. Selecting output / input representative

The third stage in the grouping algorithm is to find the output or input that represents the group of common outputs or inputs that were defined at stage 'b', i.e.: one input or output should represent each group in the DEA algorithm.

The decision criterion on the input or output representative is based on the highest average similarity coefficient for each output and for each input.

The selecting process of the output representative is based on choosing the maximum value of the average output similarity coefficients. An average is computed between each output i and the other outputs. This rule is expressed by equation 12:

$$Max \left\{ \sum_{j=1}^{J} \frac{SCO_{ij}}{J} \right\} \quad \forall i \tag{12}$$

The selecting process of the input representative is based on choosing the maximum value of the average input similarity coefficients. An average is computed between each input i and the other inputs. This rule is expressed in equation 13:

$$Max \left\{ \sum_{j=1}^{J} \frac{SCI_{ij}}{J} \right\} \quad \forall i \tag{13}$$

Stage 3: Implementing sequential DEA

Braglia et. al. (1999) presented a DEA algorithm for reducing the number of outputs and thus increases the discriminatory power of DEA. This algorithm is called sequential DEA. This algorithm includes several DEA computations based on identical input data and different output data. A summarizing process is executed containing the same output data and the input data is the DEA results of the previous DEA computations. Stage 3 also uses the sequential DEA.

The output of stage 3 represents the comparison among the different project performances and shows which project is on the efficiency frontier graph and those project that are not (i.e., having relative poor performances). This comparison provides the opportunity of determining whether the performance for the project is relatively similar to the performances of all the projects.

5.4 Computational example

The following computational example is based on a data of a typical Hi-Tech company which managing 11 projects in parallel. Their projects contain hardware, software, integration and testing elements.

Figure 19 includes the principal presentation of the GPCS structure of all the projects found in the organization. The two higher levels are identical in each project. The lower levels of each project GPCS are different in accordance with the requirements of the different projects.

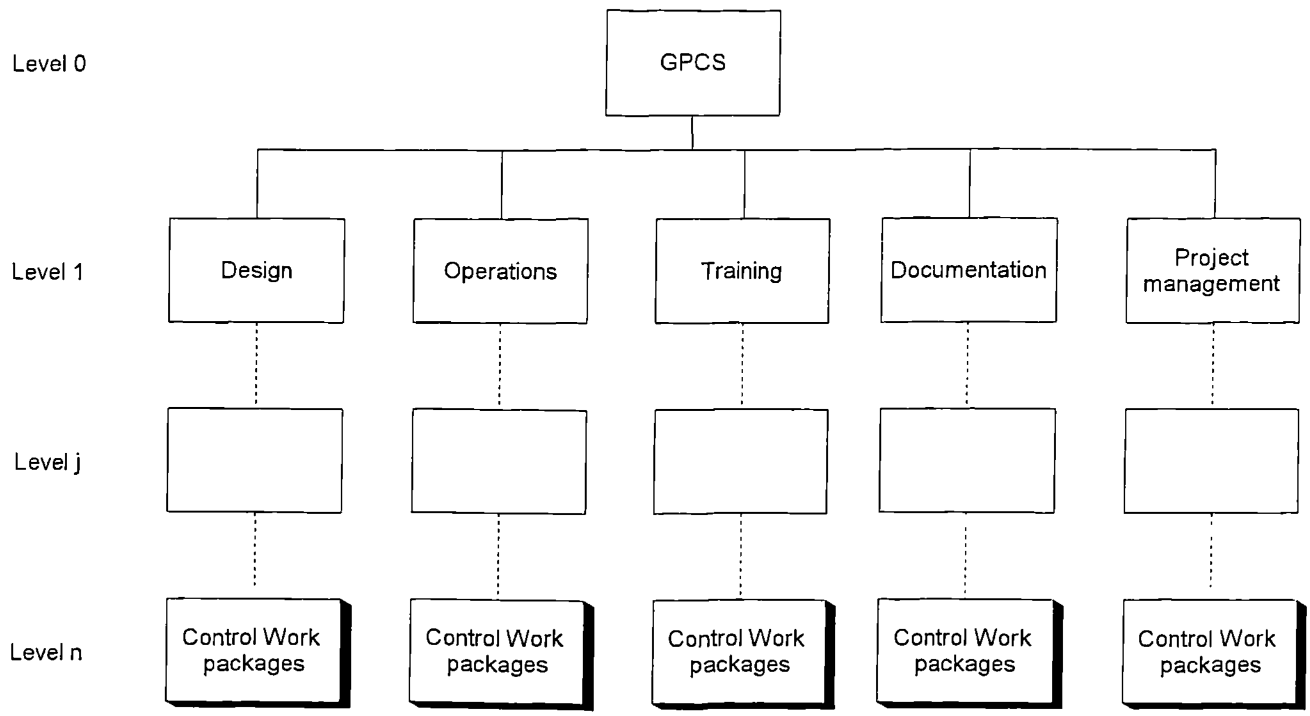

Figure 19. GPCS frame work

The uniformity described in Figure 19 defines the GPCS standardization in the organization. The upper two GPCS levels are identical and the lower levels are dependent upon each specific project. The GPCS standardization enables the DEA comparison process.

Stage 1: Inputs / Outputs Definition

Projects inputs are previously defined by the organization management according to each project characteristics and are given in table 21. For example project 3 is a medium size project with total budget of 800,000 £. The project contains 15,000 working hours; the level of monitoring required is 7 out of 10. Project 3 is a high risk project ranked 8 out of 10.

Table 21.Inputs definition

Input / Project	Cost (K£)	Work Content (00 hours)	Level of Monitoring	Level of Uncertainty
1	1500	300	6	6
2	100	50	7	6
3	800	150	7	8
4	1500	300	6	7
5	255	90	4	4
6	350	100	9	7
7	600	150	9	9
8	80	24	5	5
9	900	175	7	8
10	2000	400	8	9
11	75	40	7	6

The origination operates both MPCS and EV control systems. Table 22 contains the outputs which are direct derivatives of the MPCS methodology using GPCS structure illustrated in Figure 19: design yield, operations yield, training yield, documentation yield, project management yield.

The other outputs presented in Table 22 are the EV system outputs: the scheduling index (SI) and the cost index (CI).

Table 22.Outputs

	MPCS					**EV**	
Output / Project	**Design Yield**	**Operations Yield**	**Training Yield**	**Documentation Yield**	**Project Management Yield**	**SI**	**CI**
1	0.67	0	0.5	0.75	0.54	0.5	0.6
2	0.286	0	0.25	0.333	0.25	0.55	1.1
3	0.8	0.9	0.75	0.8	0.95	0.45	0.85
4	0.2	0.55	0.2	0.45	0.35	0.3	1.2
5	0.45	0.35	0.35	0.45	0.45	0.45	0.4
6	0.55	0.3	0.65	0.45	0.45	0.45	0.6
7	0.3	0.45	0.6	0.6	0.5	0.45	0.65
8	1	1	1	1	1	0.9	1.2
9	0.55	0.66	0.75	0.7	0.68	0.55	0.9
10	0.7	0.65	0.72	0.9	0.5	0.95	1
11	0.55	0.35	0.5	0.25	0.35	0.65	0.3

Table 22 shows that project 3 is not performing well according to the time and cost measurements (SI = 0.45, CI= 0.85) .The MPCS performances reveal gaps between the planning and the execution mainly in the: Training category (0.75); Design category (0.8); and Documentation category (0.8). Project 8 has perfect MPCS performances, i.e., 1 within every category. The EV measures are better than project 3 (SI = 0.9, CI= 1.2)

Stage 2: Grouping algorithm

a. Inputs correlations and outputs correlations computation.

At stage 'a' correlation examination is performed among the different inputs and among the different outputs.

Matrices RO_{ij} and RI_{ij} is given in Table 23 and Table 24 respectively.

Table 23. RO_{ij} **Correlation matrix**

	1	2	3	4	5	6	7
1	1	0.56	0.84	0.75	0.82	0.65	0.08
2	0.56	1	0.70	0.64	0.79	0.37	0.42
3	0.84	0.70	1	0.77	0.83	0.61	0.14
4	0.75	0.64	0.77	1	0.81	0.55	0.44
5	0.82	0.79	0.83	0.81	1	0.32	0.27
6	0.65	0.37	0.61	0.55	0.32	1	0.24
7	0.08	0.42	0.14	0.44	0.27	0.24	1

Table 24. RI_{ij} **Correlation matrix**

	1	2	3	4
1	1	0.99	0.14	0.54
2	0.99	1	0.16	0.53
3	0.14	0.16	1	0.80
4	0.54	0.53	0.80	1

b. Grouping process

At stage 'b' the adjustment of the correlation calculation results is performed as shown in Tables 23-24 which presents the similarity coefficients of both the outputs and the inputs.

The outputs and inputs similarity coefficients SCOij and SCIij are given in table 25 and table 26 respectively.

Table 25. Outputs similarity coefficients

	1	2	3	4	5	6	7
1	1	0	0.84	0	0.82	0	0
2	0	1	0	0	0	0	0
3	0.84	0	1	0	0.83	0	0
4	0	0	0	1	0.81	0	0
5	0.82	0	0.83	0.81	1	0	0
6	0	0	0	0	0	1	0
7	0	0	0	0	0	0	1

Table 26. Inputs similarity coefficients

	1	2	3	4
1	1	0.99	0	0
2	0.99	1	0	0
3	0	0	1	0
4	0	0	0	1

Based on the correlation promoters presented in Tables 26-27, the created groups can be presented.

Output groups and input groups are given in Table 27 and 28 respectively.

Table 27. Outputs groups

	Outputs
Group 1	1,3,4,5
Group 2	2
Group 3	6
Group 4	7

Table 28. Inputs groups

	Inputs
Group 1	1,2
Group 2	3
Group 3	4

c. Selecting output / input representative

The selection of the output or input representative will be performed according to the criterion of maximization of the similarity coefficient average of the output within the group. For this case group number 1 which includes the outputs 1,3,4,5 will be discussed.

Table 29 contains computational results using equation 10.

It can be seen for example that the similarity coefficient value of output 1 is 0 in the relation between it and output 4 and in the two other cases its value is higher than 0.8. The similarity coefficient average of output 1 is 0.55. On the other hand, the average of output 3 is higher with a value of 0.83, therefore output 3 is the representative of group 1.

Table 29. Selecting group 1 output

Output 1	SCij
1-3	0.84
1-4	0
1-5	0.82
Average	0.55

Output 3	SCij
3-1	0.84
3-5	0.83
3-4	0.81
Average	0.83 *

Output 4	SCij
4-1	0
4-3	0.83
4-5	0.81
Average	0.54

Output 5	SCij
5-1	0.82
5-3	0.83
5-4	0.81
Average	0.82

Dealing with the inputs in this example is less complex since only one group includes more than one input and in this specific case there are only two inputs. Hence, the choice between them will be arbitrary, i.e., input 1 is the representative of group 1.

Stage 3: Implementing sequential DEA

The application of Sequential DEA is performed when the procedure inputs are identical and the outputs vary. A Sequential DEA is performed in a 3-stage process as follows:

a. Performing DEA with MPCS outputs

At this stage, running the DEA is performed when the MPCS outputs results are given in Table 30

Table 30. MPCS Efficiency Score

Input / Project	Inputs			MPCS Outputs		DEA Score
	Work Content	Level of Monitoring	Level of Uncertainty	Design Yield	Operations Yield	
1	300	6	6	0.67	0	0.5583
2	50	7	6	0.29	0	0.2383
3	150	7	8	0.80	0.9	0.6429
4	300	6	7	0.20	0.55	0.4583
5	90	4	4	0.45	0.35	0.5625
6	100	9	7	0.55	0.30	0.3929
7	150	9	9	0.30	0.45	0.2500
8	24	5	5	1	1	1
9	175	7	8	0.55	0.66	0.4714
10	400	8	9	0.7	0.65	0.4375
11	40	7	6	0.55	0.35	0.5867

Table 30 shows the scoring of the projects using the DEA method. Project 8 is on the efficiency frontier and holds the score of 1. Project 3 has to have corrective action in order to be on the efficiency frontier, the project holds the score of 0.6429 and corrective action should be taken.

b. **Performing DEA with EV outputs**

The EV output results, using the same inputs are given in Table 31

Table 31. EV Efficiency Score

	Inputs			**EV Outputs**		**DEA Score**
Output / Project	**Work Content**	**Level of Monitoring**	**Level of Uncertainty**	**SI**	**CI**	
1	300	6	6	0.50	0.60	0.4630
2	50	7	6	0.55	1.10	0.7639
3	150	7	8	0.45	0.85	0.4427
4	300	6	7	0.30	1.20	0.7143
5	90	4	4	0.45	0.40	0.6250
6	100	9	7	0.45	0.60	0.3571
7	150	9	9	0.45	0.65	0.3009
8	24	5	5	0.90	1.20	1
9	175	7	8	0.55	0.90	0.4687
10	400	8	9	0.95	1	0.5864
11	40	7	6	0.65	0.30	0.7704

Table 31shows the scoring of the projects using the DEA method. Project 8 is on the efficiency frontier and holds the score of 1. Project 3 has to have corrective action in order to be on the efficiency frontier, the project holds the score of 0. 0.4427 and corrective action should be taken.

c. Performing DEA integrating stages a, b results

The outputs in the final stage are the combined results of the MPCS efficiency scores and the EV efficiency scores using the same inputs are given in table 32.

Table 32 Integrated score

Project	Inputs			Outputs		DEA Score
	Work Content	Level of Monitoring	Level of Uncertainty	MPCS Efficiency	EV Efficiency	
1	300	6	6	0.5583	0.4630	0.4652
2	50	7	6	0.2383	0.7639	0.6366
3	150	7	8	0.6429	0.4427	0.4018
4	300	6	7	0.4583	0.7143	0.5102
5	90	4	4	0.5625	0.6250	0.7812
6	100	9	7	0.3929	0.3571	0.2806
7	150	9	9	0.2500	0.3009	0.1672
8	24	5	5	1	1	1
9	175	7	8	0.4714	0.4687	0.2945
10	400	8	9	0.4375	0.5864	0.3258
11	40	7	6	0.5867	0.7704	0.8218

It can be seen that project 8 is on the efficiency frontier, though it is a relatively low budget project. High budgeted projects like project 10, project 1 and project 4 should improve their performances to achieve better efficiency results.

Projects 6 and 7 present relatively low performance levels compared to the other projects both in the output of the MPCS system and in the EV outputs. Many projects are far from the efficiency frontier, therefore systematical examination of them is needed in order to perform improvements.

5.5 Summary and conclusions.

The MPCS system described in the article by Rozenes et al. (2003) represents a project control system, which examines the performances of a single project using a large number of dimensions. The infrastructure of the system is the GPCS control specifications through which the project performances are examined in comparison with the original planning. The results of the examination are calculated with the help of yield indices that are calculated with aggregation. The result of the MPCS system presents the power and direction of the gap between the plans and performance. The MPCS system performs the control of each project singly .The DEA methodology allows the comparison among different projects operating in parallel at different stages of their life cycles. The performance of the DEA comparison is possible following the standardization in the GPCS definition of the different projects. It is based on the uniform definition of the two higher levels in each GPCS of the different projects. Comparison is performed on the combined control system, which includes two complementary control systems, one of them is MPCS and the other is the traditional EV system. When only a few projects are in progress the DEA methodology requires the building of an algorithm that provides the same information through a smaller number of inputs and outputs. The DEA output allows the diagnosis of those found on the efficiency frontier and those that need improvement

Chapter 6: Discussion

A project control system aims at minimizing the gap between project planning and project execution in order to achieve projects' aims, i.e., cost, time and content. Literature survey reveals that the most common world wide control methodology is Earned Value. The EV methodology, developed 40 years ago in the USA, integrates two dimensions, time and cost. A major limitation of the EV methodology is the work packages cost aggregation. The EV methodology may not alert the project manager where a low cost work package is not successfully performed. In this case the project manager may not perform a corrective action. The MPCS methodology can overcome this deficiency.

Controlling other project dimensions is based on specific systems without integration. For example a technology project usually holds a design review control methodology. Usually it is activated without any connection to the EV system. Isolated project control systems suffer from a lack of organized and standardized information that can reveal the influence between the projects' dimension. For instance, how problems in the design process will influence the project's quality demands or the project's operations, etc. Nowadays a project manager can estimate qualitatively these influences but there is a need for an established quantitative methodology performed in order to improve the decision making process. Therefore the importance of a multidimensional integrative project control system is well recognized by researchers and practitioners.

The MPCS methodology presents a solution to this need. The MPCS supports an integrative control status during the entire project life cycle. Implementing the MPCS methodology does not require extra data collation and uses the current data base. The MPCS methodology allows the project manager to determine: integrated project status; where problems exist in the project; when and where to take corrective action, and how to measure improvement.

The presentation of the control system status focuses management's attention to the power and the direction of corrective actions that must be performed in order for performance to be identical to planning.

The MPCS system includes the Global Project Control Specifications that determine control specifications by defining control tasks through the project life cycle. The GPCS defines control assignments during the course of the project's life. Should there be a gap between planning and performance, a warning is indicated by the system in order to take corrective action. This comparison process is conducted while measuring actual performance using the yield index.

The MPCS's output constitutes a yield indices for all dimensions (defined as categories) included in the GPCS specifications. Since the GPCS is hierarchically constructed, the yield's computation process is aggregative. Commencing at the lowest level, which is the control work packages level up to higher levels defined as subjects and up to the highest level a category. The control system is formulated as an orthogonal vector system whose axes constitute the various categories. The MPCS methodology should be undertaken during both the planning phase and the execution phase, as discussed below:

Planning Phase

1. GPCS definition

Defining the GPCS structure includes the entire array of the required control activities needed during the project life cycle (based on the control activities within the classic WBS content).

2. Defining Measurement Procedures.

Each control work package defines the required measurement processes in order to evaluate the project's performance (based on the existing ongoing control activities within the classic WBS content).

3. Defining Execution and Reporting Processes.

Based on the project's OBS, each organizational unit is responsible for execution of each and every specific control work package. At this stage the control work package results report is defined.

4. MPCS Threshold values.

The project management that includes both the planning and design components defines the threshold values in the MPCS system. Each subject in the GPCS has a predefined threshold value (CRj), through which the management indicates satisfactory performance of the project state.

Execution Phase

1. Yield computation.

During each control point in the project life cycle subject yields are calculated aggregately on the GPCS structure.

2. Control indices computation and examination.

MPCS input is based on the vectorial representation of the various categories. When the planning is absolutely identical to performance, the value of each category is 1, i.e., the performance of each GPCS component.

3. Corrective actions.

In order to improve the performance of the project, the project manager must take corrective actions, which will reduce the gap vector value.

MPCS implementation limitations

Implementing any control system is a demanding mission that requires discipline from the project team. An important factor for a successful implementation of a project control system is the organisational management commitment. The MPCS implementation is a demanding process that requires commitment from the project team and the organisational management. The implementation process has to be supported by a discipline project team which is willing to cooperate with the methodology reporting demands. These are essential conditions for a successful implementation of the MPCS control system. Otherwise, the MPCS implementation process may fail.

The MPCS methodology is designed for large and complex projects it will not be effective to operate the MPCS control system within small projects. The amount of data is needed to operate properly the MPCS control system is slightly big. Therefore, the added value operating this kind of control methodology is within a reasonable size project.

An estimate definition of a reasonable size project can be more than 100 work packages within the project's work breakdown structure.

The current state MPCS methodology offers to the project management a basic mechanism to define the threshold values. The project management defines the critical control work packages. A critical control work package is one that must be successfully performed in order to proceed with project execution otherwise the project will not reach its predefined aims and objectives. By defining these CWP the project management defines the lower bound of the threshold value. The upper bound for the threshold value is always 1, i.e., all of the CWPs has to be performed. The current state MPCS control system does not offer an algorithm supporting the project management to define the optimal values of the GPCS threshold values. Therefore, the project management may take wrong decisions while operating the MPCS control system.

Implementing the MPCS system: A case study

A case study of a Hi Tech project is used for demonstrating the MPCS implementation. The objective of the case study project was to develop and produce a system used to hide aircraft and ships from radar. The case study project was managed using the traditional managerial tool. The project was planned using a work break down structure that included more then 100 tasks. A Cost to Complete control system was used in order to monitor and control the project at two control points. According to the CTC control system results at control point 1 the project execution was as planned. Therefore, no corrective actions were needed. However, during the project execution phase the experienced case study project manager collected informal data notifies that the project suffers form deficiencies (the project manager performed a daily inquiry with the project participants to find out the project status). The project manager had to perform corrective action to improve the project performances in spite of the current control system indication. A thorough examination of the control mechanism was performed. An EV control system was performed based on the case study project database. The EV control system was performed at the same control point as the CTC control system. The EV control system results were similar to the CTC control system results.

The MPCS control system was performed based on the case study project database. The MPCS results indicated the problems that the case study project manager indicated using informal data. These appropriate corrective actions improved the MPCS performance measures while maintaining the CTC and EV results.

The case study project was examined at two control points during the project life cycle. At control points 1 the EV results were: CPI = 92%; SPI = 85%. These results indicted that the project was performed according to the plan. However, the MPCS results were: GP = 52.92% and the categories' gap were: Design gap = 0.33; Operations gap = 0.53; Quality gap = 0.67. The MPCS control system was indicated the project deficiencies where the EV system did not. The case study project manager performed the appropriate corrective actions. After performing the corrective actions the EV results at control points 2 were: CPI = 101%; SPI = 99%. The MPCS results were: GP = 29.56% and the categories' gap were: Design gap = 0.33; Operations gap = 0.20; Quality gap = 0.33. Both control system were indicating that there is an improvement. Using only the EV control system would have lead the case study project to poor performances. Using the MPCS control system indicted the appropriate corrective action to be performed. Using the MPCS system improved the case study project performances within the EV control system and the MPCS control system.

The MPCS control system formalized the informal knowledge into measurable multidimensional performances. The MPCS used the same database as the case study project control systems and enabled the project manager to identify the problems that existed in the project.

The need for computerized supporting tool

Design the GPCS for a complex project is complicate mission. This mission is as complicated as to design a WBS to a complex project. Furthermore, the MPCS requires a computerized database to support the entire data needed to operate the methodology. The MS project and the Excel software can support the MPCS methodology. However, performing a complex project using the MPCS control system creates a need for a software supporting tool that can be helpful while implementing the MPCS methodology. Developing such a tool should contribute to a successful implementation of the MPCS control system.

Comparing the efficiency of several projects in a MPCS environment

A Multidimensional Project Control System (MPCS) deals with the control of a single project and defines its performances in comparison with the plan. The progression of several projects in parallel is a common situation in organizations, therefore a comparison of the various project performances is required. It is proposed that a comparison process be performed using the data envelope analysis (DEA) approach. The reference points for examining the performances of different projects and the directions of improvement for the projects are not necessarily found on the efficiency frontier. An algorithm is developed for applying multi-project system control having a relatively large number of inputs and outputs while maintaining the validity of the DEA methodology.

Operating several projects in parallel using the MPCS methodology requires GPCS standardization similar to the WBS standardization. The standardization means that the two higher levels in the GPCS structure are identical in each project that is managed and controlled in the organization. The creation of this standardization also contributes to the improvement of the organizational learning process whilst creating a comparative tool for projects in progress and those that took place in the past. Using the GPCS standardization enables the DEA comparison process .

In the MPCS methodology the outputs represent the totality of dimensions in which the project is measured, examined and performed. The outputs are the yield calculations of the different categories. Their numbers derive from the control system planning process that uses GPCS. Other outputs are the control indices of the earned value system that present the schedule deviation and cost deviation.

The MPCS methodology is a novel project control system indicating the multidimensional project control status during the entire project life cycle. The MPCS uses the same data bases as the classical project control systems. The system allows the project manager to identify the problems that exist in the project. The MPCS system supports improvement measurements after the project manager has taken the appropriate corrective action.

Chapter 7: Conclusions

- In order to achieve project success the control system should support the multidimensional aims and objectives of the project.
- The MPCS system was designed to support these multidimensional aims and objectives.
- The MPCS system includes the following elements:
  - A GPCS that determines control specifications by defining control tasks throughout the project's life cycle.
  - Quantitative measures, based on the Yield concept, indicating the project's status during the project's life cycle.
- The implementation of the MPCS system includes the following phases:
  - A planning phase that includes all of the planning components of the MPCS system.
  - An execution phase that indicates the project status using the Yield term during the project's life cycle. During this phase, corrective action can take place to improve performance of the project.

- The implementation of the MPCS system can be partial supported using MS Project and MS Excel software.
- The MPCS system can be implemented within industry as the case study project proved.
- The case study project presented the add value of the MPCS control system versus the classical control system.
- The MPCS control system can identify problems that the classical control system cannot identify.
- The MPCS methodology is designed for large and complex projects.
- There is a need for a threshold value definition algorithm.
- There is a need for a software supporting tool that can be helpful while implementing the MPCS methodology.
- Implementing any control system is a demanding mission that requires discipline from the project team. Furthermore, implementing the MPCS methodology requires management commitment and involvement .
- Implementing the MPCS methodology demands project team participation and collaboration.
- Comparing several projects in parallel can be performed using a DEA analysis.
- The MPCS system supports a project achieving its multidimensional aims and objectives during the entire project's life cycle.

- The MPCS system supports a project achieving its multidimensional aims and objectives during the entire project's life cycle.

Chapter 8: Further work

8.1 Using vectorial analysis within the MPCS methodology

The MPCS methodology used vectorial presentation to provide a deeper understanding of the project's performance. It can be further developed as an analytical tool supporting project control and project management.

8.2 Developing a software tool supporting the MPCS implementation

Implementing the MPCS methodology is a complicated mission mainly because of the size and complexity of the projects that should require this kind of a control system. Developing a software tool that could support the project management to build an information system which may include the following modules: (a) GPCS builder that will help to build an appropriate GPCS based upon an existing WBS and predefined project's aims and objectives;(b) control database that should include the entire control database ;(c) control indicators that includes the needed corrective actions during the project life cycle and the MPCS control indices.

8.3 Developing a threshold value definition algorithm

The current state MPCS methodology offers lower bound and upper bound for calculating the threshold value. There is a need for a structured algorithm that can assist the project management to define the optimal needed threshold values.

8.4 Evaluate project control implementation successes factors

Much research was conducted regarding project successes factors. There is a lack of research results regarding project control systems implementation. Therefore, there is a need to conduct a survey to find the project control implementation successes factors. Furthermore, these results should improve the implementation of project control systems and particularly the MPCS control system implementation. This survey could light up human resources behavior aspects while implementing the MPCS system.

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MPCS: Multidimensional Project Control System

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Abstract

Project control systems often fail to support management in achieving their global project goals. This paper propose a MPCS (Multidimensional Project Control System) as a quantitative approach for quantifying deviations from the planning phase to the execution phase with respect to the global project control specification (GPCS). The project current state must be translated into yield terms which are expressed as a gap vector that represents the multidimensional deviation from the global project control specification. The systematic multidimensional project control is described and illustrated by a computational example.

Keywords: Managing projects; Operations

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B. MPCS Multidimensional Project Control System Implementation Algorithm

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MPCS Multidimensional Project Control System Implementation Methodology

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Abstract

Project control systems often fail to support management in achieving their global project goals. This paper propose a multidimensional project control system (MPCS) as a quantitative approach for quantifying deviations from the planning phase to the execution phase with respect to the global project control specification (GPCS). The project current state must be translated into yield terms. The MPCS system implementation methodology is described and supported using a garden building project example in order to illustrate the various characteristics and the process of the implementation.

1. Introduction

PMBoK[3] defines nine categories that exist throughout the project lifecycle: Project Integration Management, Project Scope Management, Project Time Management, Project Cost Management, Project Quality Management, Project Human Resources Management, Project Communications Management, Project Risk Management, and Project Procurement Management. Although these categories are integrated into the project lifecycle, their control systems, which are implemented in each project phase, are separate. Correct planning relies on techniques that support all categories. A practical tool, the Work Breakdown Structure (WBS), presents the hierarchical organization of work by defining the work packages in terms of supply to the customer (production, services and information) through costing identification.

Critical to accurate planning, WBS is a useful tool during performance when project control compares planning to actual performance.

In an earlier paper Rozenes et al. [4] introduced a project control methodology entitled, a Multidimensional Project Control System (MPCS). This methodology defines the control system planning process in which the Global Project Control Specifications (GPCS) are defined. GPCS specifications provide an integrative solution for all project dimensions.

2. Multidimensional Project Control System (MPCS) overview

The MPCS methodology's basic assumption is indicative of the existence of an entire project design process, which includes all of the content, the logic, schedule, resources and budget components. This project design process is based on a collection of the classical techniques, which are well defined in APMBoK [1] as well as in PMBoK [3] .Formulating the GPCS specifications as part of the project's design stage is based on a hierarchal structuring of the entire control assignments set up defined for execution in this project. The MPCS methodology positions an additional challenge for the planning team of the project which is required to define the control activities necessary in order to abide by the design aims and objectives. The project's management defines the hierarchical structure of the GPCS in accordance with the aims and objectives of the project.

Hierarchically constructed, GPCS (see Figure 1) contains all control operations that are performed during the project life cycle. The first level in the hierarchy includes all control dimensions in the project defined as categories. Each category incorporates various subjects situated on lower hierarchical levels and each subject can contain additional subtopics. The lowest level in each subject contains Control Work Packages (CWP) that include a set of control tasks that it must perform, similar to the work packages in the WBS.

Figure 1 displays a typical structure of GPCS that contains 3 control dimensions / categories: Technical/Functional, Operational and Quality.

For example, the Technical / Functional category includes technical data needed to produce the project, and may include the following subjects: functional flow, integrated test planning, data management plans, configuration management plans, system safety, human factors, value engineering studies and life cycle cost.

The Operational category contains the project operating systems. It also contains the project flow process and priorities determination. It may include the following: preliminary requirements, system/cost analysis, effectiveness analysis, synthesis, logistics support analysis, technical performance measurement planning, engineering integration, preliminary manufacturing plans, and manpower requirements/personnel analysis.

The Quality category defines the project quality requirements and may include the following: requests for contractors ISO 9000 certification, requests for contractors ISO 14000 certification, application of statistical process control (if needed), quality cost systems, and quality measures.

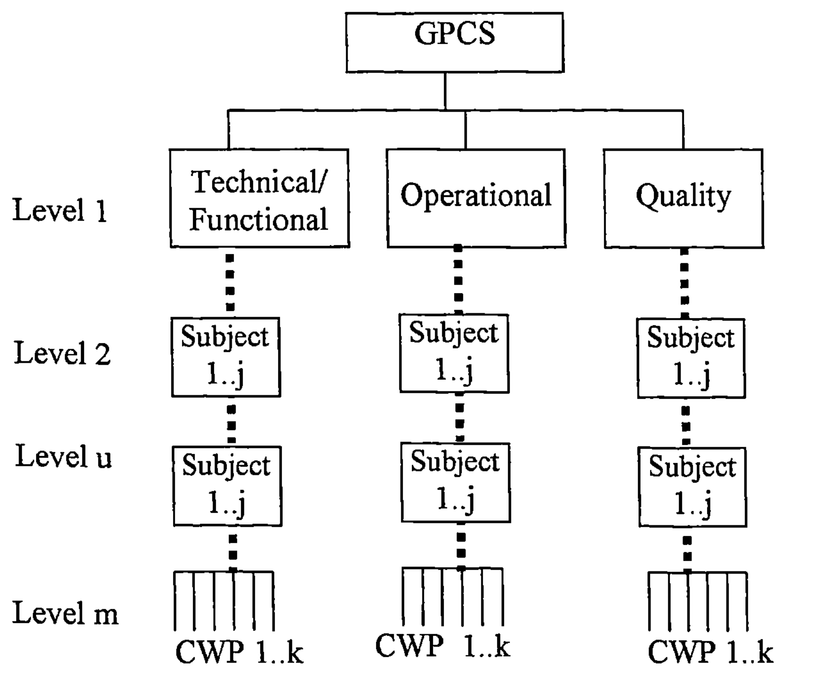

Figure 1. Global Project Control Specifications Structure

The logic of the GPCS creates the need for a measuring method to be used with various categories and various related units of measurement. A useful measuring tool has been the yield concept. We propose to utilize the yield concept as the measuring method for project categories. This is discussed below.

3. MPCS methodology principles

The control system aims at minimizing the gap between planning and results. The planning basis in the MPCS system constitutes the GPCS's control specification, as indicated in Figure 1. The GPCS defines control assignments during the course of the project's life cycle. Should there be a gap between planning and performance, a warning is indicated in order to take corrective action. This monitoring process is conducted while measuring actual performance using the yield index.

The GPCS needs to also include the required measurement processes for each Control Work Package as well as the definition of the threshold values indicating whether the work was properly preformed. Also included is the project's planning and design element which defines the threshold values incorporated with each subject in the MPCS system.

After defining the GPCS control specifications, the quantitative measures that define project performance determines the yield as the measures for controlling the project (see Rozenes et al. [4]).

The yield is calculated for every subject and aggregated for every category.

Each Control Work Package has a single organizational unit responsible for its execution, however it is possible to report results of the control work package as well as those of the subjects and categories to various organizational units. In order to solve for the project's communication problems, it is recommended to define a report matrix which determines to whom to report among the project's stake holders and the type of report required.

The project's management defines the control checkpoints to be used during the life cycle of a project. The performance of the control work packages that need to be performed is examined at each control checkpoint. Yield computation is done for each subject and for each category. Based on the Yield computation, control indices are computed identifying gaps between planning and execution which may require attention. Required corrective actions are performed according to the results of the MPCS system control indices.

a. The GPCS Topology

Every GPCS structure may include one or both of the following substructures.

I. Substructure A

Substructure A represents a single subject configuration with Control Work Packages (CWP) only. Substructure A is described in Figure 2. where every subject may contain M Control Work Packages. Level m is the lowest level in the GPCS branch and contains a compilation of control tasks that must be performed in order for the project to achieve its objectives.

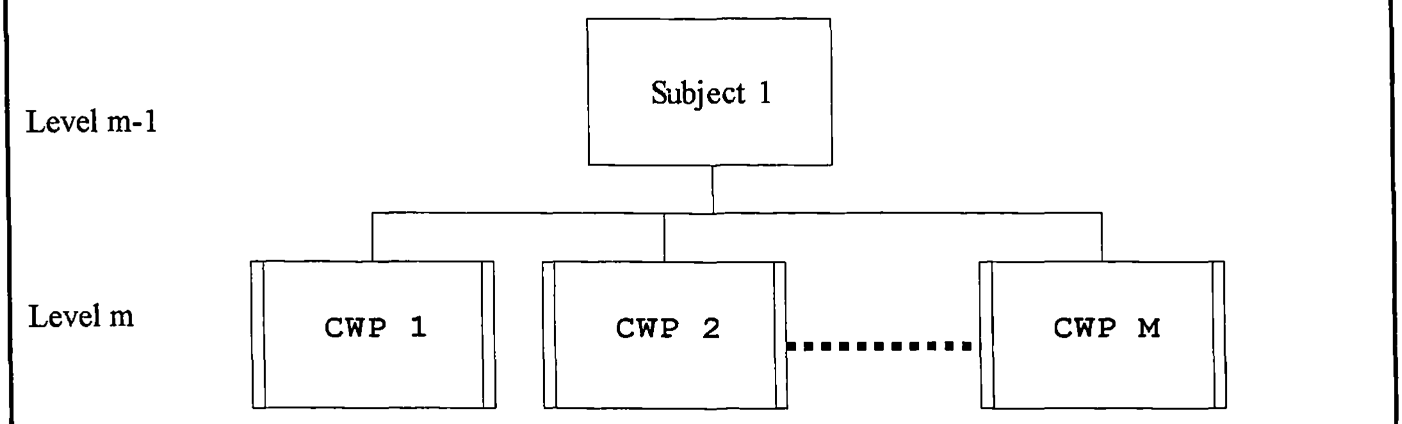

Figure 2. GPCS substructure A

II. Substructure B

Substructure B represents a single or multi subject configuration with lower level subjects and CWP's. Figure 3 shows an example of a Substructure B. Subject A includes the combination of a subject (e.g., Subject 1) or several subjects with the same level as control work packages (e.g., CW1 and CW2). Subject 1 contains only CWP's therefore it has a Substructure A configuration.

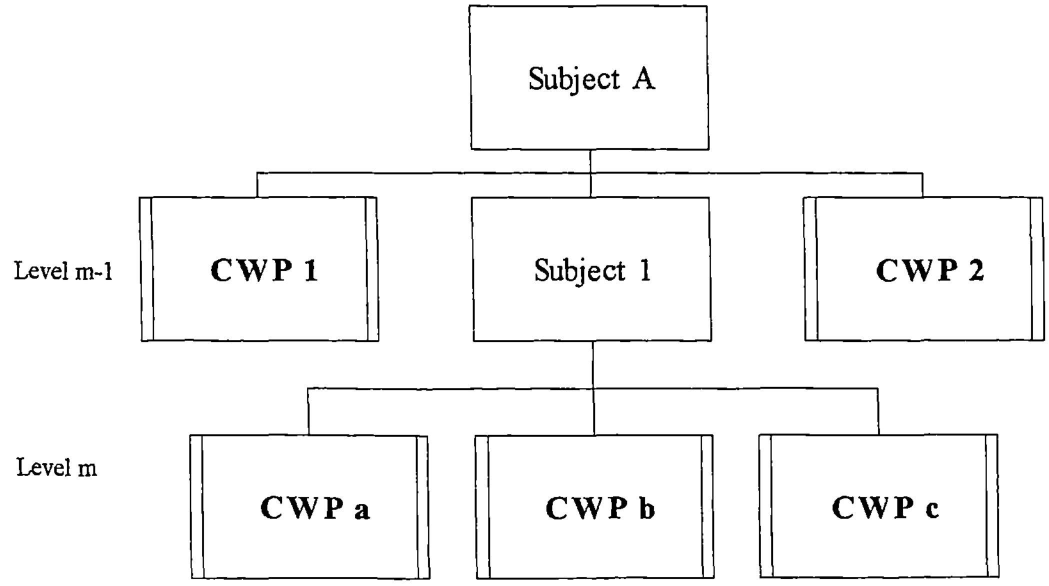

Figure 3. GPCS substructure B

b. MPCS performance measures

Since the GPCS is hierarchically constructed (see Figure 1) the yield's computation process is aggregative. Commencing at the lowest level, which is the control work packages level from subject j level up to level 1, the category level. The categories yields computation are based on comparing the subjects' performance to predefined performance levels (CRj). These levels (for the various subjects) are defined by the project's management that takes into account the required control sensitivity requirements. These levels are designed to detect unreasonable digression. A reasonable digression is one in which subject j's performance, in yield terms, is higher than the defined performance level. In case of an unreasonable digression the project's team will be asked to take corrective action. The process of defining the Threshold values by the project management is based on the definition of each control work package as a critical CWP or non-critical CWP. A critical CWP is one that must be successfully performed in order to proceed with project execution otherwise the project will not reach the predefined aims and objectives .For example, a threshold value (CRj) equals to 1 means that every CWP that belongs to a subject j must be successfully performed otherwise that project execution will not reach the project objectives. A threshold value (CRj) of a specific subject equals to 0.5 means that up to 50% of the CWP related to this specific were defined as critical CWP. Performing 50% or more of the CWP subject is defined as a successfully performed of the subject

I. Subject Yield

As described earlier every GPCS can contain both topologies: Substructure A and Substructure B (see Figures 2, 3). In the case of Substructure A the performance of each control package k is tested during the performance stage. If performed as planned, then $\delta_K = 1$, otherwise $\delta_K = 0$. An identical weight is assigned to each control work package k (out of M control work packages) related to subject j out of L subjects.

(1) $$Y_{ij} = \frac{\sum_{k=1}^{M} \delta_k}{M} \forall ij$$

Where:

$$\delta_k = \begin{cases} 1 & \text{If CWP k is successfully performed} \\ 0 & \text{Otherwise} \end{cases}$$

When index Y_{ij} is not equal to 1, it means that there are differences between planning and performance.

In the case of Substructure B, computation includes the yield calculation for all subjects on the same level, which are then compared with their respective threshold values (CRj) as defined by the project management. When the threshold value is higher than the yield, then $\delta_k = 0$, and when the subject yield value exceeds the threshold value, then $\delta_k = 1$. Control package values are calculated in the same manner as in Substructure A.

(2) $$Y_{ij} = \frac{\sum_{k=1}^{M} \delta_k}{M} \forall ij$$

Where:

$$\delta_k = \begin{cases} 1 & \text{If } Y_{ij} \geq CR_{nj} \text{ or } CWP_k \text{ is successfully performed} \\ 0 & \text{Otherwise} \end{cases}$$

II. Category yield

When the subject's yield Y_{ij} is equal to, or exceeds the threshold value then the subject's performance is defined as being successful then auxiliary variable θ_j equals to 1, otherwise $\theta_j = 0$.

The closer CR_j is to 1, the higher the control sensitivity will be, indicating that the project is responding to specification requirements. The GPCS structure includes N categories and each category has L subjects.

Due to the GPCS's structure, the categories are independent of each other. However their importance and contribution to the success of the project's performance are not identical. Therefore, each subject weight is determined according to its position in the GPCS specification based on King's algorithm [2]. Equation (3) presents the yield computation of category i.

(3) $$Y_i = \frac{\sum_{j=1}^{L} \theta_j 2^{L-j}}{\sum_{j=1}^{L} 2^{j-1}} \forall i$$

Where:

$$\theta j = \begin{cases} 1 & \text{If } Yij \geq CRj \\ 0 & \text{Otherwise} \end{cases}$$

III. MPCS managerial indices

The MPCS system defines two types of indices. The first is a performance index Y_i for each dimension/category i and the gap G_i for each dimension/category i. The second is the Gap Performance (GP) index presented in equation (4) is based on Rozenes et al. [4].

$$GP = \frac{\sqrt{\sum_{i=1}^{N} G_i^2}}{\sqrt{N}} \quad (4)$$

Where: N is the number of dimensions/categories

The Gap Performance GP index has a normalized value. The closer its value to 0, the closer the project performances are to the respective plans, i.e., complete and full responsiveness to the requirements presented in the GPCS. The GP index may be used by the manager to compare the performance several projects with the index representing performance on a 0-1 scale. Thus, planning performance can be compared with project performance within the project life cycle. This index can be easily computed with a spreadsheet.

4. MPCS implementation procedure

The MPCS Implementation methodology incorporates two phases based on the project life cycle; the planning phase and the execution phase, as shown in Figure 4. The planning phase begins with the GPCS definition. Managerial decisions defining the measurement processes are made as well as performance and report procedures and the selection of MPCS threshold values. The execution phase performs yield calculations at every GPCS level with calculations being completed at the highest level in the GPCS structure, i.e. the category. Control indices computations are done by comparing yield results to the predefined MPCS threshold values (CRj). Examination of these control indices determines what corrective actions should be taken. The implementation methodology will be discussed in details using a computational example.

Planning Phase

1. GPCS definition.
2. Defining Measurement Procedures.
3. Defining Execution and Reporting Processes.
4. MPCS Threshold values.

Execution Phase

1. Yield computation.
2. Control indices computation.
3. Control Indices examination.
4. Corrective actions.

Figure 4. MPCS Implementation Methodology

5. "Building garden project" – an illustrative example

An example of a garden building project is used for understanding the MPCS implementation. The project combines landscape construction, building techniques and planting flora. The project content is described using a work breakdown structure (WBS) and the project team is described using an organizational breakdown structure (OBS). Figure 5 describes the garden project WBS, which defines the total scope of the project. It contains all the tasks needed to build a garden and includes the planning and performance processes involved in establishing an infrastructure, followed by planting of the garden. The WBS is divided into 3 main topics: Planting, Layout functionality and Infrastructure. Each topic includes work packages that define the exact tasks that should be executed during the project life cycle.

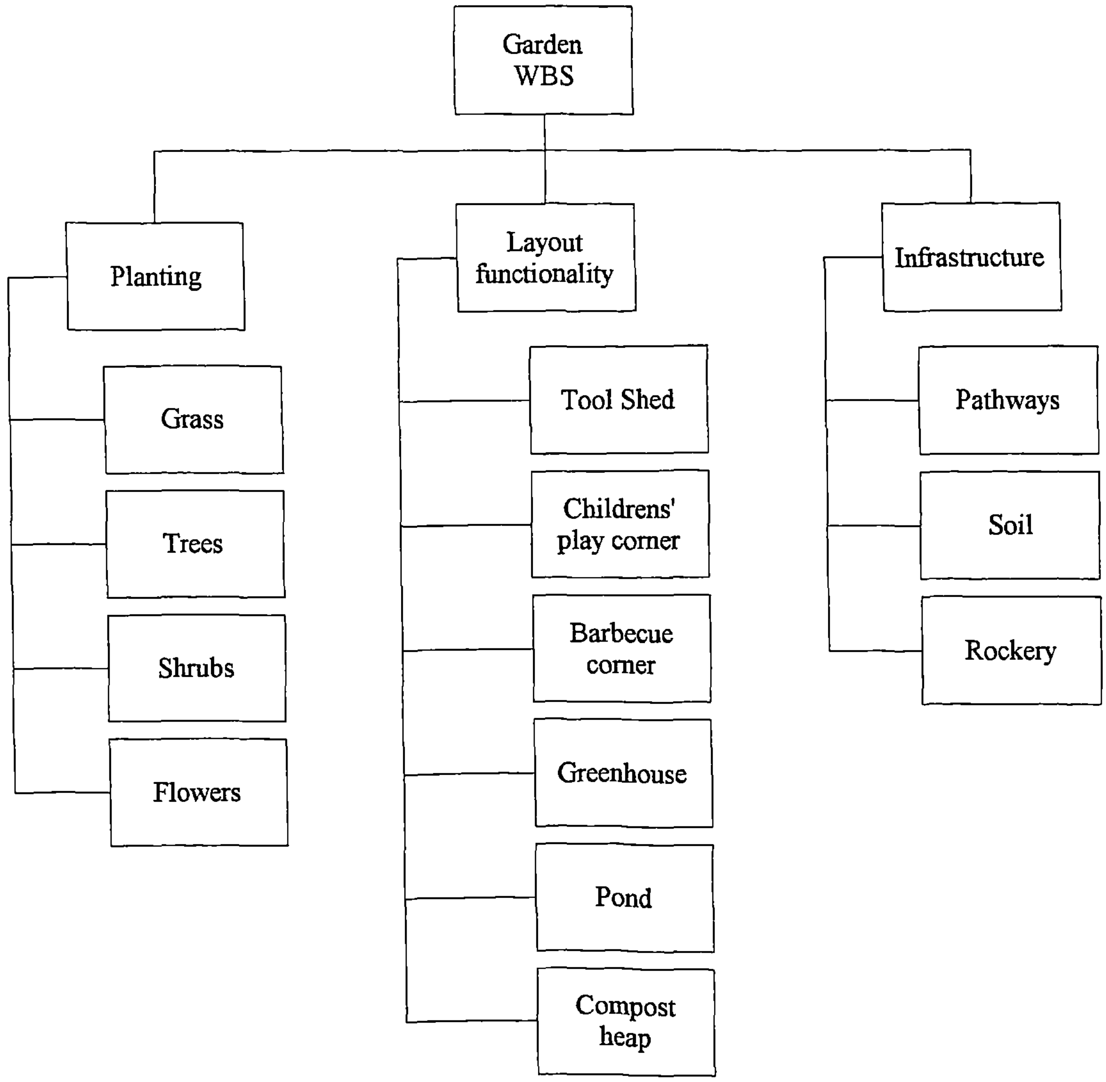

Figure 5. Garden Project WBS

Figure 6 represents the Organization Breakdown Structure (OBS) for the garden building project. It contains a traditional project structure, including the main Human Resources functions such as: Garden Operations responsible for both the garden infrastructure and flora, Purchasing, Control and Landscape Design which covers design and engineering. The garden project management is assumed to include the project manager, the landscape design manager and the garden operations manager.

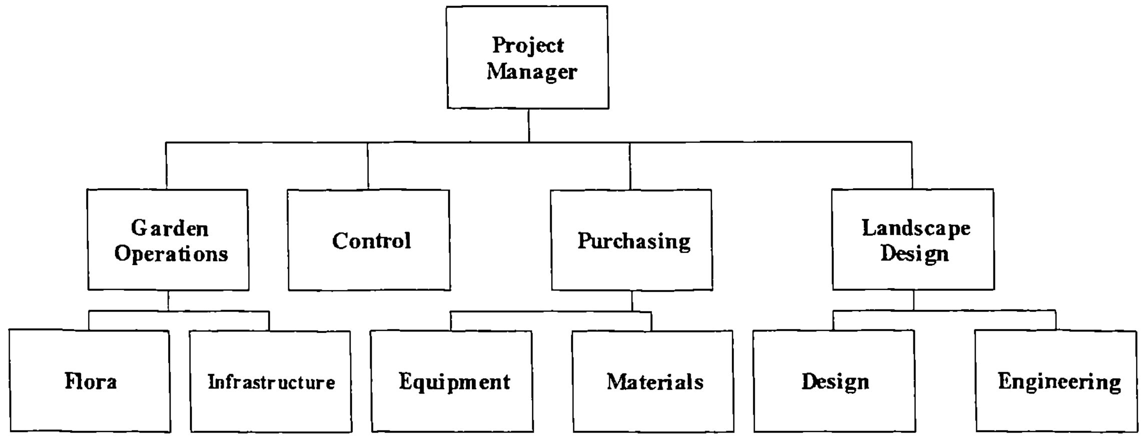

Figure 6. Garden Project Organizational Breakdown Structure

6. The implementation methodology

As discussed earlier the implementation process of the MPCS contains two phases based on a typical project life cycle: the planning phase and the execution phase (see Figure 4).

a. The planning phase

This phase includes the definition of the project control system. Following is the composition of this phase:

I. GPCS structure definition

Defining the GPCS structure includes the entire array of the required control activities needed during the life cycle of the project. Figure 7 represents the GPCS control specifications for the garden building project. The GPCS control specifications includes three categories, which comprise the control dimensions: Design, Operations, and Quality. The GPCS structure contains a combination of subjects and control work packages on various hierarchical levels. For example, the design category includes two subjects (Infrastructure, Planting (and one control work package (Concept verification).

The garden building project GPCS includes all the control activities that should be executed in order to successfully perform the project WBS. For example, successfully performing the Infrastructure issue of the WBS should result in successful performance of both Design Infrastructure and Operations Infrastructure subjects at the GPCS level 2.

It can be seen that the garden project GPCS structure differ from the garden project WBS (see Figure 5). The aim of the WBS design is to activate the project in a rational way in order to establish the bases of the Cost Breakdown Structure (CBS). The aim of the GPCS design is to controlling the project, therefore the GPCS categories represent the main control dimensions that are needed. For example, the garden project WBS (see Figure 5) includes Planting at level 1. The Planting includes the work packages Shrubs and Trees. These work packages include a definition of type, quantity, location and nature of planting. Controlling these work packages have two dimensions, Design and Operations.

The GPCS control work packages Shrubs and Trees, at the Design category, defines a comparison process between the design that was made by the Landscape Design team (see Figure 6) and the design done as is customary in the field of landscaping. At the Operations category the CWP Planting defines the control process of performance for all the Planting components during the execution phase.

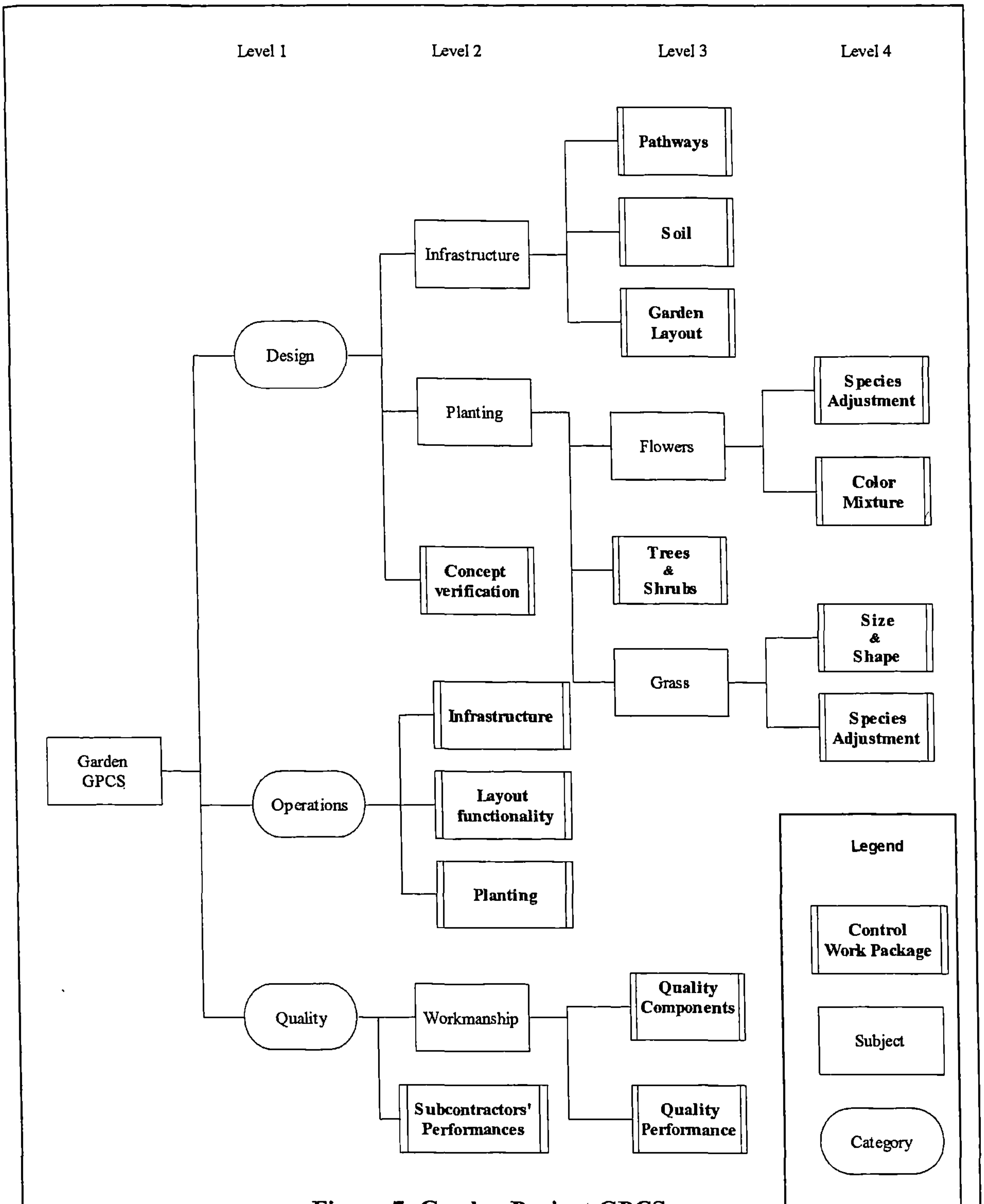

Figure 7. Garden Project GPCS

II. Measurement procedures

Each control work package defines the measurement processes for the purpose of evaluating the project's performance. For instance, the control work package Trees & Shrubs is defined in Figure 7 level 3 and includes a procedural definition of how the measurement should be executed. For example, does 'color' define the mixture of color that has the best emotional impact? and so on.

A CWP performed according to the specifications is indicated by $\delta_K = 1$, a CWP not performed according to the specifications is indicated by $\delta_K = 0$.

III. Execution and reporting procedures

Based on the project's OBS (see Figure 6), each organizational unit is responsible for execution of each specific control work package. Table 1 presents a partial report matrix of the various control work packages in the project. The Table defines those involved in the project report (i.e., the X's). A report of a CWP includes the output of the process (δ_K) and a concise description of the required corrective actions. A report of any subject or category will include a quantitative index which will be computed employing Yield terms.

Table 1. Partial report matrix

Level	Description	Classification	Project manager	Garden Operations	Landscape Design
1	Design	Category	X	-	X
2	Infrastructure	Subject	X	-	X
2	Concept verification	CWP	X	X	X
2	Planting	Subject	X	-	X

IV. MPCS threshold values

Project management defines the threshold values in the MPCS system.

Each subject in the GPCS has a predefined threshold value (CRj) through which the management indicates a satisfactory performance of the project state.

The project management (e.g. project manager, landscape design and garden operations) defines each control work package as a critical CWP or non-critical CWP. A critical CWP is a control work package that a successfully performed is needed in order to proceed with project execution, otherwise the project will not reach the predefined aims and objectives. The garden project threshold values are presented in Table 2. In the GPCS of garden project shown in Figure 7, the subject Infrastructure incorporates 3 control work packages: Pathways, Soil and Garden Layout. Project management defined CWP Soil as a critical CWP. It means that it must be successfully performed. Looking from the Infrastructure subject perspective at least ⅓ out of the 3 control work packages (CWP Soil) must be successful preformed.

If the project management would have thought that one of the two other CWP (i.e. Pathway and Garden layout) should be successfully performed then CRj should be 0.67. Therefore, the project management can define the threshold level (CRj) between 0.33 (minimum threshold level) and 1 (maximum threshold level). In this case it was fixed at 0.67, i.e. successful performance of two out of the three control packages, including Soil, will satisfy project management. The subject Planting does not have any critical CWP. The subject Workmanship incorporates 2 CWP both critical, i.e. threshold value is 1.

Table 2. Threshold value

Level	**Subject**	**CRj**	**Number of CWP/ Subjects**	**Essential CWP**
2	Infrastructure	0.67	3	Soil
2	Planting	0.67	3	-
2	Workmanship	1	2	Quality components, Quality performance
3	Flowers	0.5	2	Species adjustment
3	Grass	0.5	2	Species adjustment

b. The execution phase

This phase (see Figure 4) includes measuring, monitoring and taking corrective action. Following is the composition of this phase:

I. Yield computation

Yield Computation includes the calculation of both subjects' yield and categories' yield. These are now considered.

Subject yield calculation

Subject yields are calculated aggregately on the GPCS structure at each control point in the project life cycle. In order to compute this calculation, both substructures A and B must be assessed.

The GPCS in the Garden project represented in Figure 7 contains both Substructure A and Substructure B. In order to clarify the explanation, only the Design category in the Garden Project is displayed in Figure 8. One component of the Design category is the Infrastructure. This subject is based on the Substructure A of the GPCS and is marked with a dotted line.

The actual results of the execution phase are presented in Figure 8. The notation $\delta_k = 1$ means that a CWP was successfully performed. For example, in level 3 the CWP Pathways was successfully preformed; Figure 8 depicts the MPCS threshold encircled by a dotted line and the actual Yield results.

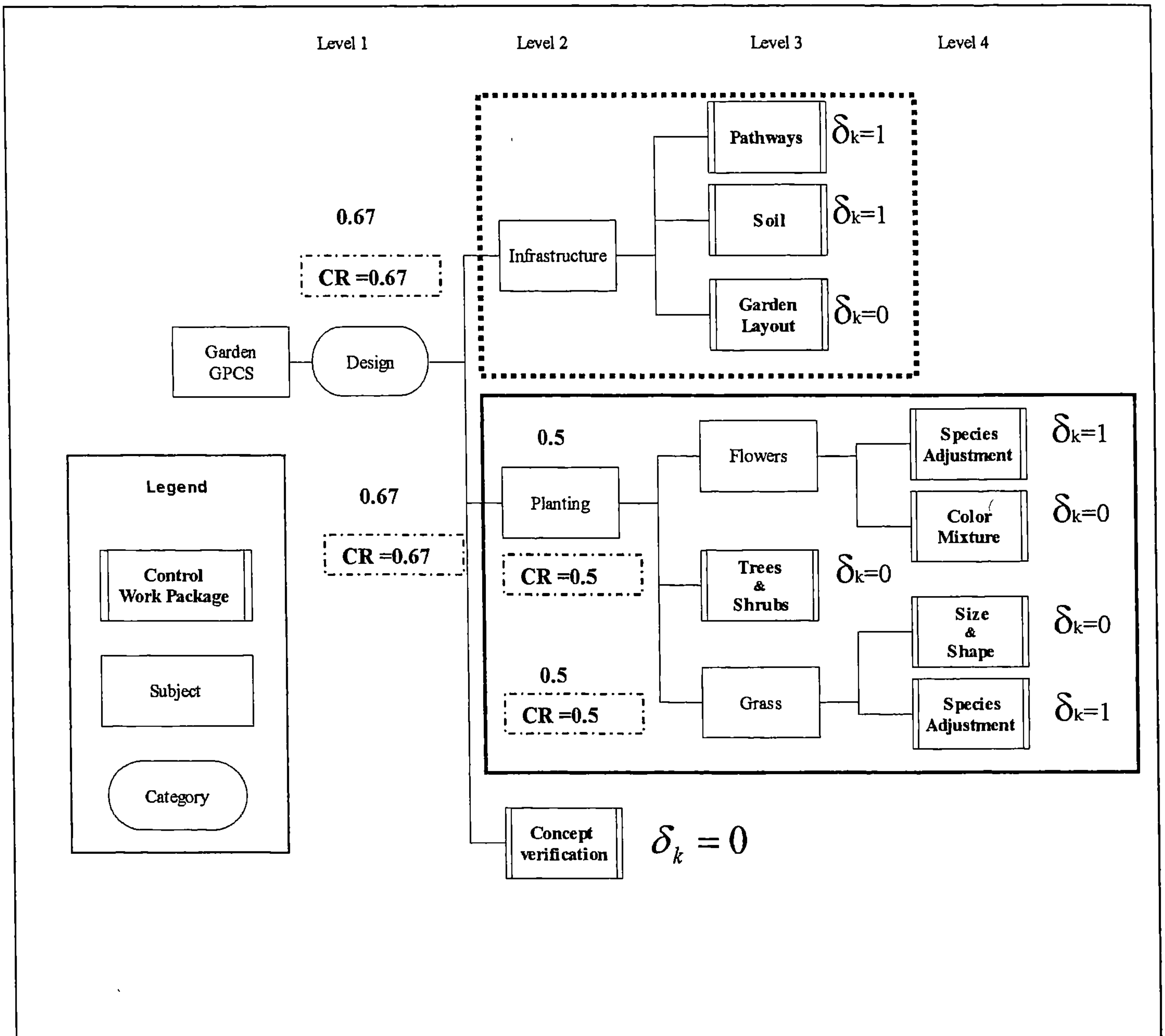

Figure 8. Design Category garden project

The CWPs' performance for the Infrastructure subject is presented in Table 3.

Table 3. Infrastructure subject - CWP performances

CWP	δ_k	**Successfully performed**
Pathways	1	Yes
Soil	1	Yes
Garden Layout	0	No

The Infrastructure subject yield calculation is presented below using Equation (1) and is calculated as follows:

$$Y_{\text{Infrastruture}} = \frac{1+1+0}{3} = 0.67$$

The Infrastructure subject yield result (0.67) is equal to the Infrastructure subject threshold value (0.67) presented in Table 2, which means that the project management will consider the Infrastructure subject as successfully performed.

The Planting subject in Figure 8 (encircled by a solid line) is presented as an example of the calculation of the yield for Substructure B. Table 4 presents the Planting subject CWP performances. Every subject contains two control packages situated at level 4. In each of the two subjects only one was successfully performed. The subject yield calculation is based on these results.

Table 4. Planting subject CWP performances

Subject Level	Subject	CWP Level	CWP	Successfully performed	δ_k
2	**Planting**	3	Trees & shrubs	No	0
3	**Flowers**	4	Species adjustment	Yes	1
3	**Flowers**	4	Color mixture	No	0
3	**Grass**	4	Size & shape	No	0
3	**Grass**	4	Species adjustment	Yes	1

The flowers subject is a Substructure A configuration and its yield is calculated as follows:

$$Y_{Flowers} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{1}{2} = 0.5$$

The Flowers subject yield result (0.5) is equal to the Flowers subject threshold value (0.5) presented in Table 2, which means that the project management will consider the Infrastructure subject as successfully performed.

The Grass subject is a Substructure A configuration and its yield is calculated as follows:

$$Y_{Grass} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{1}{2} = 0.5$$

The Grass subject yield result (0.5) is equal to the Grass subject threshold value (0.5) presented in Table 2, which means that the project management will consider the Infrastructure subject as successfully performed.

These results are shown in Figure 8. Table 5 presents the Planting subject performances. The Planting subject is defined as a Substructure B configuration where the yields for Flowers and Grass were calculated. The subject auxiliary variable value $\theta_j = 1$ indicates a satisfactory performance of the subject according to the threshold predefined value (e.g. the subject Flowers and the subject Grass).

Table 5. Planting subject performances

	CR_j	**Subject yield**	δ_k	θ_j
Flowers (Subject)	0.5	0.5	-	1
Trees & Shrubs (CWP)	-	-	0	-
Grass (Subject)	0.5	0.5	-	1

The yield for the Planting subject was calculated as follows:

$$Y_{Planting} = \frac{\sum_{k=1}^{3} \delta_k}{3} = \frac{2}{3} = 0.67$$

The Planting subject yield result (0.67) is equal to the Planting subject threshold value (0.67) presented in Table 2, which means that the project management will consider the Infrastructure subject as successfully performed.

Category yield calculation

Yield calculation for the Design category depicted in Figure 7 is based on Equation (3) and presented in Table 6.

Table 6. Design category performances

	θ_j	δ_k	CRj	Subject yield
Infrastructure (subject)	1	-	0.67	0.67
Planting (subject)	1	-	0.67	0.67
Concept verification (CWP)	-	0	-	-

Yield calculation for the design category is as follows:

$$Y_{Design} = \frac{1*4+1*2+0*1}{7} = 0.86$$

GPCS control specifications for the Garden project presented in Figure 7 includes two additional control dimensions, the categories of Operations and Quality. Listed below is the yield calculation for both categories. Table 7 presents the performance data for the Operations category.

Table 7. Operations category performances

CWP	δ_k	**Successfully performed**
Infrastructure	1	Yes
Layout functionality	0	No
Planting	0	No

The yield for the Operations category is calculated as follows:

$$Y_{\text{Operations}} = \frac{1*4+0*2+0*1}{7} = 0.62$$

Performance data for the Quality category is given in Table 8.

Table 8. Quality category performances

Subject Level	Subject	CWP Level	CWP	δ_k	Successfully performed
2	Workmanship	3	Quality Components	0	No
2	Workmanship	3	Quality Performance	0	No
		2	Suppliers performance	1	Yes

The yield calculation for the category includes the yield calculation for the Workmanship subject situated on level 2.

$$Y_{\text{Workmanship}} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{0}{2} = 0$$

The Workmanship subject yield result (0) is lower than Workmanship subject threshold value (1) presented in Table 2, which means that the project management will consider the Infrastructure subject as not successfully performed.

The yield for the Quality category is thus:

$$Y_{\text{Quality}} = \frac{0*2+1*1}{3} = 0.33$$

II. Control indices computation and examination

MPCS control indices computations results are $Y_{Design} = 0.86$, $Y_{\text{Operations}} - 0.62$ and $Y_{\text{Quality}} = 0.33$, as calculated previously. There is a gap between the ideal situation defined by yield values equal to 1 and the Garden project performances. Gap values are calculated as; Design Gap = 0.14, Operations Gap = 0.38, Quality Gap = 0.67. It is noticeable that the Quality performance is poor and corrective actions must be taken. The Gap Performance (GP) index, presented in equation (4) is a managerial support tool, where the lower this index, the smaller is the gap between planning and performance. Applied to the Garden project, the GP index is:

$$GP = \frac{|\overline{G}|}{\sqrt{3}} = \frac{\sqrt{0.14^2 + 0.38^2 + 0.67^2}}{\sqrt{3}} = 0.45$$

The project performances according to the GP index are revealed to be unsatisfactory and that corrective actions are required to improve project performance.

III. Corrective actions

In order to improve the performance of the project, the project manager must take corrective actions, which will reduce the value of GP. In the garden building project the Quality category holds the largest gap; therefore a corrective action should be taken in order to reduce the gap. Table 9 summarizes the performance results given in Tables 2 through 6 and presents the control work packages that have not been properly performed. Table 9 indicates in which CWP a corrective action will contribute to the yield result. For example, performing a corrective action in CWP Garden Layout can increase the Infrastructure subject yield result to 1. However the Infrastructure subject threshold value (CRj) is 0.67. Therefore the Design category yield cannot be changed, i.e. the corrective action is redundant.

Table 9. Control Work Packages that do not satisfy the GPCS demand ($\delta_k = 0$)

Category	Subject	Yield	CWP
Design	Infrastructure	0.67	Garden Layout
Design	Planting – Flowers	0.5	Color Mixture
Design	Planting – Grass	0.5	Size & Shape
Design	Planting	0.67	Trees & Shrubs
Design	NA	0.86	Concept Verification
Operations	NA	0.62	Integration
Operations	NA	0.62	Planting
Quality	Workmanship	0	Components Quality
Quality	Workmanship	0	Performance Quality

The Quality category shows that the Workmanship subject contains two control packages: Components Quality and Performance Quality. The threshold value determined for this subject was 1, i.e., the two control packages should be accurately performed. The improvement in both the Gap Vector and the GP index will be examined when these packages are satisfactory performed, when both receive the value of $\delta_k = 1$.

Yield calculation for the category will include the yield calculation for Workmanship found on level 2.

$$Y_{\text{Workmanship}} = \frac{\sum_{k=1}^{2} \delta_k}{2} = \frac{2}{2} = 1$$

The Quality category yield would then give:

$$Y_{\text{Quality}} = \frac{1*2+1*1}{3} = 1$$

The updated yield results are $Y_{Design} = 0.86$, $Y_{Operations} = 0.62$ and $Y_{Quality} = 1$,

The updated gaps are: Design Gap=0.14, Operations Gap=0.38, Quality Gap=0, and the GP index will be:

$$GP = \frac{|\overline{G}|}{\sqrt{3}} = \frac{\sqrt{0.14^2 + 0.38^2 + 0^2}}{\sqrt{3}} = 0.23$$

There was a 49% improvement in the GP index when the Quality subject deficit was corrected. Corrective actions in other dimensions did not generate as meaningful improvement. For example, corrective action performance in level 4 (see Figure 7) control packages that belong to the Flowers and Grass subjects will increase the yield value of the subjects. However, since the original values were greater than the threshold value, δ_k of the subjects, the yield value of the Garden subject remained unchanged, as did all project dimensions. The data presented in Table 9 serves as a managerial report. It points out which CWP needs to be revised. Computerizing the MPCS implementation methodology will include Table 9 as a printout.

7. Summary and conclusions

A new methodology called the MPCS, has been presented which integrates all known dimensions of the project giving appropriate weightings to each. The MPCS uses a control tool, the GPCS, which determines control specifications by defining control tasks through the project life cycle.

The use of MPCS presents the project performance in all of its dimensions of operation. There is no averaging of the various operations. Accordingly, the system will be able to draw attention to poor performance in a certain dimension, and the Project Manager will be able to understand the extent of its influence on achieving the project objectives.

The MPCS methodology presents an innovative concept that integrates definition of GPCS control specifications with a computational process that presents the status of each dimension in terms of yield.

MPCS is implemented using a procedure based on the GPCS hierarchical structure.

The presentation of control system status focuses management's attention to the power and the direction of corrective actions that must be performed in order for performance to be identical to planning.

A computerized system supporting the MPCS methodology is planned to be develop as a friendly managerial tool.

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C. Using DEA to compare projects efficiency in a MPCS environment

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Using DEA to compare projects efficiency in a MPCS environment

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Abstract

The progression of several projects in parallel is a common situation in organizations, therefore a comparison of the various project performances is required. It is proposed that a comparison process be performed using the data envelope analysis (DEA) approach together with the MPCS (Multidimensional Project Control System) which provides control of individual project. The reference points for examining the performances of different projects and the directions of improvement for the projects are not necessarily found on the efficiency frontier. An algorithm is developed for applying multi-project system control having a relatively large number of inputs and outputs while maintaining the validity of the DEA methodology.

Keywords

Project Management, Control, DEA

1. Introduction

Project control systems indicate deviations from agreed project specifications. For Figure 1 shows the gap between the planned and actual variables, and narrowing this gap may be accomplished by one of the following alternatives:
(a) Define corrective actions to achieve the desired results according to the original plan (moving from B to A in figure 1) ; (b) Define adjusting activities , changing planned variables to actual performed results (moving from A to B in figure 1).

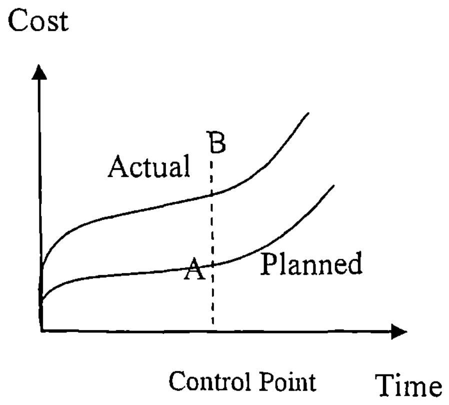

Figure 1. The gap between planned and actual values of a given variable

Mayor (1999), Meredith et. al. (2000) , Shtub, et. al. (1996) PMBok (2000), and project management practitioners suggest that each project should strive to achieve the following aims: (a) be on time , (b) be within budget, and (c) satisfy the customers technical and/or performance standards.
PMBoK (2000) defines nine categories that exist throughout the project lifecycle: Project Integration Management, Project Scope Management, Project Time Management, Project Cost Management, Project Quality Management, Project Human Resource, Management, Project Communications Management, Project Risk Management and Project Procurement Management
Although these categories are integrated into the project lifecycle, they have separate control systems which are implemented at each project phase.

Correct planning relies on techniques that support all categories. The Work Breakdown Structure (WBS) via cost identification defines the hierarchical organization of work in terms of supply to the customer – production, services and information,. Critical to accurate planning, WBS is a useful tool during performance when project control equates planning vs. actual performance. The typical project control system is not an integrative system that incorporates all project categories but performs control in that specific category (such as, quality control, engineering content control, etc). The methodology that effectively integrates two categories is the Earned Value (EV).

Integrated cost and scheduled control systems were introduced in the USA during the sixties and were mainly used in defense projects. These systems created standards supported by guidelines such as DoD 7000.2 (1997). Rozenes Vitner and Spraggett (2003) introduce another control methodology called MPCS (Multidimensional Project Control System).The MPCS is a quantitative approach for quantifying deviations from the planning phase to the execution phase with respect to the global project control specification (GPCS). The GPCS specifications provide an integrative solution for all project categories; it is hierarchically constructed and contains all control operations that are performed during the project life cycle. The first level in the hierarchy includes all indexed dimensions in the project which are defined as categories. Each category incorporates various subjects situated on the lower hierarchical levels. Each subject may contain additional subtopics. The lowest level in each subject contains control packages that include a set of control tasks that it must perform and are similar to the work packages in WBS.

Figure 2 displays a typical GPCS structure that contains 3 control dimensions (or, categories): "Technical/ Functional"" Operational" and "Quality". Each category contains various control subjects.

The "Technical / Functional" category includes the technical data needed to produce the project. It may include the following subjects: functional flow analysis, integrated test planning, data management plans, configuration management plans, system safety, human factors analysis, value engineering studies and life cycle cost analysis.

The "Operational" category contains the project operating system, as well as the project flow process and priorities determination. It may include the following: preliminary requirements, system/cost analysis, effectiveness analysis, synthesis, logistics support analysis, technical performance measurement planning, engineering integration, preliminary manufacturing plans and manpower requirements/personnel analysis.

The "Quality" category defines project quality requirements. Among the subjects included are the following: requests for contractors ISO 9000 certification, requests for contractors ISO 14000 certification, application of statistical process control (if needed), quality cost systems, and quality measures

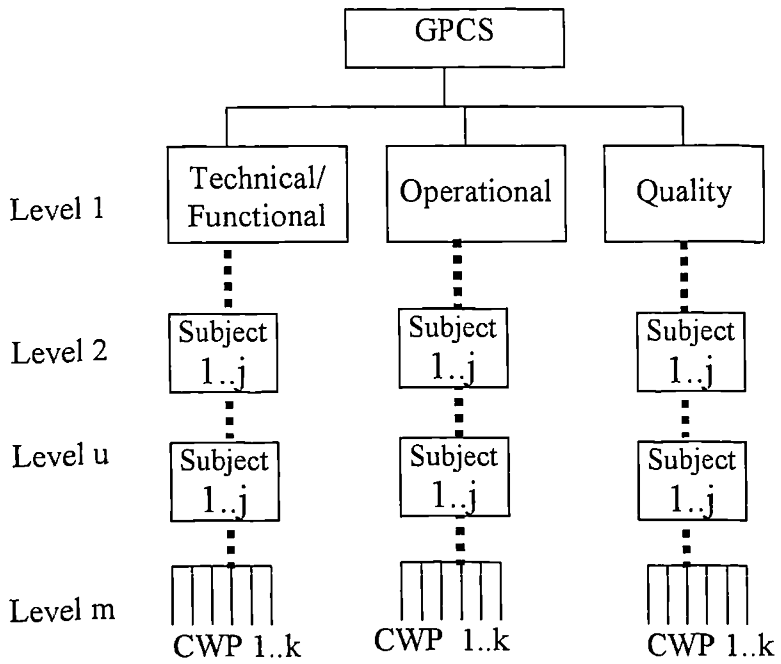

Figure 2. Global Project Control Specifications Structure

The MPCS aims at minimizing the gap between planning and results, and uses the GPCS's control specifications, as illustrated in Figure 2. The GPCS defines control assignments during the course of the project's life. The logic of the GPCS methodology creates the need for a measuring method to be used with various categories and various related units of measurement. A useful measuring tool has been the yield concept. Should there be a gap between planning and performance, a warning is indicated by the system in order to take corrective action. This comparison process is conducted while measuring actual performance using the yield index. The MPCS's output constitutes the category yield's for all categories included in the

GPCS specifications. Since the GPCS is hierarchically constructed, the yield's computation process is aggregative commencing at the lowest level (control work packages level) up to level 1 (category level) through the subject level. The subject level yield computation input is based on performance in the control packages level. The categories yields computation input is based on the subjects' performance. The project's management, taking into account that the leading consideration is the required control sensitivity measure, defines the minimal acceptable measure of these levels in the various subjects. These levels are designed to detect unreasonable digression. A reasonable digression is one in which subject j's performance, in yield terms, is higher than the defined performance level. In case of an unreasonable digression the project's team will be asked to take corrective measures.

2. The data envelope analysis (DEA)

The data envelope analysis (DEA) is a mathematical programming approach which assess the comparative efficiency of a set of decision making units (DMU), such as banks, hospitals, factories, universities etc, where the presence of multiple inputs and outputs makes comparison difficult. Charnes et al. (1978) first introduced the DEA concept and many articles have appeared that deal with the various types of implementations (e.g. Friedman et al. (1998), Park et al (2000) , Cook et al. (2000), Maital et al.(2001)). Thamassoulis (2001) introduced a DEA comprehensive explanation that elaborates DEA foundations and applications. The DEA is a non-parametric approach that allows efficiency to be measured without any assumptions regarding the functional form of the production function or the weights for the different inputs and outputs chosen. The DEA defines best practice efficiency frontier that can be used.

Charnes et al. (1978) recognized the difficulty in seeking a common set of weights to determine relative efficiency. They proposed that each DMU should be allowed to adopt a set of weights, which shows it in the most favorable light in comparison to the other DMUs. They used the following formulation: the efficiency of a decision-making unit (DMU) j incorporated multiple inputs and outputs denoted in equation 1; the efficiency of a DMU j is defined as weighted sum of its m outputs divided by a weighted sum of its n inputs.

(1) $$\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

subject to:

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad j = 1,\dots n,$$

$$u_r, v_i \geq 0 \qquad r = 1,\dots,m.$$

3. Using DEA methodology to evaluate project performance efficiency

Several projects performed in parallel and at varying stages of their respective life cycles occur fairly frequently in industry. The MPCS methodology is designed for the multi-dimensional control of single projects and it is not suitable for the control of several projects in parallel. However, the comparative process for the performances of several projects each controlled by the MPCS system can be accomplished through the use of the DEA methodology. Each project presents its performance at specific control points through the yield indices of the MPCS methodology while the DEA enables the examination of performances of each project based on these indices. Furthermore, the two control methods, the EV and MPCS method, can be used in independently for each project.

Operating several projects in parallel using the MPCS methodology requires GPCS standardization similar to the WBS standardization. The standardization means that the two higher levels in the GPCS structure are identical in each project that is managed and controlled in the organization. The creation of this standardization also contributes to the improvement of the organizational learning process whilst creating a comparative tool for projects in progress and those that took place in the past. Using the GPCS standardization enables the DEA comparison process.

In the MPCS methodology the outputs represent the totality of dimensions by which the project is measured. The outputs are the yield calculations of the different categories. Their number derives from the control system planning process that uses GPCS. In the EV method the system outputs are the control indices of the earned value that present the schedule deviation and cost deviation. This combination will usually make the characteristic systematical project controlled by the two methods include many outputs.

The DEA evaluation is constrained by the total number of inputs and outputs. In general, the following rule of thumb (see Friedman et al. 1998 and Jenkins 2003)) is used: the sum of input and outputs types should not exceed one third of the number of decision-making units (DMU). There are cases that the total number of projects executing in parallel are relatively small. However, the number of inputs and outputs are relatively high because of these projects nature. Therefore there is a need for a reducing inputs and outputs methodology.

A 3-stage methodology was developed, which adjusts the total number of outputs and inputs to meet the rule of thumb while also representing the necessary information.

Stage 1: Inputs / Outputs Definition

When implementing the DEA in conjunction with the MPCS methodology, it is essential to create a standardized frame for project control on all projects involved in a given organization.

This procedure allows uniformity of reporting on all projects in the organization to enable comparisons to be made.

Inputs definition

The input data characterize the different projects of the organization and generally includes the following:

Cost

The total cost of the project is derived from the total costs of the cost breakdown structure (CBS) of the project. The cost as an input variable represents the budgetary importance of the project in the process of comparing different projects.

Work content

The total hours allocated for the project including the planning stage. This input represents the investment of resources required for the project. A large gap between the Work Content cost and the total project cost represents an indication for the characteristics of the project, for example the existing purchase percentage in the project.

Level of monitoring

Control and follow up level required for performing the project. The higher the complexity of the project is the higher the value given on a scale of 0-10. Therefore this number indicates the complexity of a project is complicated comparing with all the other projects of the organization.

Level of uncertainty

The level of uncertainty existing in the project is measured on a scale of 0-10. The higher the value, the higher is the uncertainty level. In high tech projects this number indicates the level of using advanced technology.

Output definition

The project control system combines the EV system with the MPCS system, therefore the outputs of the system include the total output of both systems. The EV outputs are Schedule Index (SI) and also Cost Index (CI). These outputs are relative and will therefore have the same numerical level as the MPCS system outputs used for comparison between the systems. The MPCS outputs are defined at the planning stage through the GPCS and result from the Yield of each GPCS category. These outputs are Yield category1, Yield category 2 up to Yield category n.

Stage 2: Grouping algorithm

When only a few projects are involved, a problem may occur when the definition of outputs and inputs at stage 1 results in a relatively large number of inputs and outputs. In order to maintain the rule of thumb for such a case the number of outputs and inputs should be reduced while maintaining their information. The algorithm consolidates the different inputs and different outputs to a reduced number to meet the rule of thumb. The 3-step algorithm contains the following:

a. Inputs correlations and outputs correlations computation.

Stage 'a' includes the examination of correlation between the different inputs and outputs. The correlation results are presented in the following matrixes:

Matrix [RI ij] contains input correlations. It presents the correlation ratio between input j and i. Matrix [RO ij] contains outputs correlations. It presents the correlation ratio between output i and output j.

b. Grouping process

The grouping process leads to the creation of inputs and outputs groups. When the similarity level among these groups is high, it is possible to consolidate them in order to perform comparison without significant loss of information.

Heragu (1997) describes a similarity coefficient (SC) algorithm that is used as a grouping process.

The calculation of the similarity coefficient is based on the results of correlation calculations that were calculated at the previous stage. In order to create suitable statistic reliability, each correlation result that is lower or equal to 0.8 is defined as being insufficient, therefore the value of the similarity coefficient is defined as 0. SCOij is the output similarity coefficient for output pair ij as expressed in equation 2.

$$(2) \qquad SCO_{ij} = \begin{cases} 0 & \text{If } RO_{ij} \leq 0.8 \\ RO_{ij} & \text{Otherwise} \end{cases} \qquad \forall ij$$

Each case where $RO_{ij} \geq 0.8$ reduces at least one output.

The similarity among the different inputs is examined in a similar way. SCIij is the inputs similarity coefficient for input pair ij as expressed in equation 3.

$$(3) \qquad SCI_{ij} = \begin{cases} 0 & \text{If } RI_{ij} \leq 0.8 \\ RI_{ij} & \text{Otherwise} \end{cases} \qquad \forall ij$$

Using the SC algorithm results in inputs and of outputs groups with similar characteristics.

c. Selecting output / input representative

The third stage in the grouping algorithm is to find the output or input that represents the group of common outputs or inputs that were defined at stage 'b', i.e.: one input or output should represent each group in the DEA algorithm.

The decision criterion on the input or output representative is based on the highest average similarity coefficient for each output and for each input.

The selecting process of the output representative is based on choosing the maximum value of the average output similarity coefficients. An average is computed between each output i and the other outputs. This rule is expressed by equation 4:

$$(4) \qquad Max \left\{ \sum_{j=1}^{J} \frac{SCO_{ij}}{J} \right\} \qquad \forall i$$

The selecting process of the input representative is based on choosing the maximum value of the average input similarity coefficients. An average is computed between each input i and the other inputs. This rule is expressed in equation 5:

$$(5) \qquad Max \left\{ \sum_{j=1}^{J} \frac{SCI_{ij}}{J} \right\} \qquad \forall i$$

Stage 3: Implementing sequential DEA

Braglia et. al. (1999) presented a DEA algorithm for reducing the number of outputs and thus increases the discriminatory power of DEA. This algorithm is called sequential DEA. This algorithm includes several DEA computations based on identical input data and different output data. A summarizing process is executed containing the same output data and the input data is the DEA results of the previous DEA computations. Stage 3 also uses the sequential DEA.

The output of stage 3 represents the comparison among the different project performances and shows which project is on the efficiency frontier graph and those project that are not (i.e., having relative poor performances). This comparison provides the opportunity of determining whether the performance for the project is relatively similar to the performances of all the projects.

4. Computational example

The following computational example is based on a data from of a typical Hi-Tech company managing 11 projects in parallel. These projects contain hardware, software, integration and testing elements.

Figure 3 includes the principal presentation of the GPCS structure of all the projects found in the organization. The lower levels of each project GPCS are different in accordance with the requirements of the different projects.

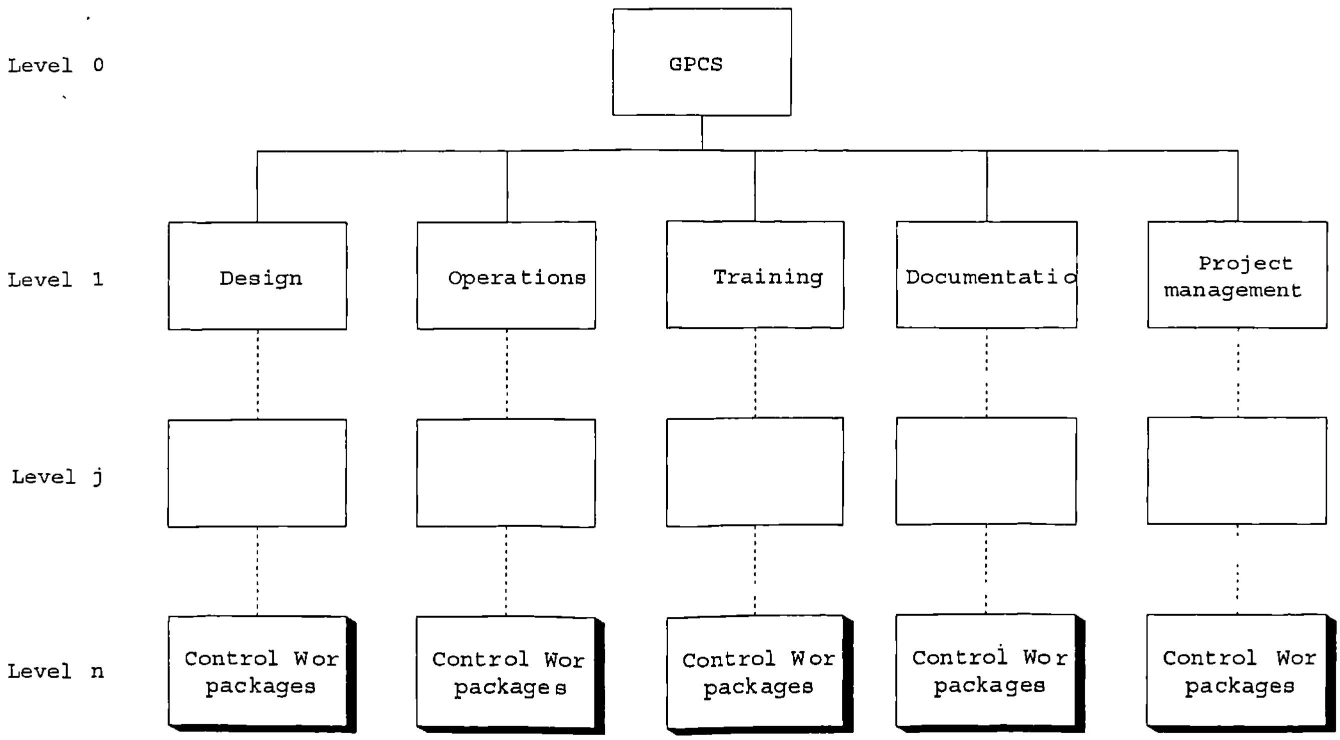

Figure 3. GPCS frame work

The uniformity described in Figure 3 defines the GPCS standardization in the organization. The upper two GPCS levels are identical and the lower levels are dependent upon each specific project. The GPCS standardization enables the DEA comparison process.

Stage 1: Inputs / Outputs Definition

Projects inputs are previously defined by the organization management according to each project characteristics and are given in table 1. For example project 3 is a medium size project with total budget of 800,000 £. The project contains 15,000 working hours; the level of monitoring required is 7 out of 10. Project 3 is a high risk project ranked 8 out of 10.

Table 1.Inputs definition

Input / Project	Cost (K£)	Work Content (00 hours)	Level of Monitoring	Level of Uncertainty
1	1500	300	6	6
2	100	50	7	6
3	800	150	7	8
4	1500	300	6	7
5	255	90	4	4
6	350	100	9	7
7	600	150	9	9
8	80	24	5	5
9	900	175	7	8
10	2000	400	8	9
11	75	40	7	6

The origination operates both MPCS and EV control systems. Table 22 contains the outputs which are direct derivatives of the MPCS methodology using GPCS structure illustrated in Figure 3: design yield, operations yield, training yield, documentation yield, project management yield.

The other outputs presented in Table 2 are the EV system outputs: the scheduling index (SI) and the cost index (CI).

Table 2.Outputs definition

Output / Project	MPCS					EV	
	Design Yield	Operations Yield	Training Yield	Documentation Yield	Project Management Yield	SI	CI
1	0.67	0	0.5	0.75	0.54	0.5	0.6
2	0.286	0	0.25	0.333	0.25	0.55	1.1
3	0.8	0.9	0.75	0.8	0.95	0.45	0.85
4	0.2	0.55	0.2	0.45	0.35	0.3	1.2
5	0.45	0.35	0.35	0.45	0.45	0.45	0.4
6	0.55	0.3	0.65	0.45	0.45	0.45	0.6
7	0.3	0.45	0.6	0.6	0.5	0.45	0.65
8	1	1	1	1	1	0.9	1.2
9	0.55	0.66	0.75	0.7	0.68	0.55	0.9
10	0.7	0.65	0.72	0.9	0.5	0.95	1
11	0.55	0.35	0.5	0.25	0.35	0.65	0.3

Table 22 shows that project 3 is not performing well according to the time and cost measurements (SI = 0.45, CI= 0.85) .The MPCS performances reveal gaps between the planning and the execution mainly in the: Training category (0.75); Design category (0.8); and Documentation category (0.8). Project 8 has perfect MPCS performances, i.e., 1 within every category. The EV measures are better than project 3 (SI = 0.9, CI= 1.2)

Stage 2: Grouping algorithm

a. Inputs correlations and outputs correlations computation.

At stage 'a' correlation examination are performed among the different inputs and outputs.

Matrices RO_{ij} and RI_{ij} is given in Table 3 and Table 4 respectively.

	1	2	3	4	5	6	7
1	1	0.56	0.84	0.75	0.82	0.65	0.08
2	0.56	1	0.70	0.64	0.79	0.37	0.42
3	0.84	0.70	1	0.77	0.83	0.61	0.14
4	0.75	0.64	0.77	1	0.81	0.55	0.44
5	0.82	0.79	0.83	0.81	1	0.32	0.27
6	0.65	0.37	0.61	0.55	0.32	1	0.24
7	0.08	0.42	0.14	0.44	0.27	0.24	1

Table 4. RI_{ij} **Correlation matrix**

	1	2	3	4
1	1	0.99	0.14	0.54
2	0.99	1	0.16	0.53
3	0.14	0.16	1	0.80
4	0.54	0.53	0.80	1

b. Grouping process

At stage 'b' the adjustment of the correlation calculation results are performed as shown in Tables 3-4 which present the similarity coefficients of both the outputs and the inputs.

The outputs and inputs similarity coefficients SCOij and SCIij are given in Table 5 and Table 6 respectively.

Table 5. Outputs similarity coefficients

	1	2	3	4	5	6	7
1	1	0	0.84	0	0.82	0	0
2	0	1	0	0	0	0	0
3	0.84	0	1	0	0.83	0	0

4	0	0	0	1	0.81	0	0
5	0.82	0	0.83	0.81	1	0	0
6	0	0	0	0	0	1	0
7	0	0	0	0	0	0	1

Table 6. Inputs similarity coefficients

	1	**2**	**3**	**4**
1	1	0.99	0	0
2	0.99	1	0	0
3	0	0	1	0
4	0	0	0	1

Based on the correlation promoters presented in Tables 6-7, the created groups can be presented.

Output groups and input groups are given in Table 7 and 8 respectively.

Table 7. Outputs groups

	Outputs
Group 1	1,3,4,5
Group 2	2
Group 3	6
Group 4	7

Table 8. Inputs groups

	Inputs
Group 1	1,2
Group 2	3
Group 3	4

c. Selecting output / input representative

The selection of the output or input representative is performed according to the criterion of maximization of the similarity coefficient average of the output within the group. For this case group number 1 which includes the outputs 1,3,4,5 will be discussed.

Table 9 contains computational results using equation 2.

It can be seen for example that the similarity coefficient value of output 1 is 0 in the relation between it and output 4 and in the two other cases its value is higher than 0.8. The similarity coefficient average of output 1 is 0.55. On the other hand, the average of output 3 is higher with a value of 0.83, therefore output 3 is the representative of group 1.

Table 9. Selecting group 1 output representative

Output 1	SCO_{ij}
1-3	0.84
1-4	0
1-5	0.82
Average	0.55

Output 3	SCO_{ij}
3-1	0.84
3-5	0.83
3-4	0.81
Average	0.83 *

Output 4	SCO_{ij}
4-1	0
4-3	0.83
4-5	0.81
Average	0.54

Output 5	SCO_{ij}
5-1	0.82
5-3	0.83
5-4	0.81
Average	0.82

Dealing with the inputs in this example is less complex since only one group includes more than one input and in this specific case there are only two inputs. Hence, the choice between them can be arbitrary, i.e., let input 1 be the representative of group 1.

Stage 3: Implementing sequential DEA

The application of Sequential DEA is performed when the procedure inputs are identical and the outputs vary. A Sequential DEA is performed in a 3-stage process as follows:

a. Performing DEA with MPCS outputs

The DEA is performed on the MPCS outputs results are given in Table 30, resulting in the DEA score is given in the last column.

Table 30. MPCS Efficiencv Score

	Inputs			MPCS Outputs		DEA Score
Input / Project	Work Content	Level of Monitoring	Level of Uncertainty	Design Yield	Operations Yield	
1	300	6	6	0.67	0	0.5583
2	50	7	6	0.29	0	0.2383
3	150	7	8	0.80	0.9	0.6429
4	300	6	7	0.20	0.55	0.4583
5	90	4	4	0.45	0.35	0.5625
6	100	9	7	0.55	0.30	0.3929
7	150	9	9	0.30	0.45	0.2500
8	24	5	5	1	1	1
9	175	7	8	0.55	0.66	0.4714
10	400	8	9	0.7	0.65	0.4375
11	40	7	6	0.55	0.35	0.5867

b. Performing DEA with EV outputs

Using the same inputs the EV output results are given in Table 11

Table 11. MPCS Efficiency Score

Output / Project	Inputs			EV Outputs		DEA Score
	Work Content	Level of Monitoring	Level of Uncertainty	SI	CI	
1	300	6	6	0.50	0.60	0.4630
2	50	7	6	0.55	1.10	0.7639
3	150	7	8	0.45	0.85	0.4427
4	300	6	7	0.30	1.20	0.7143
5	90	4	4	0.45	0.40	0.6250
6	100	9	7	0.45	0.60	0.3571
7	150	9	9	0.45	0.65	0.3009
8	24	5	5	0.90	1.20	1
9	175	7	8	0.55	0.90	0.4687
10	400	8	9	0.95	1	0.5864
11	40	7	6	0.65	0.30	0.7704

c. Performing DEA integrating stages a, b results

The outputs in the final stage are the combined results of the MPCS efficiency scores and the EV efficiency scores using the same inputs as given in Table 12.

Table 12 Integrated score

Project	Inputs			Outputs		DEA Score
	Work Content	Level of Monitoring	Level of Uncertainty	MPCS Efficiency	EV Efficiency	
1	300	6	6	0.5583	0.4630	0.4652
2	50	7	6	0.2383	0.7639	0.6366
3	150	7	8	0.6429	0.4427	0.4018
4	300	6	7	0.4583	0.7143	0.5102
5	90	4	4	0.5625	0.6250	0.7812
6	100	9	7	0.3929	0.3571	0.2806
7	150	9	9	0.2500	0.3009	0.1672
8	24	5	5	1	1	1
9	175	7	8	0.4714	0.4687	0.2945
10	400	8	9	0.4375	0.5864	0.3258
11	40	7	6	0.5867	0.7704	0.8218

It can be seen that project 8 is on the efficiency frontier, though it is a relatively low budget project. High budgeted projects like projects 10, 1 and 4, should improve their performances to achieve better efficiency.

Projects 6 and 7 present relatively low performance levels compared to the other projects both in the output of the MPCS system and in the EV outputs. Many projects are far from the efficiency frontier, therefore systematical examination are needed in order to achieve improvements.

5. Summary and conclusions.

The MPCS system described in the article by Rozenes, Vitner, Spragett (2003) represents a project control system, which examines the performances of a single project using a large number of dimensions. The infrastructure of the system is the GPCS control specifications through which the project performances are examined in comparison with the original planning. The results of the examination are calculated with the help of yield indexes that are calculated with aggregation. The result of the MPCS system presents the power and direction of the gap between the plans and performance. The MPCS system performs the control of each project individualy .The DEA methodology allows the comparison among different projects operating in parallel at different stages of their life cycles. The performance of the DEA comparison is possible following the standardization in the GPCS definition of the different projects. It is based on the uniform definition of the two higher levels in each GPCS of the different projects. Comparisons are performed on the combined control system, which includes two complementary control systems, the MPCS and the traditional EV system. When only a few projects are in progress the DEA methodology requires the building of an algorithm that provides the same information through a smaller number of inputs and outputs. The DEA output allows the diagnosis of those found on the efficiency frontier and those projects that need improvement.

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D. MPCS: Multidimensional Project Control System

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MPCS: Multidimensional Project Control System

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Introduction

"A project" is defined by PMBoK [1] as "a temporary endeavor undertaken, to create a unique product or service". Temporary means that every project has a definite beginning and a definite end. Unique means that the product or service is different in some distinguishing way from all similar products or services. Typically, projects utilise a control system, which monitors the difference or gap between the planning variables and the actual performed results.
Project control systems indicate the direction of change in preliminary planning variables compared with actual performance. Shtub et. al.[2], suggest that the design of a project control system is an important part of the project management effort. A control system is based on a set of project goals and their relative importance. For each goal, at least one performance measure is required. There is overall agreement between project management researchers, (Lock [3] and Nicholas [4]), and project management practitioners that each project should strive to achieve the following objectives: (a) be on time, (b) be within its cost budgets,(c) satisfy customer technical or performance standards. Objective (c) combines and encompasses various dimensional measures from different disciplines, e.g. quality, operational, technical, etc. Control systems may consist of one variable, two variables (principally time and cost), or more. Integrated cost and scheduled control systems were introduced in the USA during the sixties and were mainly used in defense projects. These systems created standards supported by guidelines such as DoD 7000.2 [5]. Abba [6] describes the development process of an integrated project control system in the US Department of Defense (DoD).

Multidimensional Project Control System (MPCS)

Earned Value (EV) is the classical project control method used for monitoring two dimensions: time and cost. This concept is based on the work breakdown structure (WBS) planning tool.
The proposed MPCS methodology uses a multidimensional control system which assists in controlling projects. Project management methodologies are used in two phases of the project life cycle: the planning phase and the execution and control phase. The WBS is the classic method used at the planning stage. However, the Global Project Control Specifications (GPCS) replaces the WBS during the execution and control phases when the MPCS methodology is used in preference to the EV approach.
The differences between the two methodologies (EV and MPCS) are exemplified by using the structures illustrated in figures 1 and 2. Figure 1a illustrates a classical structure of a project using the EV methodology. It shows two types of tasks. Work packages (WP) and control work packages (CWP) determine task content and control content respectively. Note that activities of both phases (planning, control) are present in one structure.
Figure 1b presents the planning phase and Figure 1c represents the execution and control phase. When implementing the MPCS methodology, each phase has its unique structure.

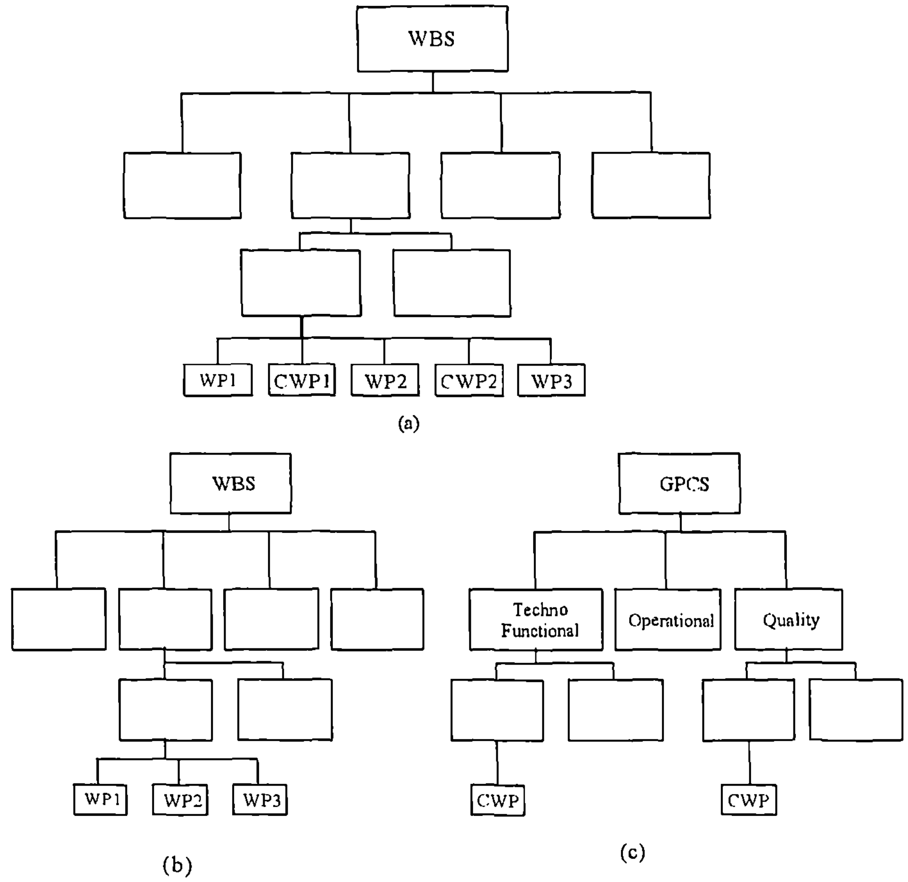

Figure 1 MPCS methodology structure

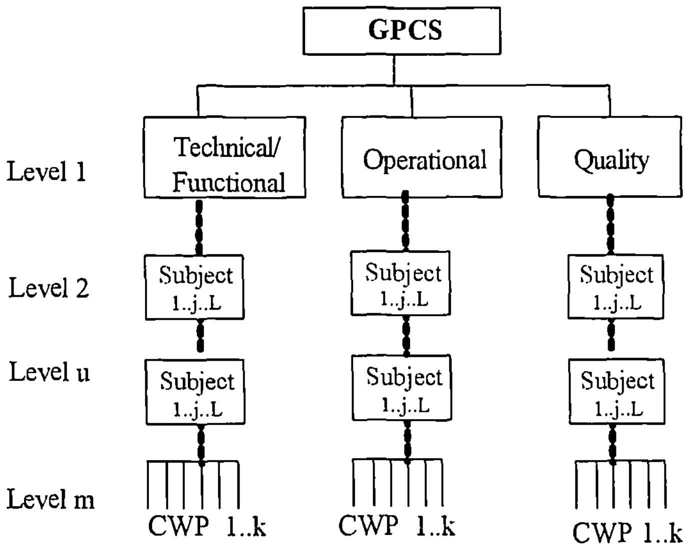

Figure 2 Global Project Control Specifications

Figure 2 illustrates a typical GPCS structure (based on Figure 1c). It presents the detailed control activities throughout the execution phase.

Level 1 defines the various control dimensions / categories, noting, there is no limit to the number of dimensions that may be used. Typical categories are quality, operational characteristics etc. The type and number of dimensions depend on the nature of the project. Each category presented in level 1 may have subcategories in level 2 to level m. These subcategories are denoted as subjects. The lowest level of any category defines the related control work package (CWP).

The Technical / Functional category includes technical data needed to produce the project. It may include for example the following topics: functional flow analysis, integrated test planning, data management plans, configuration management plans, system safety, human factors analysis, value engineering studies and life cycle cost analysis.

The Operational category contains project operating systems. It also contains project flow process and priorities determination. It may include for example the following: preliminary requirements, system/cost analysis, effectiveness analysis, synthesis, logistics support analysis, technical performance measurement planning, engineering integration, preliminary manufacturing plans and manpower requirements/personnel analysis.

The Quality category defines project quality requirements and may include the following: requests for contractors ISO 9000 certification, requests for contractors ISO 14000 certification, application of statistical process control , quality cost systems, and quality measures.

The logic of the GPCS methodology creates the need for a measuring method to be used with various categories and various related units of measurement. A useful measuring tool has been the yield concept. We propose to utilize the yield concept as the measuring method for project categories. This is discussed below.

MPCS Principles

The control system aims at minimizing the gap between planning and results. The planning basis in the MPCS system constitutes the GPCS's control specification, as indicated in Figure 2. The GPCS defines control assignments during the course of the project's life. Should there be a gap between planning and performance, a warning is indicated by the system in order to take corrective action. This comparison process is conducted while measuring actual performance using the yield index.

The MPCS's output constitutes the category yield's vector presentation for all categories included in the GPCS specifications. Since the GPCS is hierarchically constructed, the yield's computation process is aggregative. Commencing at the lowest level, which is the control work packages level from subject j level up to level 1, which is the category level. The subject level yield (Y_{ij}) computation input is based on performance in the control packages level. The categories yields computation input is based on comparing the subjects' performance to predefined performance levels (CRj). The measure of these levels in the various subjects is defined by the project's management, taking into account that the leading consideration is the required control sensitivity measure. These levels are designed to detect unreasonable digression. A reasonable digression is one in which subject j's performance, in yield terms, is higher than the defined performance level. In case of an unreasonable digression the project's team will be asked to take corrective measures.

Subject yield

The various GPCS control packages are defined in the planning stage. The performance of each control package k is tested during the performance stage. If performed is as planned, then $\delta_K = 1$, otherwise, $\delta_K = 0$. An identical weight assigned to each control work package k, out of M control work packages, related to subject j out of L subjects.

$$Y_{ij} = \frac{\sum_{k=1}^{M} \delta_k}{M} \quad \forall ij \tag{1}$$

Where:

$$\delta_k = \begin{cases} 1 & \text{If CWP k is successfully performed} \\ 0 & \text{Otherwise} \end{cases}$$

When the index Y_{ij}, is not equal to 1, it means that there are differences between planning and performance.

Category yield

When the subject's yield Y_{ij} . equals or exceeds the threshold value defined by the project administration, then subject's performance is defined as successful. i.e., $\theta_j = 1$. The closer CR_j is to 1, the higher control sensitivity will be, indicating that the project is responding to specification requirements. The GPCS structure includes N categories and each category has L subjects.

Due to the GPCS's structure, the categories are independent of each other. However their importance and contribution to the success of the project's performance are not identical. For example, the subject "configuration management" in a software project is more important than the subject "value engineering studies". Therefore, subject weight is determined according to its position in the GPCS specification based on King's algorithm [7]. Equation (2) presents the yield computation of category i.

(2)
$$Y_i = \frac{\sum_{j=1}^{L} \theta_j 2^{L-j}}{\sum_{j=1}^{L} 2^{j-1}} \quad \forall i$$

Where:

$$\theta j = \begin{cases} 1 & \text{If Yij = CRj} \\ 0 & \text{Otherwise} \end{cases}$$

Vectorial presentation

Based on the lack of dependence between the GPCS's categories. the control system is formulated as an orthogonal vector system whose axes constitute the various categories. Nicholas [4] and Meredith et.al. [8] performed a similar use of an orthogonal presentation for representing the project's goals. Such a formulation of the control system enables the use of vector analysis's mathematical principles and tools. Employing the results of equation (2), vector $\bar{P}$ can be formulated as the actual performances of the various N categories in yield terms as in equation (3).

(3) $$\bar{P} = Y_1\hat{i} + Y_2\hat{j} + \cdots + Y_N\hat{n}$$

Where: $\hat{i}, \hat{j}, \ldots \hat{n}$ are unit vectors.

Vector, $\bar{P}$, shown in Figure 3a, represents a three-dimensional case of actual performance which is not compatible with planning. There is evidence of a gap existing between the planned and actual performance, represented by the $\bar{I}$ vector, where $Y_i = 1 \forall i = 1 \cdots N$.

The smaller the gap, the closer will vector, $\bar{I}$ be to vector, $\bar{P}$.

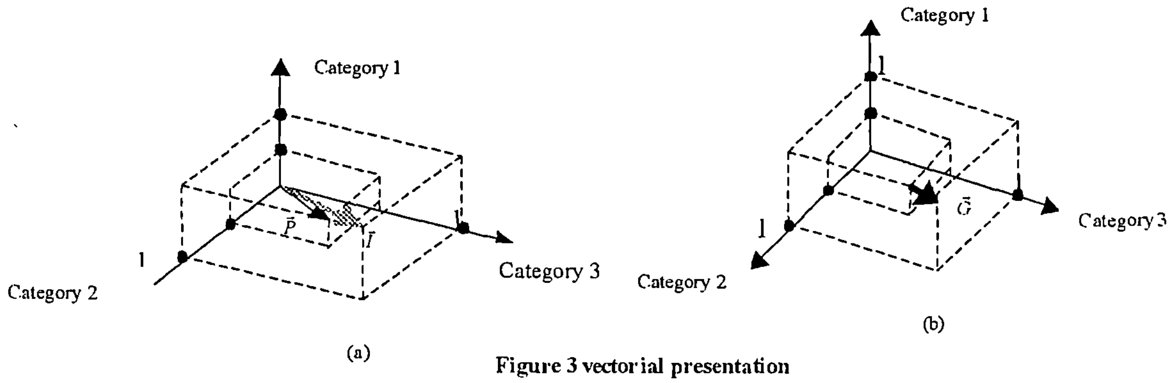

Figure 3 vectorial presentation

(4) $\bar{G} = \bar{I} - \bar{P}$

(5) $\bar{G} = (1 - Y_1)\hat{i} + (1 - Y_2)\hat{j} + \cdots + (1 - Y_N)\hat{n}$

The gap vector ($\bar{G}$) presented in Figure 3b is a managerial tool whose size and direction represent the effort required in taking corrective action, i.e., comparing planned to actual performance. The desired value for this vector is zero.

The MPCS system defines two types of indices. The first is a performance index Y_i for each dimension/category, and the second is the gap vector $\bar{G}$ which constitutes an inclusive index examining the entire array of the project's performance. The Gap Perfo rmance (GP) index presented in equation (6) serves as an additional inclusive index.

$$(6) \qquad GP = \frac{|\bar{G}|}{\sqrt{N}}$$

Where: N is the number of dimensions/categories

The Gap Performance (GP) index has a normalized value. The doser this value is to 0, the closer project performances are to planning, i.e., complete and full responsiveness to the requirements presented in the GPCS. The GP index is designed to be used by the manager, comparing the performance of a number of projects with the index representing performance on a 0-1 scale. Thus, planning performance can be compared with project performance within the project life cycle. This index can be easily computed with a spreadsheet so that the manager need not know vectorial analysis to derive these measures.

Summary and Conclusions

Typically, project specifications will be hierarchically structured, based on the WBS structure. Controlling a project is a highly complex activity and is currently achieved by using a number of independent systems. The EV methodology, although used internationally, only integrates the cost and the schedule. Hence, other dimensions such as quality, technology, operations etc. are not integrated into the system and consequently must be controlled using other systems.

The EV methodology is based on an integrative calculation of the WBS. Accordingly, there may be situations in which the control indices indicate a reasonable project status, but the actual situation will lead to non-compliance with the p roject goals.

A new methodology, MPCS, has been presented, which integrates all known dimensions of the project giving appropriate weights to each. The MPCS uses a control tool, the GPCS, which determines control specifications by defining control tasks through the project life cycle.

The use of MPCS presents the project performance in all of its dimensions of operation. There is no averaging of the various operations; accordingly, the system will be able to draw attention to poor performance in a certain dimension, and the Project Manager will be able to understand the extent of its influence on achieving the project objectives.

The computational example illustrates the advantage of the MPCS methodology over the classic EV methodology. It may be seen that the MPCS system draws attention to problems of integration whose cost is relatively low and whose advantage is relatively high in contrast to the EV system which does not provide such alerts to the senior management level.

The MPCS methodology presents an innovative concept that integrates definition of GPCS control specifications with a computational process that presents the status of each dimension in terms of yield and provides a vectorial representation of the entire system.

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E. Measuring efficiency of projects in SME organizations

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Measuring Efficiency of Projects in SME Organizations

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Abstract - Currently, project control systems often fail to support management in achieving their global project goals. A Multidimensional Project Control System (MPCS) deals with its the control of a single project and defines its performances in comparison with the plan. The progression of several projects in parallel is a common situation in organizations, therefore a comparison of the various project performances is required. It is proposed that a comparison process be performed using the Data Envelope Analysis (DEA) approach. The reference points for examining the performances of different projects and the directions of improvement for the projects are not necessarily found on the efficiency frontier. An algorithm is developed for applying multi-project system control in Small Manufacturing Enterprises (SME) organizations having a relatively large number of inputs and outputs while maintaining the validity of the DEA methodology.

Keywords: Data envelope analysis, Project control, Project management.

I. INTRODUCTION

Project control systems indicate deficiencies from agreed project specifications. It can be illustrated in Fig. 1 while shows the gap between the planned and actual variables. Narrowing this gap may be accomplished by one of the following alternatives:

(a) Define corrective actions to achieve the desired results according to the original plan (moving from B to A in Fig. 1);
(b) Define adjusting activities , changing planned variables to actual performed results (moving from A to B in Fig. 1).

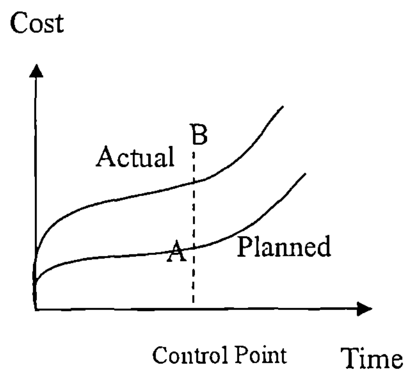

Fig. 1 The gap between planned and actual values of a given variable

Mayor[9] , Meredith et al.[10], Lock [7], Shtub, et al. [14] PMBok [12] , and project management practitioners suggest that each project should strive to achieve the following aims: (a) be on time , (b) be within budget, and (c) satisfy the customers technical and/or performance standards.

PMBoK [12] defines nine categories that exist throughout the project lifecycle: Project Integration Management, Project Scope Management, Project Time Management, Project Cost Management, Project Quality Management, Project Human Resource, Management, Project Communications Management, Project Risk Management, Project Procurement Management

Although these categories are integrated into the project lifecycle, their control systems, which are implemented in each project phase, are separate.

Correct planning relies on techniques that support all categories. The Work Breakdown Structure (WBS) defines the hierarchical organization of work by defining the work packages in terms of supply to the customer – production, services and information, through cost identification. Critical to accurate planning, WBS is a useful tool during performance when project control equates planning vs. actual performance. The typical project control system is not an integrative system that incorporates all project categories but performs control in that specific category. Such as, quality control, engineering content control, etc. The methodology that effectively integrates two categories is the Earned Value system (EV).

Integrated cost and scheduled control systems were introduced in the USA during the sixties and were mainly used in defense projects. These systems created standards supported by guidelines such as DoD 7000.2 [15].

Rozenes et al. [13] introduce another control methodology, Multidimensional Project Control System (MPCS). This methodology defines the control system planning process in which the control specifications (GPCS) are defined. GPCS specifications provide an integrative solution for all project categories. Hierarchically constructed, GPCS contains all control operations that are performed during the project life cycle. The first level in the hierarchy includes all indexed dimensions in the project, defined as categories. Each category incorporates various subjects situated on the lower hierarchical levels. Every subject can contain additional subtopics. The lowest level in each subject contains control packages that include a set of control tasks that it must perform, similar to the work packages in WBS.

Fig. 2 displays a typical GPCS structure that contains 3 control dimensions / categories: Technical/ Functional

Operational and Quality. Each category contains various control subjects.

The Technical / Functional category includes technical data needed to produce the project. It may include the following subjects: functional flow analysis, integrated test planning, data management plans, configuration management plans, system safety, human factors analysis, value engineering studies and life cycle cost analysis.

The Operational category contains project operating systems. It also contains project flow process and priorities determination. It may include the following: preliminary requirements, system/cost analysis, effectiveness analysis. synthesis, logistics support analysis, technical performance measurement planning, engineering integration, preliminary manufacturing plans and manpower requirements/personnel analysis.

The Quality category defines project quality requirements. Among the subjects included are the following: requests for contractors ISO 9000 certification, requests for contractors ISO 14000 certification, application of statistical process control (if needed), quality cost systems, and quality measures

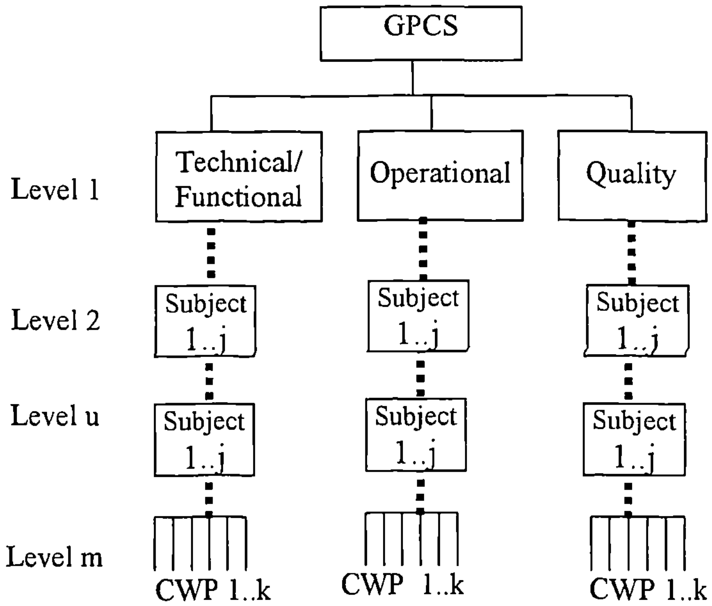

Fig. 2. Global Project Control Specifications Structure

The MPCS control system aims at minimizing the gap between planning and results. The planning basis in the MPCS system constitutes the GPCS's control specifications, as indicated in Fig. 2. The GPCS defines control assignments during the course of the project's life. Should there be a gap between planning and performance, a warning is indicated by the system in order to take corrective action. This comparison process is conducted while measuring actual performance using the yield index. The MPCS's output constitutes the category yield's for all categories included in the GPCS specifications. Since the GPCS is hierarchically constructed, the yield's computation process is aggregative. Commencing at the lowest level, which is the control work packages level from subject j level up to level 1, which is the category level. The subject level yield computation input is based on performance in the control packages level. The categories yields computation input is based on comparing the subjects' performance to predefined performance levels. The project's management, taking into account that the leading consideration is the required control sensitivity measure, defines the minimal acceptable measure of these levels in the various subjects. These levels are designed to detect unreasonable digression. A reasonable digression is one in which subject j's performance, in yield terms, is higher than the defined performance level. In case of an unreasonable digression the project's team will be asked to take corrective measures.

II. USING DEA METHODOLOGY TO EVALUATE PROJECT PERFORMANCE EFFICIENCY

The data envelope analysis (DEA) is a mathematical programming approach which assess the comparative efficiency of a set of decision making units (DMU), such as banks, hospitals, factories, universities etc, where the presence of multiple inputs and outputs makes comparison difficult. Charnes et al. [2] first introduced the DEA concept and many articles have appeared that deal with the various types of implementations (e.g. Friedman et al.[4], Park et al [11] , Cook et al.[3], Maital et al.[8]. The DEA is a non-parametric approach that allows efficiency to be measured without any assumptions regarding the functional form of the production function or the weights for the different inputs and outputs chosen.

In many Small Manufacturing Enterprises (SME) organizations several projects are performed in parallel which are found in varying stages of their life cycle. The MPCS methodology is designed for the multi-dimensional control of a single project and it is not suitable for several projects. The comparison process among the performances of several projects controlled by the MPCS system can be performed with the help of the DEA methodology. Each project presents its performances at specific control points through the yield indexes of the MPCS methodology while the DEA enables the examination of performances of each project found in the organization based on these indexes. Furthermore, the two control methods, the EV method and MPCS method, can be used in parallel and independently for each project in order to gain more control dimensions, i.e., time cost, operations, etc. This comparison process can take place since there is standardization of the different control specifications. i.e. the two higher levels in the GPCS structure are identical in each project that is managed and controlled in the organization. The creation of this standardization also contributes to the improvement of organizational learning process while creating a comparative tool for projects in progress and those that took place in the past. In the MPCS methodology the outputs represent the totality of dimensions in which the project is measured, examined and performed. The outputs are the yield calculations of the different categories. Their number derives from the control system planning process that uses GPCS. In the EV method the system outputs are the control indexes of the earned value that present the synchronization deviation and cost deviation. This combination will usually make the characteristic systematical project controlled by the two methods include many outputs.

Using DEA - CCR evaluation is constrained by the total number of inputs and outputs. Jenkins et al. [6] describe the following rule of thumb used: the sum of input and outputs types should not exceed one third of the number of decision-making units (DMU).

A 3-stage methodology was developed, which adjusts the total number of outputs and inputs to meet the rule of thumb while also representing the necessary information.

Stage 1: Inputs / Outputs Definition

When implementing the DEA in conjunction with the MPCS methodology, it is essential to create a standardized frame for project control on all projects involved in a given organization.

This procedure allows uniformity of reporting on all projects in the organization to enable their comparison and grading.

Inputs definition

The input data characterize the different projects of the organization:

Cost

The total cost of the project is derived from the total costs of the CBS of the project. The cost as an input variable represents the budgetary importance of the project in the process of comparing different projects.

Work content

The total hours allocated for the project including the planning stage. This input represents the investment of resources required for the project. A large gap between the Work Content cost and the total project cost represents an indication for the characteristics of the project, for example the existing purchase percentage in the project.

Level of monitoring

Control and follow up level required for performing the project. The higher the complexity of the project is measured on a scale of 0-10, the higher the power of follow up, therefore this number indicates the amount of how the project is complicated among the different projects of the organization.

Level of uncertainty

The level of uncertainty existing in the project is measured on a scale of 0-10. The higher the value, the higher the uncertainty level is. In high tech projects this number indicates the level of using advanced technology.

Output definition

The project control system combines the EV system with the MPCS system, therefore the outputs of the system include the total output of both systems. The EV outputs are Schedule Index – SI and also Cost Index – CI. These outputs are relative will therefore have the same numerical level as the MPCS system outputs used for comparison between the systems. The MPCS outputs are defined at the planning stage through the GPCS and result from the Yield of each GPCS category. Call these outputs are Yield category1, Yield category 2 and up to Yield category n.

Stage 2: Grouping algorithm

When only a few projects are in progress, a problem occurs when the definition of outputs and inputs at stage 1 leads to a relatively large number of inputs and outputs. In order to maintain the rule of thumb for such a case the number of outputs and inputs should be reduced while maintaining their information. The algorithm consolidates the different inputs and different outputs to a reduced number to meets the rule of thumb. The 3-step algorithm contains the following:

A. Inputs correlations and outputs correlations computation.

Stage 'a' includes the examination of correlation between the different inputs and outputs. The correlation results are presented in the following matrixes:

Matrix [RI ij] contains input correlations. It presents the correlation ratio between input input j and i. Matrix [RO ij] contains outputs correlations. It presents the correlation ratio between output i and output j.

B. Grouping process

The grouping process leads to the creation of inputs and outputs groups. When the similarity level among these groups is high, it is possible to consolidate them in order to perform comparison without significant loss of information.

Heragu [5] describes a similarity coefficient (SC) algorithm that is used as a grouping process.

The calculation of the similarity coefficient is based on the results of correlation calculations that were calculated at the previous stage. In order to create suitable statistic reliability, each correlation result that is low or equals to 0.8 is defined as being insufficient, therefore the value of the similarity coefficient is defined as 0. SCOij is the output similarity coefficient for output pair ij as expressed in (1).

$$(1) \quad SCO_{ij} = \begin{cases} 0 & \text{If } RO_{ij} \leq 0.8 \\ RO_{ij} & \text{Otherwise} \end{cases} \qquad \forall ij$$

Each case where $RO_{ij} \geq 0.8$, reduces at least one output.

The similarity among the different inputs is examined in a similar way. SCIij is the output similarity coefficient for input pair ij expressed in (2).

$$(2) \quad SCI_{ij} = \begin{cases} 0 & \text{If } RI_{ij} \leq 0.8 \\ RI_{ij} & \text{Otherwise} \end{cases} \qquad \forall ij$$

Using the SC algorithm results in inputs and of outputs groups with similar characteristics.

C. Selecting output / input representative

The third stage in the grouping algorithm is to find the output or input that represents the group of common outputs or inputs that were defined at stage B, i.e: one input or output should represent each group in the DEA algorithm.

The decision criterion on the input or output representative is based on the highest average similarity coefficient for each output and for each input.

The selecting process of the output representative in group i, is to use the rule expressed in (3):

$$(3) \quad Max \left\{\overline{SCO_{ij}}\right\} \qquad \forall i$$

The selection process of the input representative in group i, is using the rule expressed in (4):

$$(4) \quad Max \left\{\overline{SCI_{ij}}\right\} \qquad \forall i$$

Stage 3: Implementing sequential DE

Braglia et al. [1] presented a sequential DEA algorithm in to reduce the number of outputs and thus increase the discriminatory power of DEA.

This process includes several DEA runs based on identical input data and different output data and after a summarizing process that contains the same output data with the DEA results of the previous runs. Stage 3 also uses the sequential DEA.

The output of stage 3 represents the comparison among the different project performances and it shows which project is on the efficiency frontier graph and those project that do not (i.e., relative poor performances). This comparison provides the opportunity of determining whether the performance of the project is relatively similar to the performances of all the projects.

III. COMPUTATIONAL EXAMPLE

The computational example is based on a case of a typical MSE company which managing 9 projects in parallel. Their projects contain hardware, software, integration and testing elements.

Fig. 3 includes the principal presentation of the GPCS structure of all the projects found in the organization. The two higher levels are identical in each project. While the lower levels differ in accordance with the requirements of the different projects.

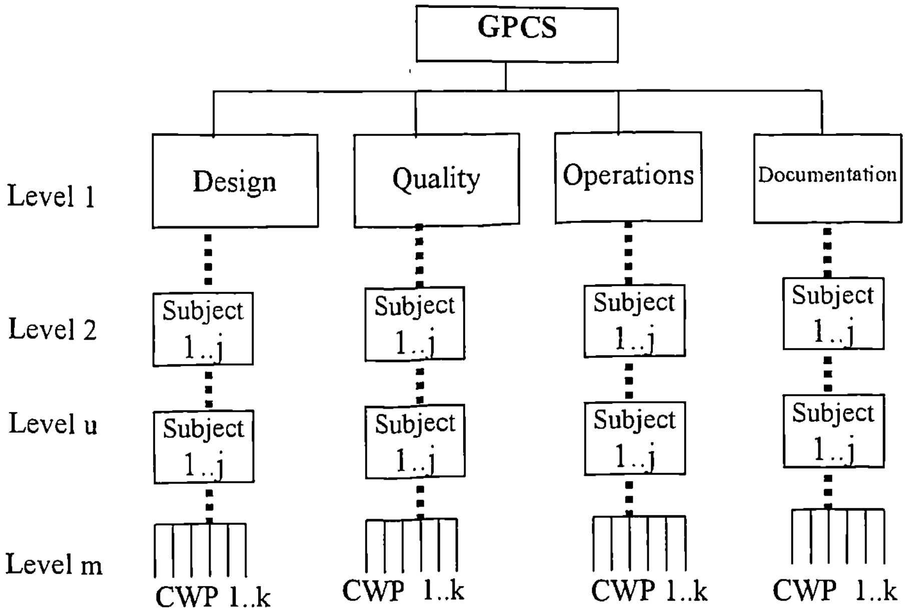

Fig. 3 GPCS frame work

The uniformity described in Figure 3 defines a homogeneous work standard in all the projects of the organization and allows the performance of comparison among the managerial performances of the different projects

Stage 1: Inputs / Outputs Definition

Projects inputs are previously defined and are given in table 1.

TABLE 1 INPUTS DEFINITION

Project \ Input	Cost	Work Content	Level of Monitoring	Level of Uncertainty
1	1000	400	8	8
2	800	300	7	6
3	700	175	6	6
4	1000	450	9	9
5	600	135	8	7
6	500	325	7	9
7	200	85	3	3
8	900	350	8	7
9	100	30	4	7

Table 2 contains the outputs which are direct derivatives of the MPCS methodology using GPCS structure illustrated in Fig. 2: design yield, quality yield, operations yield, documentation yield, project management yield.

Other outputs presented in Table no. 2 are the outputs of the EV system, i.e.: SI- Scheduling Index, CI- Cost Index

TABLE 2 OUTPUTS DEFINITION

	MPCS				EV	
Output / Project	Design Yield	Quality Yield	Operations Yield	Documentation Yield	SI	CI
1	0.75	0.65	0.78	0.8	0.35	0.4
2	0.54	0.45	0.62	0.6	0.8	0.9
3	0.84	0.69	0.75	0.8	0.75	1
4	0.68	0.65	0.65	0.59	0.88	1.2
5	0.49	0.48	0.3	0.34	0.4	0.35
6	0.55	0.57	0.62	0.65	0.5	0.5
7	0.9	0.75	0.85	0.78	1	1
8	0.67	0.71	0.68	0.59	0.78	0.88
9	0.82	0.75	0.76	0.87	0.8	0.7

Stage 2: Grouping algorithm

A. Inputs correlations and outputs correlations computation.

At stage 'a' correlation examination is performed among the different inputs and among the different outputs.

Matrices RO_{ij} and RI_{ij} is given in Table 3 and Table 4 respectively.

TABLE 3 RO_{ij} CORRELATION MATRIX

	1	2	3	4	5	6
1	1	0.89	0.85	0.83	0.51	0.42
2	0.89	1	0.76	0.71	0.47	0.37
3	0.85	0.76	1	0.92	0.5	0.44
4	0.83	0.71	0.92	1	0.3	0.22
5	0.51	0.47	0.5	0.3	1	0.9
6	0.42	0.37	0.44	0.22	0.9	1

TABLE 4 RI_{ij} CORRELATION MATRIX

	1	2	3	4
1	1	0.88	0.88	0.49
2	0.88	1	0.82	0.64
3	0.88	0.82	1	0.71
4	0.49	0.64	0.71	1

B. *Grouping process*

At stage 'b' the adjustment of the correlation calculation results is performed as shown in Tables 3-4 which presents the similarity coefficients of both the outputs and the inputs.

The outputs and inputs similarity coefficients SCOij and SCIij are given in table 5 and table 6 respectively.

TABLE 5 OUTPUTS SIMILARITY COEFFICIENTS

	1	2	3	4	5	6
1	1	0.89	0.85	0.83	0	0
2	0.89	1	0	0	0	0
3	0.85	0	1	0.92	0	0
4	0.83	0	0.92	1	0	0
5	0	0	0	0	1	0.9
6	0	0	0	0	0.9	1

TABLE 6 INPUTS SIMILARITY COEFFICIENTS

	1	2	3	4
1	1	0.88	0.88	0
2	0.88	1	0.82	0
3	0.88	0.82	1	0
4	0.49	0	0	1

Based on the correlation promoters presented in Tables 6-7, the created groups can be presented. Output groups and input groups are given in table 7.

TABLE 7 INPUT / OUTPUTS GROUPS

Outputs	
Group 1	1,2,3,4
Group 2	5,6
Inputs	
Group 1	1,2,3
Group 2	4

C. *Selecting output / input representative*

The selection of the output or input representative will be performed according to the criterion of maximization of the similarity coefficient average of the output within the group. For this case we discuss group number 1 which includes the outputs 1,2,3,4.

Table 8 contains computational results using equation 3.

We see for example, the similarity coefficient value of output 4 is 0 in the relation between it and output 1 and in the two other cases its value is higher than 0.8. The similarity coefficient average of output 4 is 0.58. On the other hand, the average of output 1 is higher value therefore output 1 is the representative of group 1.

TABLE 8 SELECTING GROUP 1 OUTPUT REPRESENTATIVE

Output 1	
1-2	0.89
1-3	0.85
1-4	0.83
Average*	0.86

Output 3	
3-1	0.85
3-2	0
3-4	0.92
Average	0.59

Output 2	
2-1	0.89
2-3	0
2-4	0
Average	0.30

Output 4	
4-1	0.83
4-2	0
4-3	0.92
Average	0.58

Dealing with the group 2 in this example is less complex since it includes only two outputs. Hence, the choice between them will be arbitrary, i.e., output 5 is the representative of group 2. The inputs example presented in Table 9 is dealt with the same methodology.

Stage 3 Implementing Sequential DEA

The application of Sequential DEA is performed when the procedure inputs are identical and the outputs vary. A Sequential DEA is performed in 3-stage process as follows:

A. Performing DEA with MPCS outputs

At this stage, running the DEA is performed when the MPCS outputs results are given in Table 10

TABLE 9 SELECTING INPUT REPRESENTATIVE

Input 1	
1-2	0.88
1-3	0.88
Average*	0.88
Input 2	
2-1	0.88
2-3	0.82
Average	0.85
Input 3	
3-1	0.88
3-2	0.88
Average	0.88

TABLE 10 MPCS EFFICIENCY SCORE

Project	Inputs		MPCS Output	DEA Score
	Cost	Level of Uncertainty	Design Yield	
1	1000	6	0.67	31.25
2	800	6	0.29	30.00
3	700	8	0.80	46.67
4	1000	7	0.20	25.19
5	600	4	0.45	23.33
6	500	7	0.55	23.40
7	200	9	0.30	100.00
8	900	5	1	31.90
9	100	8	0.55	100.00

B. Performing DEA with EV outputs

The EV output results, using the same inputs are given in Table 11

TABLE 11 EV EFFICIENCY SCORE

Project	Inputs		EV Output	DEA Score
	Cost	Level of Uncertainty	SI	
1	1000	6	0.35	13.12
2	800	6	0.8	40.00
3	700	8	0.75	37.50
4	1000	7	0.88	29.33
5	600	4	0.4	17.14
6	500	7	0.5	19.37
7	200	9	1	100.00
8	900	5	0.78	33.43
9	100	8	0.8	100.00

TABLE 12 INTEGRATED SCORE

	Inputs		Outputs		DEA Score
	Cost	Level of Uncertainty	MPCS Efficiency	EV Efficiency	
1	1000	6	31.25	13.12	11.72
2	800	6	30.00	40.00	20.00
3	700	8	46.67	37.50	23.33
4	1000	7	25.19	29.33	9.78
5	600	4	23.33	17.14	10.00
6	500	7	23.40	19.37	8.88
7	200	9	100.00	100.00	100.00
8	900	5	31.90	33.43	14.33
9	100	8	100.00	100.00	100.00

C. Performing DEA integrating stages a, b result

The outputs in the final stage are the combined results of the MPCS efficiency scores and the EV efficiency scores using the same inputs as given in table 12

It can be noticeable that project 9 is on the efficiency frontier, though it is a relatively low budget project. High budgeted projects like project 1, project 2 and project 4 should improve their performances to achieve better efficiency results. Many projects are far from the efficiency frontier, therefore systematical examination is needed in order to perform improvement.

IV. SUMMARY AND CONCLUSIONS.

The MPCS system described in the article by Rozenes et al. [13] represents a project control system, which examines the performances of a single project using a large number of dimensions. The infrastructure of the system is the GPCS control specifications through which the project performances are examined in comparison with the original planning. The results of the examination are calculated with the help of yield indexes that are calculated with aggregation. The result of the MPCS system presents the power and direction of the gap between the plans and performance. The MPCS system performs the control of each project singly .The DEA methodology allows the comparison among different projects operating in parallel at different stages of their life cycles. The performance of the DEA comparison is possible following the standardization in the GPCS definition of the different projects. It is based on the uniform definition of the two higher levels in each GPCS of the different projects. Comparison is performed on the combined control system, which includes two complementary control systems, one of them is MPCS and the other is the traditional EV system. When only a few projects are in progress the DEA methodology requires the building of an algorithm that provides the same information through a smaller number of inputs and outputs. The DEA output allows the diagnosis of those found on the efficiency frontier and those that need improvement.

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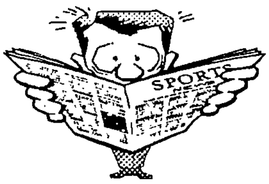
MPCS: Multidimensional Project Control System



Project

A temporary endeavor undertaken, to create a unique product or service.

Temporary means that every project has a definite beginning and a definite end. Unique means that the product or service is different in some distinguishing way from all similar products or services

PMBoK 2000

Control

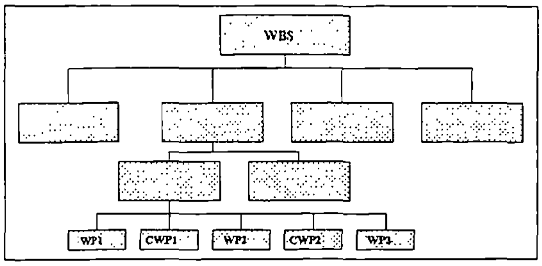
A broad view of what is meant by Control is taken. Planning, measuring, monitoring and taking corrective action are all usually included in the Control cycle.

APMBoK 2000

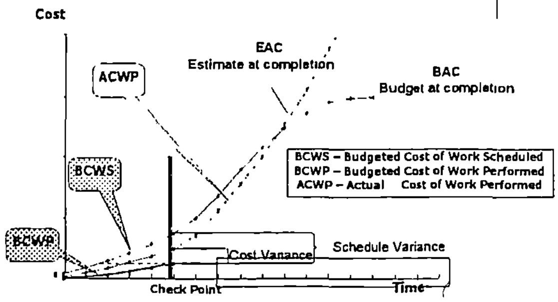
Project Life Cycle

- *Conceptual Phase*
- *Planning Phase*
- *Execution Phase*
- *Termination Phase*

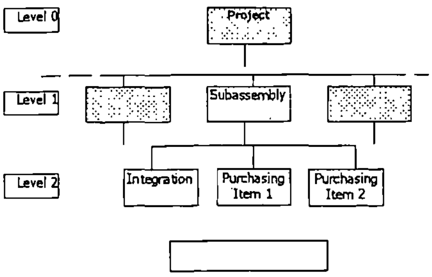
WBS
Work Breakdown Structure



Earned Value System Principles

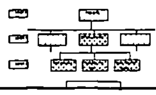


EV Implementation example



EV control status

	BCWP ($K)	*BCWS ($K)*	*ACWP ($K)*	$CPI=\frac{BCWP}{ACWP}$	$SPI=\frac{BCWP}{BCWS}$
Subassembly	***301***	***303***	***305***	***0.99***	***0.99***
Purchasing Item 1	100	100	100	1	1
Purchasing Item 2	200	200	200	1	1
Integration	1	3	5	0.2	0.33



MPCS Methodology

Conceptual Phase

Planning Phase

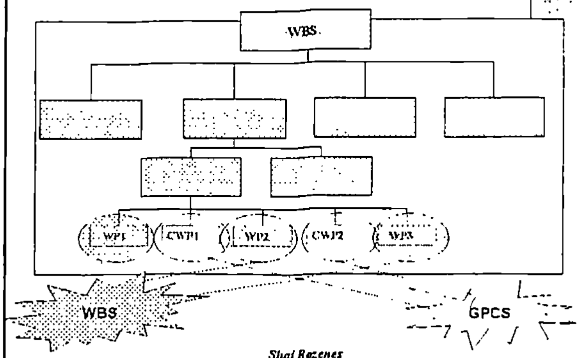
- WBS + GPCS definition.
- Defining Measurement Procedures.
- Defining Execution and Reporting Processes.
- MPCS Threshold values.

Execution Phase

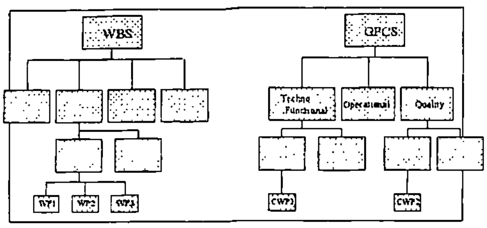
- Yield computation.
- Control indices computation.
- Control Indices examination.
- Corrective actions.

Termination Phase

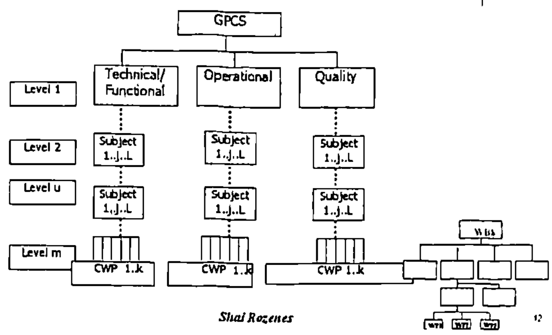
GPCS definition



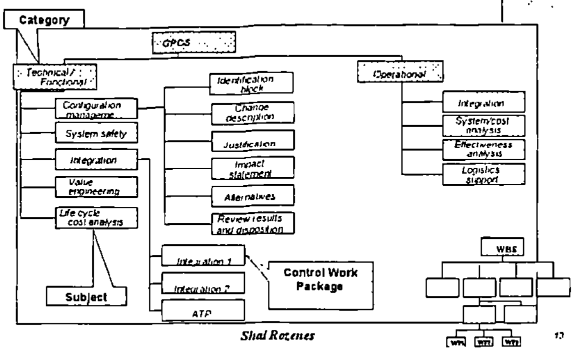
GPCS definition



A Typical GPCS
Global Project Control Specifications



GPCS example



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MPCS Methodology

- ***Planning Phase***
  - WBS + GPCS definition.
  - ☞ Defining Measurement Procedures.
  - Defining Execution and Reporting Processes.
  - MPCS Threshold value
- ***Execution Phase***
  - Yield computation.
  - Control indices computation.
  - Control Indices examination.
  - Corrective actions.

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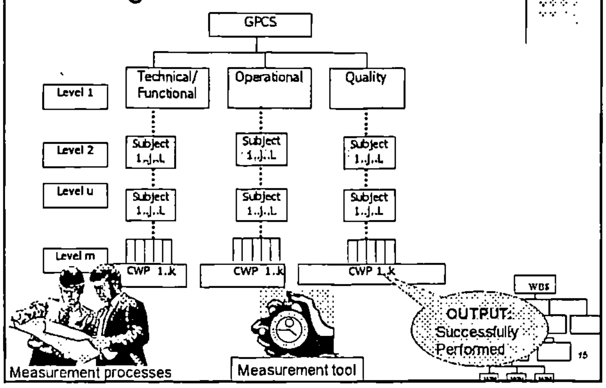
Defining Measurement Procedures



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MPCS Methodology

- ***Planning Phase***
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  - ☞ Defining Execution and Reporting Processes.
  - MPCS Threshold values.
- ***Execution Phase***
  - Yield computation.
  - Control indices computation.
  - Control Indices examination.
  - Corrective actions.

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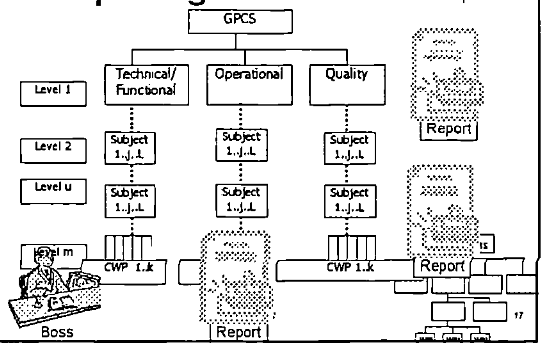
Defining Execution and Reporting Processes



Defining Execution and Reporting Processes

Report Matrix

Level	Description	Classification	Project manager	OPS	R&D
1	Techno / Functional	Category	X		X
2	Configuration Management	Subject	X		X
3	Justification	CWP	X	X	X

MPCS Methodology

- ***Planning Phase***
  - WBS + GPCS definition.
  - Defining Measurement Procedures.
  - Defining Execution and Reporting Processes.
  - ☞ MPCS Threshold values.
- ***Execution Phase***
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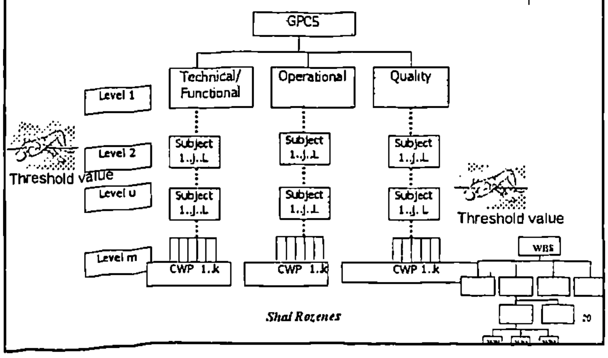
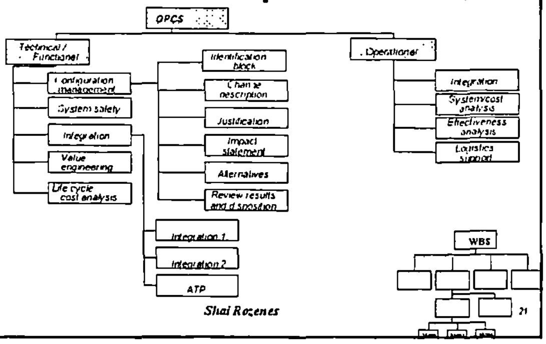
  - Control indices computation.
  - Control Indices examination.
  - Corrective actions.

MPCS Threshold values



Threshold values definition example



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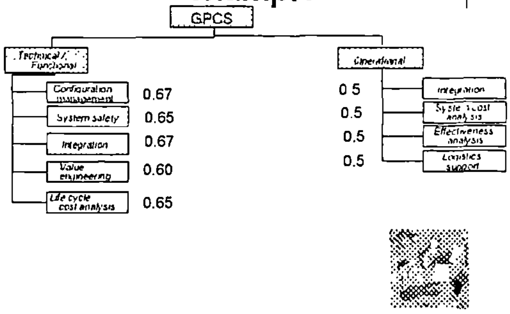
Threshold values definition example



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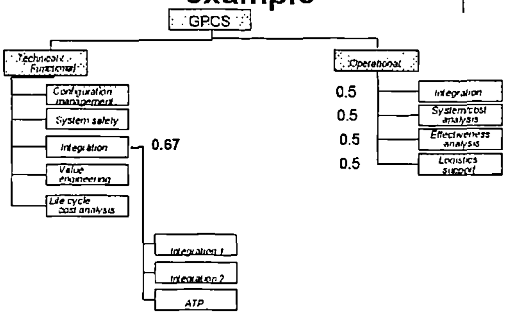
Threshold values definition example



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MPCS Methodology

- ***Planning Phase***
  - WBS + GPCS definition.
  - Defining Measurement Procedures.
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- ***Execution Phase***
  - Yield computation.
  - Control indices computation.
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  - Corrective actions.

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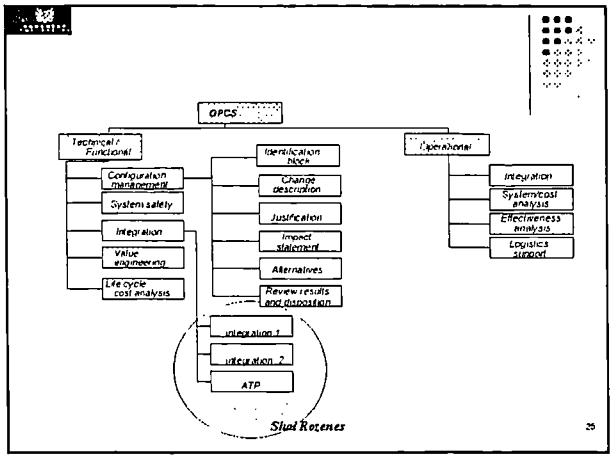
OPCS
Technical / Functional
Configuration management
System safety
Integration
Value engineering
Life cycle cost analysis
Identification block
Change description
Justification
Impact statement
Alternatives
Review results and disposition
Operational
Integration
System/cost analysis
Effectiveness analysis
Logistics support
Integration 1
Integration 2
ATP
Shai Rozenes
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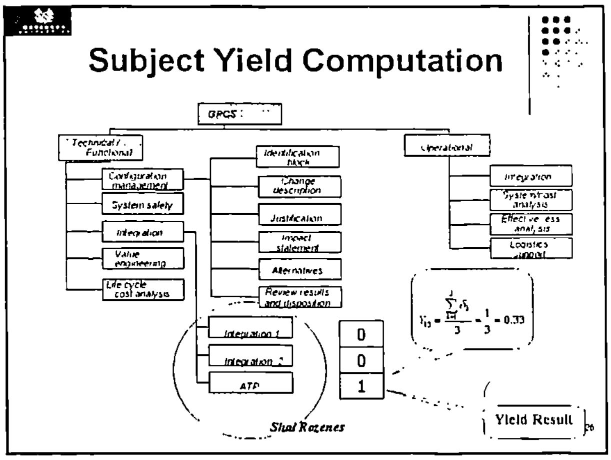
Subject Yield Computation
OPCS
Technical / Functional
Configuration management
System safety
Integration
Value engineering
Life cycle cost analysis
Identification block
Change description
Justification
Impact statement
Alternatives
Review results and disposition
Operational
Integration
System/cost analysis
Effectiveness analysis
Logistics support
Integration 1
Integration 2
ATP
0
0
1
$Y_{13} = \frac{\sum_{i=1}^{3} r_i}{3} = \frac{1}{3} = 0.33$
Yield Result
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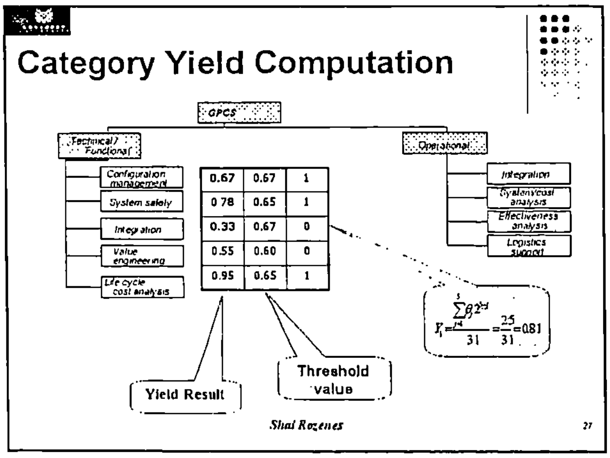
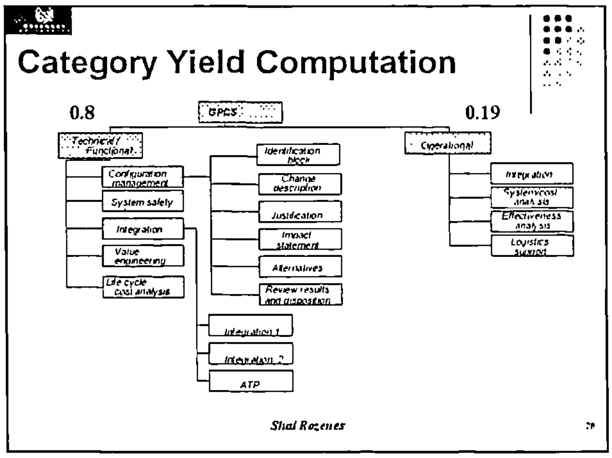

Category Yield Computation
OPCS
Technical / Functional
Configuration management
System safety
Integration
Value engineering
Life cycle cost analysis
0.67 0.67 1
0.78 0.65 1
0.33 0.67 0
0.55 0.60 0
0.95 0.65 1
Operational
Integration
System/cost analysis
Effectiveness analysis
Logistics support
$Y_1 = \frac{\sum_{j=1}^{5} \beta_j 2^{5-j}}{31} = \frac{25}{31} = 0.81$
Yield Result
Threshold value
Shai Rozenes
27


Category Yield Computation
0.8
OPCS
0.19
Technical / Functional
Configuration management
System safety
Integration
Value engineering
Life cycle cost analysis
Identification block
Change description
Justification
Impact statement
Alternatives
Review results and disposition
Operational
Integration
System/cost analysis
Effectiveness analysis
Logistics support
Integration 1
Integration 2
ATP
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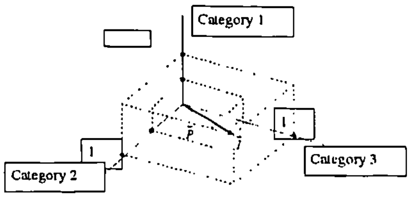
MPCS Methodology

- ***Planning Phase***
  - WBS + GPCS definition.
  - Defining Measurement Procedures.
  - Defining Execution and Reporting Processes.
  - MPCS Threshold values.
- ***Execution Phase***
  - Yield computation.
  - Control indices computation.
  - Control Indices examination.
  - Corrective actions.

Yield Vector

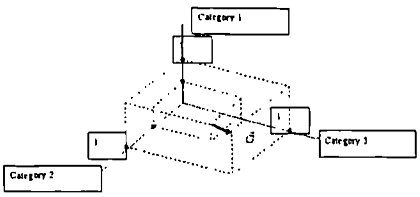
$$\vec{P} = Y_1\hat{i} + Y_2\hat{j} + \cdots + Y_N\hat{n}$$



Gap Vector

$$\vec{G} = \vec{I} - \vec{P}$$

$$\vec{G} = (1 - Y_1)\hat{i} + (1 - Y_2)\hat{j} + \cdots + (1 - Y_N)\hat{n}$$

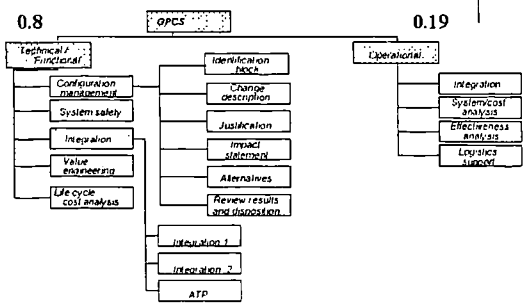


Control indices computation

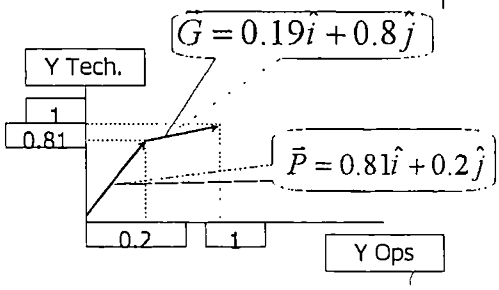
$$GP = \frac{|\vec{G}|}{\sqrt{N}}$$

Gap Performance (GP) index

Example Results



Example Results



Gap Performance (GP) index

$$GP = \frac{|\vec{G}|}{\sqrt{2}} = \frac{\sqrt{0.8^2 + 0.19^2}}{\sqrt{2}} = 0.58$$

MPCS Methodology

- ***Planning Phase***
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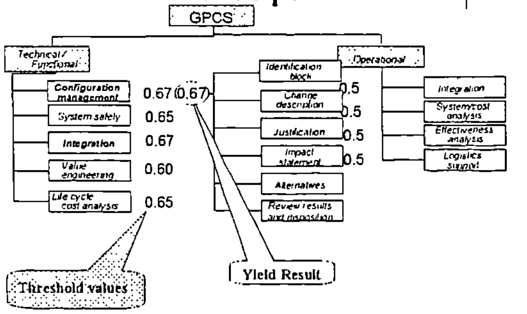
- ***Execution Phase***
  - Yield computation.
  - Control indices computation.
  - ☞ Control Indices examination.
  - Corrective actions.

Threshold values definition example



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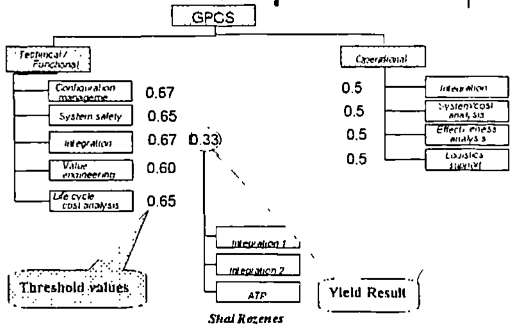
Threshold values definition example



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MPCS Methodology

- ***Planning Phase***
  - WBS + GPCS definition.
  - Defining Measurement Procedures.
  - Defining Execution and Reporting Processes.
  - MPCS Threshold values.
- ***Execution Phase***
  - Yield computation.
  - Control indices computation.
  - Control Indices examination.
  - ☞ Corrective actions.

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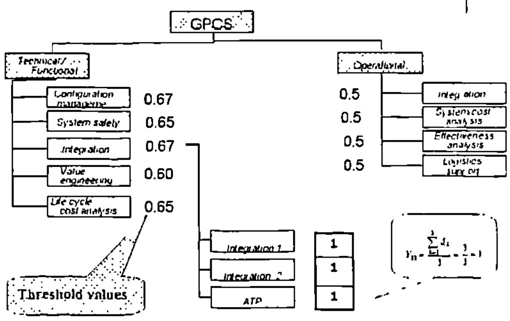
Performing Corrective Actions



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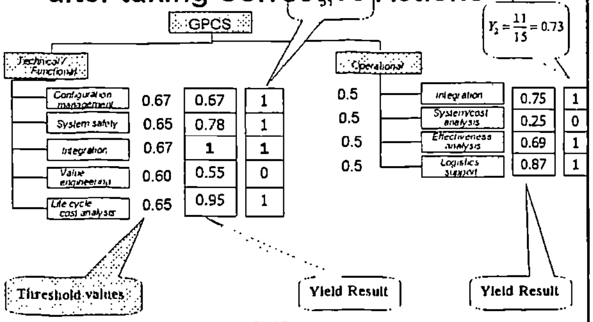
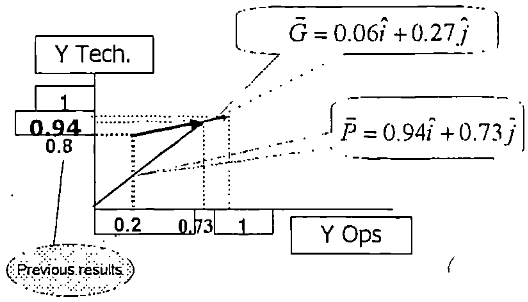
Category Yield computation after taking Corrective Actions



The Gap Vector illustration



Gap Performance (GP) index

$$GP = \frac{|\bar{G}|}{\sqrt{2}} = \frac{\sqrt{0.06^2 + 0.27^2}}{\sqrt{2}} = 0.2$$

Previous results $$GP = \frac{|\bar{G}|}{\sqrt{2}} = \frac{\sqrt{0.8^2 + 0.19^2}}{\sqrt{2}} = 0.58$$

Summary

- MPCS- Project control methodology.
  - GPCS
  - Yields.
  - Vectorial presentation

G. Implementing the MPCS system: A case study

Appendix G

This Appendix has been withheld from publication for reasons of confidentiality.

If information is required please contact the author.