UNIVERSITÉ DU QUÉBEC

PROPOSITION D'UN MODÈLE INTÉGRÉ TEMPS/COÛT/QUALITÉ SOUS INCERTITUDE EN PLANIFICATION DE PROJET

MÉMOIRE PRÉSENTÉ À

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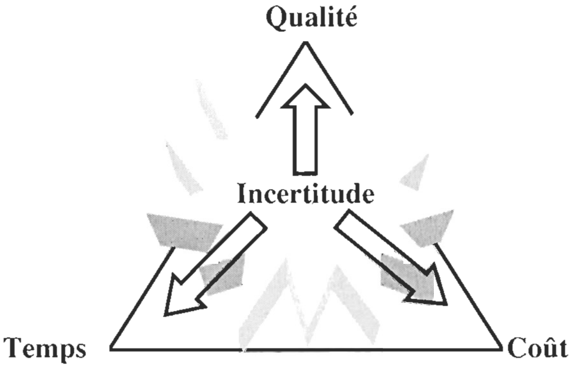
Résumé

L'environnement d'affaires des organisations est aujourd'hui fortement incertain et les organisations vivent une pression croissante pour améliorer la qualité, la valeur de leurs prises de décision à tous les niveaux et, en particulier, au niveau de leurs projets car c'est au travers des projets que l'organisation s'assure d'être réactive envers son environnement. En gestion de projet, une des principales approches développées pour répondre à cette préoccupation est la gestion des risques (Risk Management). Une autre approche importante, utilisée dans l'analyse intégrée, a priori, du temps et du coût du projet, est celle de l'Analyse de la Valeur Acquise ou EVM (Earned Value Management). Plus récemment, et afin de contrôler la qualité tout au long du cycle de vie du projet, Paquin, Couillard et Ferrand (2000) ont proposé la méthode de la qualité acquise ou EQM (Earned Quality Method). Ces approches contribuent ensemble à la performance des projets et, en retour, à la performance des programmes, des portefeuilles de projets et finalement à l'organisation. En fait, ces approches fournissent des informations de gestion pour aider le gestionnaire de projet à prévoir les résultats futurs du projet en terme de qualité, de temps et de coût et permettent ainsi au gestionnaire de projet de prendre des décisions et des actions sur des bases plus solides. Cependant, les résultats futurs d'un projet sont généralement affectés par l'incertitude et la gestion du risque est alors utile pour aborder ces incertitudes qui, quand elles se sont produites, pourraient avoir un effet sur les objectifs de projet en terme de temps/coût/qualité. Ainsi, l'incertitude, qui pourrait se transformer en risque pour les objectifs du projet, est considérée comme une méta-variable.



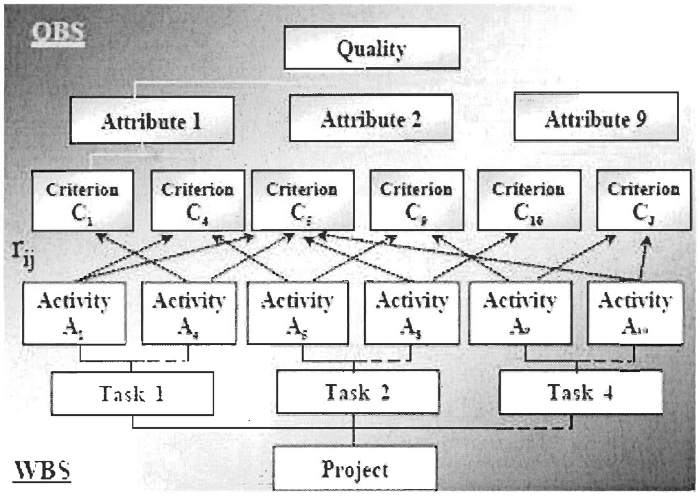
Généralement, la gestion des risques, la gestion de qualité, la gestion de l'échéancier du projet comme la gestion des coûts sont traitées en tant que processus indépendants mais récemment, quelques rares papiers (Hillson, 200 ; Paquin, Couillard et Ferrand, 2000) se sont intéressés à l'intégration de ces approches afin de créer une synergie sur la performance des projets. Ce mémoire se situe dans cette tendance et propose un cadre général qui peut être mis en application pour combiner EVM, EQM et RM de manière à maximiser l'atteinte des objectifs (temps/coût/qualité) durant la phase de planification des projets. Après une présentation des techniques d'estimation de l'incertitude et des outils de gestion des risques discrets en planification de projet, de l'analyse de la valeur gagnée (EVM) comme de la qualité gagnée (EQM), le modèle intégré temps/coût/qualité en situation d'incertitude est présenté et illustré à partir d'un exemple didactique.

L'incertitude est un terme utilisé dans un grand nombre de domaines (philosophie, statistiques, sciences économiques, finances, assurance, psychologie, ..) et s'applique aux prévisions d'événements futurs. Elle représente le fossé informationnel entre ce qu'il faut pour estimer des résultats futurs et l'information que possède déjà le décideur. En 1921, Frank Knight a établi une distinction entre le risque et l'incertitude. Le risque est défini comme une incertitude pour laquelle une probabilité peut être calculée (avec des données historiques par exemple) ou au moins être estimée (en faisant des scénarios de projection) mathématiquement. Formellement, risque = (la probabilité qu'un certain événement se produit)*(les conséquences s'il se produit). L'incertitude concerne, par opposition à la notion du risque, des événements non statistiques, qui sont essentiellement uniques ou considérés comme tels. Ces événements uniques peuvent être considérés comme des opportunités pour le chef de projet et on pourrait proposer cette équation formelle : Incertitude = risque + opportunités.

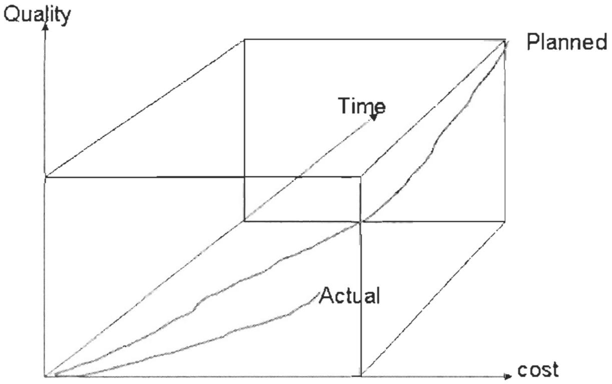
Aujourd'hui, les mathématiciens modélisent l'incertitude en employant non seulement la théorie des probabilités, mais aussi la théorie d'évidence de Dempster-Shafer, la théorie des ensembles flous ou encore celle des intervalles. En gestion de projet, et en particulier en planification de projet, nous pouvons distinguer plusieurs approches pour traiter l'incertitude ou la mauvaise estimation des durées des activités d'un projet (Herroelen et Leus, 2005) : la planification stochastique, planification floue, la planification réactive et la planification proactive ou robuste. La planification de projet stochastique vise à ordonnancer les activités d'un projet avec des durées incertaines de manière à réduire au minimum la durée espérée du projet. Cet aspect a été abordé dans l'approche PERT (Malcolm, Rosenboom, Clark, Fazar, 1959) et on retrouve une littérature abondante au sujet du PERT probabiliste. Les avocats de la théorie des ensembles flous défendent l'idée que les distributions de probabilité des durées des activités d'un projet ne peuvent être connues à cause du manque de données historiques et qu'alors les durées d'activité doivent être estimées par des experts humains, c'est-à-dire avec à base de jugements qui sont vagues et imprécis. Dans ces situations, qui impliquent de l'imprécision plutôt que de l'incertitude, il est alors recommandé d'utiliser des nombres flous pour modéliser les durées des activités (Slowinsky et Hapke, 2000), plutôt que de recourir à des variables stochastiques. Ainsi, au lieu d'utiliser des distributions de probabilité, on recourt à des fonctions de vraisemblance basées sur la théorie des possibilités. Récemment, Dubois et autres. (2005) ont utilisé la forme la plus simple de représentation de l'incertitude relative à la durée des activités d'un projet, à savoir un intervalle de valeur pour estimer la durée des activités incertaines. Assigner un certain intervalle de temps à la durée d'une activité signifie que la durée réelle de cette activité prendra une des valeurs de cet intervalle, mais il n'est pas possible actuellement de prévoir laquelle. La planification réactive n'essaye pas de traiter a priori l'incertitude, soit dans la planification initiale, mais consiste à mettre à jour ou à re-optimiser la planification initiale quand un événement inattendu se produit (Sabuncuoglu et Bayiz, 2000, Vieira et autres., 2003). La dernière approche, qui gagne en popularité parmi des praticiens de gestion de projet, est celle relative à la méthode de la chaîne critique (Goldratt, 1997) et se rapporte à ce que l'on appelle la planification proactive. En fait, pour aborder l'incertitude, une approche d'insertion de durée tampon est employée. Cette approche est nouvelle en planification de projet mais certains auteurs ont déjà noté certaines simplifications exagérées dans cette méthode (Herroelen et autres. 2001 ; Herroelen à Al 2002, Giard, 2003). Ce type d'incertitude, se rapportant à la mauvaise estimation des durées des activités d'un projet, est généralement considéré en planification de projet grâce au recours de la méthode Monte Carlo. La simulation de Monte Carlo est la technique la plus utilisée pour tenir compte de la variabilité des paramètres incertains dans l'estimation des coûts ou des durées des activités et est généralement employée pour estimer la

criticité des différentes activités, des différents chemins du réseau de projet mais aussi pour estimer la distribution de probabilité de la durée totale du projet.
En gestion de projet, nous abordons généralement un autre type de risques, à savoir les risques discrets. Généralement, les risques discrets sont abordés au moyen de plans de contingence et en recourant à des techniques comme celle des branchements conditionnels et probabilistes (Hulett et Hillson, 2005) ou du GERT (Pristker et Happ, 1966).

Dans le cadre de notre mémoire, ces deux types de risques (d'estimation et discret) et leur conséquences sur les objectifs (temps/coût/qualité) du projet seront considérés. Bien évidemment, pour atteindre cet objectif, il faut être en mesure dans le cas certain d'intégrer les facteurs temps, coût et qualité. Pour ce faire, nous allons recourir à l'EVM et l'EQM. L'analyse de la valeur acquise (EVM), à partir d'une structuration du projet au moyen d'une structure de fractionnement du travail ou WBS (Work Breakdown Structure) et de la planification initiale du projet, procède à une analyse temps/coût du projet et permet de calculer des indices de performance du projet en terme de temps comme de coût. Les écarts de coûts ou de temps évalués à un moment (t) permettent également au gestionnaire de projet de prendre des actions correctives afin de satisfaire au mieux les objectifs de temps et de coût qu'il s'était fixé. La méthode de la qualité acquise (EQM) nécessite, quant à elle, une relation entre le WBS et le QBS (Quality Breakdown Structure) ou structure de fractionnement de la qualité et d'avoir en main la planification initiale du projet. Cette méthode fournit alors une mesure au temps (t) de l'écart de qualité en rapport avec la planification initiale et ainsi permet au gestionnaire de projet de prendre des actions correctives.

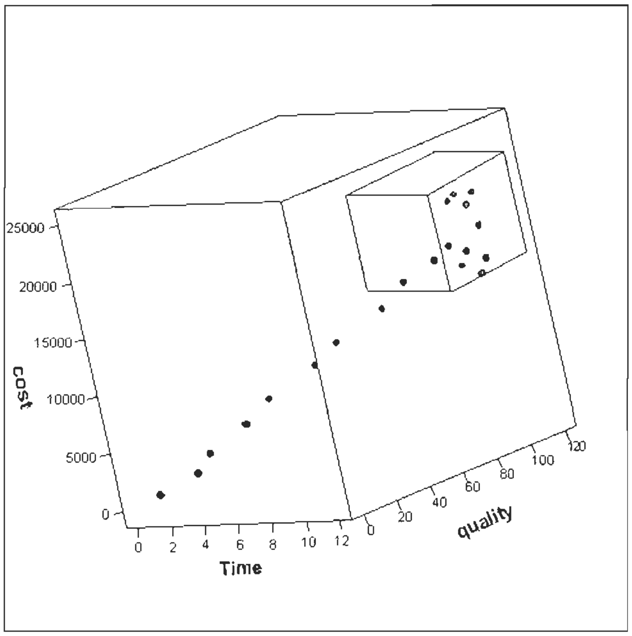


Ainsi, il semble intéressant d'intégrer l'EVM et l'EQM pour estimer la performance d'un projet dans une perspective tridimensionnelle : le budget, l'échéancier et la qualité et d'utiliser cette information pour le suivi et le contrôle de la performance du projet d'une façon intégrée comme illustrée par la figure suivante.

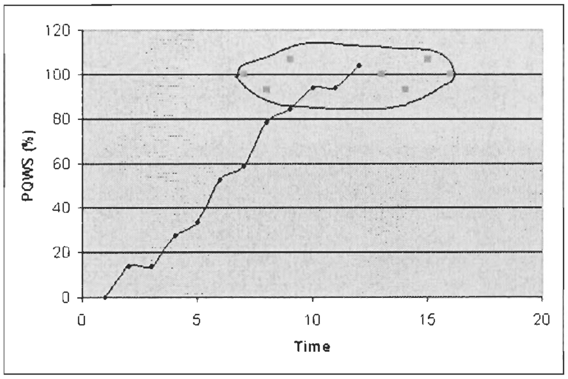


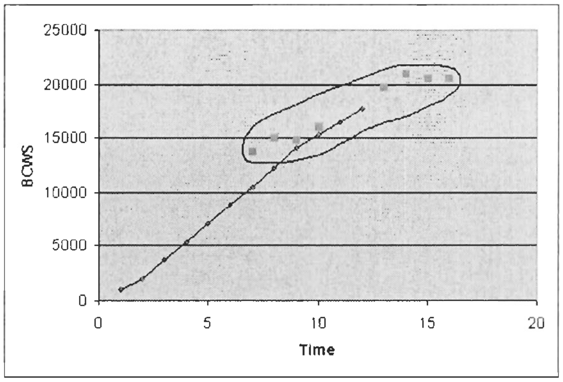
Maintenant, en présence d'incertitude dans l'estimation des durées des activités du projet et des risques discrets du projet, cette intégration devient plus complexe mais non infaisable. Nous proposons, dans ce mémoire, un modèle général temps/coût/qualité en situation d'incertitude reposant sur une modélisation du risque au niveau de la planification du projet par le recours à des plans de contingence intégrés à la planification initiale et par une utilisation combinée de l'EVM et de l'EQM pour la mesure multidimensionnelle de la performance du projet.

Ainsi, dans une analyse a priori (étape de planification), notre modèle peut être employé par le gestionnaire de projet pour visualiser les différents scénarios pour le projet compte tenu des risques discrets comme des incertitudes dans l'estimation des durées des activités. Il permet au gestionnaire de projet de focaliser son attention sur un ou des scénarios possibles et de choisir une planification de base en terme d'échéancier, de coût et de qualité pour le projet. Cela permet ainsi de faire certains arbitrages entre ces grandes composantes de la performance que sont le temps, le coût et la qualité.



Ce cube de la performance de projet peut être vu comme une intégration de deux S-courbes reliées (BCWS et PQWS) et qui tiennent compte de l'incertitude (variabilité des durées des activités du projet) et des risques discrets.





L'ellipse à l'extrémité des courbes représente l'enveloppe, délimitée par les scénarios extrêmes, de tous les scénarios possibles pour le projet.

Ce modèle constitue donc un outil d'aide à la planification pour le gestionnaire de projet. Il lui permet d'avoir une vue globale et dynamique des impacts sur le temps, le coût et la qualité de la réalisation de certains risques comme des incertitudes dans l'estimation des durées des activités du projet et ainsi de réagir à des écarts trop importants dans la performance de son projet. Notons que si l'intégration du coût, du temps et de la qualité est souvent discutée en gestion de projet, à notre connaissance, notre modèle est le premier qui s'attaque concrètement à cet aspect. Bien évidemment, notre modèle a quelques limites. D'abord, il s'adresse à des projets qui ont un produit final. Cependant, ce n'est pas une contrainte importante parce que l'approche pourrait néanmoins être adaptée à d'autre type de projet. Une autre limite à notre modèle réside dans la difficulté à obtenir les informations sur les critères de qualité du client. Par ailleurs, comme notre modèle utilise une approche par scénarios pour modéliser l'incertitude (des risques ou incertitude discrets de estimer), une augmentation du nombre de plans de contingence entraîne une croissance exponentielle du nombre de scénarios à considérer. Il serait alors intéressant, dans un travail ultérieur, de développer un algorithme efficace de manière à pouvoir aborder des problèmes de grande taille. A titre de développements futurs, il nous apparaît qu'il serait pertinent de considérer des situations où il est possible d'avoir plus d'informations sur l'incertitude, par exemple, des situations où l'on pourrait disposer de probabilités ou de fonctions de vraisemblance. Enfin, il faudrait généraliser ce travail au cas où l'on disposerait, pour chaque plan de contingence, d'une mesure de 'possibilité' comme, par exemple, un intervalle des probabilités. En conclusion, le modèle proposé fournit des informations de gestion pour aider le gestionnaire de projet à prévoir les résultats futurs du projet en terme de qualité, de temps et de coût, à arbitrer entre ces différentes facettes de la performance, et ainsi donner au gestionnaire de projet une base solide pour ses décisions et ses actions.

Abstract

With the development of the technology and economics, the project management gradually becomes the focus of the management theory and practice. To stay competitive, companies are increasingly implementing initiatives to improve their project delivery by continually reducing cycle times, minimizing costs, and controlling quality. These dimensions (quality, time, and cost) are also referred to as the Project Management Triangle where each side represents a constraint. One side of the triangle cannot be changed without impacting the others. The time constraint refers to the amount of time available to complete a project. The cost constraint refers to the budgeted amount available for the project. The scope constraint refers to what must be done to produce the project's end result. These three constraints are often competing constraints: increased scope typically means increased time and increased cost, a tight time constraint could mean increased costs and reduced scope, and a tight budget could mean increased time and reduced scope. The discipline of project management is about providing the tools and techniques that enable the project team (not just the project manager) to organize their work to meet these constraints. Project Management tries to gain control over these three variables taking account the uncertainty inherent to every project situation. It requires skilled people, standardized processes, and technology—unified and driven by effective project management. This thesis tackle this difficult problem and proposes a general framework, based on the WBS that can be implemented to combine earned value management, earned quality management and risk management in order to 'maximise' the likelihood of achieving project objectives (time/cost/quality).

Key words: time, cost, quality, risk, project management.

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Introduction

Project refers to the once-off endeavor made for creation of unique product and service under restriction of a certain resource. Popularly speaking, project is the once-off assignment made to realize the designed target and reach a certain quality under the restriction of a certain schedule and cost.

Project management refers to the project manager applies systemic theory and method to manage whole work involving in the project under the condition of limited resource to make the project through planning, organization, commanding, coordination, control and summative evaluation in overall process from decision to implementation to realize the specific target of the project. The project management is a scientific management means, which emphases personal responsibility in leading style and practicing project manager responsibility system, adopts temporary dynamic to organize form-project group in management structure, adheres to the target management under the benefit priority principle in management target and has more complete technical methods in management means. (Bai Sijun, 2003)

The human being has already learned to apply project management method to solve problem in work and life as early as in remote antiquity. Project management has intentionally or unintentionally been applied in the construction progress of the Great Wall in China as well as the Pyramid in ancient Egypt. The budding of modern project management took place in the 20th century 40s and the more typical case is the Manhattan Project of the American military to develop atomic bomb.

Any review of how project management evolved must include a brief insight into how projects have played a key role in the initiation of change in the societies of antiquity. One could think for example to the grand canal of China, to Prince Henry the navigator (1394-1460) who developed and operated what could be called today a research and development laboratory, to the construction of a new city in the north of Russia, St. Petersburg.

In more recent times, other projects have played key roles in changing society as the following:

- The panama canal, in the 1860s, a project which was initiated to join the continent of North America
- The Manhattan Project for the development delivery of the atomic bomb had a major impact on the strategy for the winning of World War II by U.S.

The method of project management has been widely applied in 50s-60s of 20th century. The project management in that time had more scientific systemic method with the key duty of project implementation and mainly was applied in national defense and building industry. It was a period for the theory and method of project management to rapidly broadcast in the world and go toward modernization in 70s-80s of 20th century, which expanded to various types of civil projects form military project and aerospace project and initially formed the frame of modern project management. The project management has experienced new development since 90s of 20th century. In order to meet the challenge of economic integration in the market with rapid change and cutthroat competition, project management has paid more attention to the factor of human, customer and flexible management to strive for the surviving and development in the revolution. In this stage, the applying field of project management has further expanded, especially realized rapid development in new emerging industry such as the modern project management fields including telecommunication, software, information, finance and medicine.

Today, there are four large project management associations in the world, three of us are professional associations (IPMA, AFITEP and PMI) and the fourth (IRNOP) is a researchers association. The first one (see http://www.ipma.ch/asp/) is the association headed by European professionals and researchers, i.e. International Project Management Association (IPMA). IPMA presided to hold the first international meeting in Vienna in 1967, which has become a mark to establish the project management as a subject. The main members of IPMA are project management committees of each country. At present, there are 28 country organizations being its formal members representing more than 20 thousand members in the world. The individual member in formal member organization can automatically become the individual member of the association. IPMA is responsible to coordinate the requirements of project management with general character in the world and provide wide-range products and services including research and development, training and education, standard and certificate as well as hold various workshops to study relevant theory knowledge of project management. PMI is a non-profit professional association in the leading level of international project management field, which is responsible to establish management standard, provide services such as scholar exchanges, education procedure and professional certificate and whose members are mainly the experts from enterprises, universities and research institutes. The exiting members have been over 70 thousand. These two institutes provide perfect carrier for the study on project management and have made great contribution to the research and development of project management.

The second is the professional association headed by American professionals (see http://www.pmi.org/info/default.asp), i.e. Project Management Institute (PMI). The members of PMI are mainly the experts from enterprises, universities and research institute, which develops a set of project management system—PMBOK. This knowledge system divides the project management into 9 knowledge fields including range management, time management, cost management, quality management, human resource management, communication management, risk management and comprehensive management. The International Organization for Standardization formulates ISO10006 standard relevant to management with this file as framework. By now, the deep study on project management started by relevant project management research institutes at home and abroad from 60s of last century has acquired rich result. For example, PMI published the first special report related to project management research in project management magazine in August of 1983, and based on this, it formally published a unique project management document named 'The Project Management Body of Knowledge' (PMBOK) in August of 1987 with 4-year continuous research. In 1996, PMI published A Guide to The Project Management Body of Knowledge (PMBOKGUIDE) to replace PMBOK of 1987 as project management standard. The International Organization for Standardization (ISO) formulated international standard ISO10006 of project management on

December 15, 1997 based on PMBOK GUIDE of 1996 edition by PMI. At present, this standard has upgraded to 2000 edition and more recently to the 2004 edition.

The third association is the one headed by French professionals (http://www.afitep.fr/), i.e. Association Francophone De Management De Projet (AFITEP). The members of IPMA mainly came from project management organization representing each country, which registered in Switzerland in the year of 1965 and is a non-profit organization. The organization pays much more attention to the qualification certificate of personnel. Generally speaking, the certificate of project management personnel is divided into four levels including A, B, C and D with very large difference of level standard between each level. Finally, IRNOP (see http://www.irnop.org/) was founded in 1993 as a network of researchers and have developed from there, adding researchers in countries all over the world. The IRNOP network connects scholars with a background in business, economics, engineering and other fields, with a common interest in projects, project organizations and temporary systems.

In China, the studies on project management systems and industry practices have started later. From 50s of 20th century to 80s, project management was regarded as the activities in small range to devote to estimation and planning to realize specific target, whose main contents included four aspects, i.e. range management, time management, cost management and human resource management. The application of project management has gradually expanded to other fields since 80s such as telecommunication industry, software development industry, pharmacy industry and finance industry. The project management with true meaning started from Lubuge Hydropower Station Project, a project with World Bank loan. Lubuge Hydropower Station firstly adopt international bidding at home in 1984 and implemented project, which shortened the construction period, reduced building cost and realized apparent economic benefit. After that, the Construction Ministry, Chemical Industry Ministry, Electric Power Ministry and Coal Ministry have successively developed training and certificate system of relevant technical personnel related to project management. By 90s of 20th century, all large projects in China basically adopted project management mode including project fund system, legal person responsibility system, contract system and construction supervision system such as Xiaolangdi Water Conservancy Project, the largest water control project in Yellow Rive basin, Daya Bay Nuclear Power Station and Three Gorges Project gained the focus of the world attention. Project Management Research Committee was founded in 1991. China formally implemented Bidding and Tendering Law on February 1, 2000, which involves in many aspects of project management and provides law guarantee for the stable and health development of project management. In order to meet with the world, the project management committee of China joined in IPMA, after that the academic exchanges activities with IPMA have been increasing frequent. However, generally speaking, the development level of project management in China is still in elementary stage with shortage of project management talent and lagging behind of method and technology, there will need some time to meet with the world.

The modern project management has spread abroad in China since 60s of 20th century. China translated and published Program Evaluation and Review Technique Base and translation collection of New Program Evaluation and Review Technique separately in 1965 and 1966. In 1991, Project Management Committee of China was founded with full name of Chinese Society of Optimization, Overall Planning and Economic Mathematics Project Management Research committee (Project Management Research Committee, China for short, PMRC or PMRCC for abbreviation), which is affiliated to Northwest Polytechnic University and whose competent department is Chinese Society of Optimization, Overall Planning and Economic Mathematics founded by Professor Hua Luogong, the famous mathematician of China. At present, the members of PMRC have spread in 29 provinces, cities and municipalities all over the country. It mainly engages in the popularization and application of project management, construction and development of project management subject and communication and exchanges at home and in the world. It edits an inner publication named Project Management. PMRC is a member organization of IPMA. However, it is still only a second-level institute. At present, there still is not a professional publication of project management published formally in China. In addition, the domestic research institute also includes Zhongke Project Management Research Center, Beijing, which builds Project Management Web of China in Internet along with Training Center for Leaders from Economic Field, the State Economic & Trade Commission to centralize project management experts, professors and project management high-grade engineer with superexcellent achievements from Chinese Academy of Science and relevant universities to drive project management level in China to rapidly improve.

China National Chemical Engineering Corporation has started organizing experts to independently develop Engineering Project Comprehensive Management System (IPMS) of Chinese themselves based on the international general project management principle under the leadership and support of Construction Ministry and original Chemical Industry Ministry since 90s of last century. This system was formally completed in 1996, revised in 1998 and formally published and issued by Chemical Industry Publishing House, which includes 3 large parts, i.e. Practical Manual of Engineering Project Management (PMM), Basic Data of Engineering Project Management (PMD) and Engineering Project Management Software (PMS), of which, PMS has upgraded to 2000 edition. Moreover, overseas project management software have also entered into China's market, such as Primavera Project Plan of American Primavera Company, i.e. 3P or P3 software and Project2003 project management software of Microsoft Company.

Project management can be seen as a socially constructed field of practice that has developed from tools and techniques designed to support the management of major projects, from the conversations of practitioners and from their deliberate efforts to define a field of practice through definition of a distinct body of knowledge and associated standards. Fundamental to this is recognition of projects as phenomena with shared characteristics (Crawford, 2006).

The first signs of project management as a distinct field of practice were the network analysis and planning techniques, like PERT and CPM, that emerged in the 1950s for use on major projects in construction, engineering, defence, and aerospace industries (Kerzner, 1979; Morris, 1994; Stretton, 1994). Users of these tools and techniques recognized shared interests leading to the formation of project management professional associations in the late 1960s, initially to facilitate knowledge sharing between practitioners.

The mid-1990s were a crucial point in the development of project management standards and related certification programs. Indicative of the conception of project management at this stage in its development, all of the emerging standards focused on stand-alone projects and individual project management practitioners. The Project Management Institute issued A Guide to the Project Management Body of Knowledge in 1996, and in the same year the Association for Project Management in the U.K. issued the Third Edition of its Body of Knowledge. The Australian and United Kingdom governments endorsed performance-based competency standards for project managers in 1996 and 1997, respectively. The British Standards Board also issued their Guide to Project Management in 1996. The International Project Management Association issued their IPMA Competence Baseline in 1998.

From the mid-1990s onward, interest in project management grew progressively stronger, with a move towards the concept of project management as an organizational capability, fuelled by a series of articles in PMNetwork by Dinsmore (1996) who has consistently acted as a chronicler of project management practice. In this period also, an interest in benchmarking of corporate project management practices emerged. Two notable initiatives were the PMI-supported Fortune 500 Project Management Benchmarking Forum, which was formed in the mid-1990s, and the Human Systems Knowledge Network, which started collecting organizational project management practice data and facilitating knowledge sharing between corporate owners of project management in 1993. Both initiatives have contributed to the development of the concept of organizational project management capability through publication and conference presentations. Meanwhile, the majority of key project management professional associations have broadened their attention from facilitating the knowledge sharing and professional development of individual practitioner members to engaging and addressing the needs of what they term "corporates" either as a new class of membership or in other ways as key stakeholders.

This change from focus on the individual project and practitioner to project management as an organizational capability reflects the wider adoption of project management and a change in the nature of the concerns and conversations of this broader group of practitioners. When the project management associations first developed, the conversations between members involved senior project managers of large and often high-profile projects. As the disciplines developed on these major projects have been adopted "to cope with the management of employees involved with irregular assignments and to apply a structure to complex and discontinuous undertakings" (Hodgson, 2004) in finance and other sectors, the actors and their context have changed. There are now many conversations taking place at many different levels. The shift can be seen in the membership and participation of the project management associations, which are now dominated by consultants, trainers and relatively junior project managers and team members. Staff and leadership of the associations conduct conversations with the senior management of "corporates" who may have no direct experience in management of projects. The managers of major projects whose shared experience and interactions led the development of the field until the early to mid-1990s now tend only to appear as the occasional invited keynote speaker at a conference. With a change in the actors and their context, the nature of the discourse has changed.

The desire of senior practitioners to share and codify their experience in management of major projects has been replaced by the desire of relatively junior practitioners for training and certification for career advancement and the desire of senior managers for guidance in development of organizational capability, one aspect of which is the project management competence of their personnel. This change in focus has been accompanied by practitioner- and association-led initiatives for development of standards and guides that structure understanding of organizational project management capability. A key issue is recognition that in this broader application, projects in organizations are rarely isolated from environments that organizations must balance the re-sourcing of portfolios of projects, and that more than one project may be responsible for the delivery of the same strategic goal or set of outcomes or desired benefits.

The previous section has given a brief overview of the historical and social setting of the field of project management. It focused on the evolution of the concept and context of project management through the interactions of practitioners. The current section will focus on the evolution of the concept of organizational project management capability (OPMC) as a specific discourse within the wider field of project management. The intent is to provide the context for the following examination of a specific organizational discourse as a basis for comparing espoused theories, represented by Discourse 1 with theories in use or practice, and to test whether development of OPMC in practice reflects the espoused theories as presented in the literature and standards for practice.

Extension of the focus of project management beyond the individual project to encompass multiple projects, programs, portfolios, and enterprise wide approaches has changed the context, the actors, and the nature of conversations between them. The changing nature of the discourse is reflected in the commencement of development in 2005, by the Project Management Institute, of standards and guides for Program and Portfolio Management and the development, by the Association for Project Management in the United Kingdom, of A Guide to Governance of Project Management (Association for Project Management, 2004). Another strong voice in the conceptualization of project management as an organizational capability, has been the development and promotion by the U.K. government of a project management methodology, PRINCE2, initially designed for use on IT projects but further developed for wider application. Although the standards and guides for management of individual projects focused on project-related practices relating to time, cost, quality, risk, human resources, communication, and procurement, the shift toward project management as an organizational capability has been accompanied by interest in benefits management and governance which are featured in both PRINCE2 and Managing Successful Programs (MSP), developed and promoted by the U.K. Office of Government Commerce, ostensibly to help public sector organizations to improve their efficiency, gain better value for money from their commercial activities, and deliver more successful programs and projects.

Development of the Project Management Institute's Organizational Project Management Maturity Model (OPM3®) commenced in 1998 and was released in 2003 (Project Management Institute, 2003). During this time, it generated its own discourse with several hundred volunteers taking part in the discussions, the talk, and the text surrounding its development. Although the content of OPM3 is not widely known beyond those who were involved in its development, and because it is potentially too diverse (with more than 600 "best practices," more than 3,000 "capabilities," and more than 4,000 relationships between capabilities [Cooke-Davies, 2004]) to have clear impact on the construction and conceptualization of practice, it has already had a pervasive influence on the discourse by institutionalizing the notion of project management maturity. As early as 1998, the PMI Standards Committee established a standards project that was initially conceptualized as a guide to creating organizational environments to support management of projects1. Both Englund and Graham (1999) and Dinsmore (1999), who was a member of the PMI Standards Committee, contributed to development of this concept. However, early development of OPM3 was influenced by the discourse in software engineering around capability maturity (Humphrey & Sweet, 1987; Paulk, Weber, Curtis, & Chrissis, 1995), and the consequent emergence of a number of project management maturity models in the mid-1990s (Cooke-Davies, 2004; Pennypacker & Grant, 2003), so it is not surprising that the initial idea was re-formulated as an organizational maturity model.

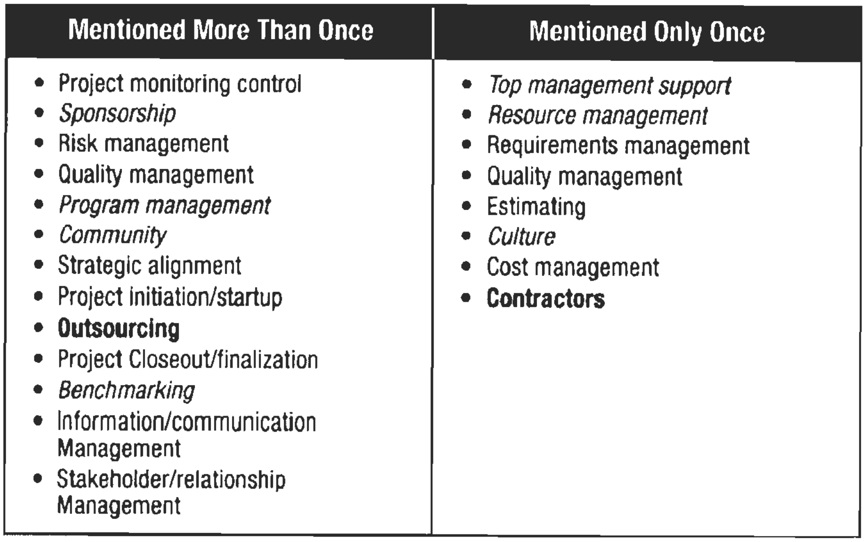
In Europe, the concept of organizational project management maturity has been reinforced by the work of Gareis (1990) who has been a leader in promotion of the concept of management by projects rather than the traditional concern with management of projects. In the early 1990s Gareis talked of project-oriented companies performing "simultaneously small and large projects, internal and external projects, and unique and repetitive projects to cope with new challenges and potential from a dynamic business environment" (Gareis, 1990). He also talked about the need to support the performance of projects with adequate strategies, structures, and cultures.

Through the discussions, conference presentations, and papers of consultants, academics and practitioners, project management as an organizational capability has become an important focus for discourse in the field. Strongly associated with this are ideas of assessment and development in terms of capability maturity. As Cooke-Davies (2004) suggested, maturity models "seek to do for organizations seeking to implement strategy through projects what 'bodies of knowledge' have done for individual practitioners seeking to improve their ability to manage projects". Interestingly, while there is much written about maturity models, the focus is not so much on the content as on the concept of maturity itself. Although the concept of maturity is generally accepted and much discussed, the aspects of capability that are assessed in the various maturity models (the OPM3 team examined more than 30 extant models, and other approaches to organizational project management capability are, in the literature, often left instated. When looked at they have strong similarities and some differences. However, while interpretations may differ across industries, application areas and regions, the concept of organizational project management capability and of maturity of that capability has become a widely accepted feature of the discourse.

Another strong emergent theme in organizational project management is the project or program management office (PMO), an organizational entity established to provide coordination or support for management of a number of projects or programs. Although it is generally agreed that one size does not fit all, there is some consistency in the types of functions provided, as found in studies reported Hobbs and Aubry (2005), and Dai and Wells (2004).

Examination of a number of studies of trends and topic coverage in the project management journals (Belts & Lansley, 1995; Crawford, Pollack, & England, 2006; Kloppenborg & Opfer, 2000; Morris, 2000; Morris, Patel, & Wearne, 2000; Themistocleous & Wearne, 2000; Urli & Urli, 2000; Zobel & Wearne, 2000), the content of a number of the maturity models and other publications relating to aspects of organizational project management capability, reveals common themes. Clearly, the PMBOK® Guide both reflects and has had a pervasive influence on the rhetoric of both management of, and by, projects, as integration, time, cost, quality, human resources, communications, risk, and procurement appear consistently in both the general project literature and, in one form or another, in many of the maturity models. From an organizational perspective, they are generally associated not only with project processes, but in some cases at program or portfolio level as well. Program and portfolio management are emergent themes in the literature. Associated with this is strategic alignment of projects and programs with organizational aims. Further, increasing application of project management to internal projects-particularly in business-changes and, in the financial and government sectors, has raised interest in benefits management and governance, both of which have also been highlighted by the wider discourse on corporate governance. Leadership, performance management, and top management support, including the role of the project/executive sponsor have also attracted increasing interest in recent years.

In a recent paper, Crawford (2006) presents the topics and themes mentioned by specialists in project management as the most important of the four last years (Figure 1).



Mentioned More Than Once	Mentioned Only Once
• Project monitoring control • *Sponsorship* • Risk management • Quality management • *Program management* • *Community* • Strategic alignment • Project initiation/startup • **Outsourcing** • Project Closeout/finalization • *Benchmarking* • Information/communication Management • Stakeholder/relationship Management	• *Top management support* • *Resource management* • Requirements management • Quality management • Estimating • *Culture* • Cost management • **Contractors**

Figure 1. Topics and themes in project management

In our thesis, the focus will remain on the core theme of project management, namely 'operational planning'. In this context, it's quite obvious to present a tool which is used frequently in operational planning, the Work Breakdown Structure. This tool is surely the basic tool to structure a project and constitutes the basis for the project planning, the earned value analysis, the quality analysis and also the risk analysis.

WBS is defined, in PMBOK Guide, as follows: WBS are group project elements geared to the needs of project deliverables, which organize and define the whole work range of this project. It represents the more detailed definition of project components by descending one level each. Project components can not only be the project deliverable product but also be project service activities. The project elements at the bottom are called work packages (WPs). One work package represents one deliverable at the lowest level in WBS. Work package can be further broken down to project activities. The project work content can be regarded as a series of work packages acquired by adopting WBS.

WBS is an important planning and control tool in project management, which is the basis for resource distribution, schedule, quality, risk control and cost estimation. The actions of WBS for managers are shown as follows:

1) Break down work project into known task
2) Provide resource planning information
3) Identify final deliverable project product
4) Help to completely consider project cost and schedule process
5) Help to assign work task and determine responsibility

The application of WBS methods and tools in modern project management are mainly shown as follows:

1) WBS is a planning and designing tool to describe clue, which help project manager and project team determine the work to effectively manage project
2) WBS is a structure design tool to clearly show the interrelations between each project work
3) WBS is a planning tool to shown full view of project and explain each work in detail must be completed for accomplishment of project
4) WBS defines milestone events, which can report the high-level management and customer the project accomplishment and be as reporting tool of project status.

Perfectly designed WBS can bring many advantages for management:

1) Prevent the project deliverables from omitting
2) Help project manager pay attention to project target and clarity responsibility
3) Build visualized project deliverables to facilitate workload calculation and work distribution
4) Help improve the accuracy of time, cost and resource estimation
5) Help to build project team and acquire promise of project personnel

6) Define a benchmarking for performance measurement and project control
7) Assist to communicate the clear work responsibility
8) Build framework for formulation of other project plan
9) Help to analyze the initial risk

Design principle and breakdown process of WBS

The creation process of WBS is firstly to break down one functional entity (project) into sub project according to tree diagram, which is then gradually broken down into many relatively independent working cell and determine the task of each working cell and its subordinate work (or is called activity). Creation of WBS can be divided into following steps:

1) Acquire project article, work range specifications or contract
2) Convene relevant personnel of project to collectively discuss all main project work and determine the breakdown method of project work to break down project work.
3) If there is ready-made template, it shall be used as best as possible.
4) Draw hierarchy structure diagram of WBS. Some work at higher hierarchy of WBS can be defined as sub project and sub lifecycle phase.
5) Finely divide main project deliverables into smaller and easily managed group or work package. The work package must be so detailed that (cost and duration) estimation, schedule arrangement, calculation and management personnel or organizing unit distribution can be made for it.
6) Verify the correctness of above breakdown. If project at lower hierarchy is found not necessary, the composition shall be modified.
7) If necessary, build a set of numbering system.
8) Continue to update or revise WBS with the process of other scheduled activities till it can cover all works.

The purpose to create WBS is to break down whole project work into elements that can directly control schedule, cost and quality. The final result shall be neither over coarse nor over fine, which shall be determined according to the specific features of project and environmental factors. At the same time, the creation of WBS shall follow some basic principles:

1) Some task shall appear in one place of WBS and only in one place.
2) The contents of some task in WBS shall be the total of all WBS items following it.
3) Only one person shall be responsible for one WBS, even if many persons may work on it, only one person shall be responsible for it, other persons can only be participants.
4) WBS must be in accordance with the implementation method in actual work.
5) Shall engage members of project team to actively take part in the creation of WBS to ensure the consistency of WBS.
6) Each WBS item must be documented to ensure to preciously understand the included and not included work range.
7) WBS must adapt to unavoidable changing at the same time when normally maintain project working content according to range specifications.

There are many methods for structure breakdown of WBS such as division according to specialty, division according to sub system and sub project and division according to different phase of project. In actual work, different methods shall be used at different hierarchy in WBS and various methods shall be comprehensively used according to the customer's requirement. There are different methods to create the WBS and the main methods are the following:

1) Use guidelines: some organizations like DOD of America provide guidelines such as MIL-STD to be used for creation of project WBS.
2) Analogy approach: refer to WBS of similar projects to create WBS of new project.
3) Top-down approach: Gradually break down project work from project target till participants think satisfactorily that the project work has fully been defined. This method can more accurately estimate the project period, cost and resource requirement since it can define the project work at an appropriate detail level.
4) Bottom-up approach: Gradually classify the identified and approved project task into the upper hierarchy from the detailed task till realizing the project target. The main risk existing in this method is that it may not fully identify all tasks or the identified tasks are over coarse or over trivial.

The breakdown process in WBS can depend on different standards, such as:

1) Breakdown according to the physical structure of product
2) Breakdown according to the function of product or project
3) Breakdown according to implementation process
4) Breakdown according to area distribution of project
5) Breakdown according to each target of project
6) Breakdown according to department
7) Breakdown according to function

The breakdown means of specific project shall be determined according to the actual situation of project. The breakdown is on the basis of project elements, which can be function or technical principle of project, organizational structure of project, geographic location where project is located and even the difference between main systems or sub systems of project. During actual project management process, the breakdown of WBS is often made by synthesizing various different breakdown means in the guidance of key factors.

It needs to be inspected whether it is reasonable and effective and whether it can meet with the requirement of project management activities after completion of WBS. The standard to inspect the correctness of WBS definition and breakdown mainly are:

1) The state and completion of each task can be quantified.
2) Definitely define the beginning and ending of each task
3) Each task has one deliverable
4) The construction period is easy to be estimated and within the acceptable period.
5) Cost is easy to be calculated.
6) Each task is independent.

Besides this, following several problems shall be paid attention for effective WBS:

1) The task after breakdown shall be manageable, quantitatively checked and task-distributed.
2) The complex work shall be broken down at least into two tasks.
3) Show the relation between tasks.

4) Not shown ordering relation.
5) The work at the lowest level shall be comparable.
6) Carry out along with task description list.
7) Include management activities
8) Include sub contractor's activities (Bai Sijun, 2003)

In our thesis, the WBS will be the tool used to integrate time, cost and quality under uncertain situation. In project management, it exist different methods or approaches to provide management information to assist the project manager in predicting the future outcomes of the project in term of quality, time and cost and to generate sound basis for decisions and actions. But, the future outcomes of the project are possibly affected by uncertainty and RM is useful to tackle these uncertainties that, when they occurred, could have an effect on the project objectives of time-cost-quality. So, uncertainty, that could be transform in risk for the objectives of the project, is considered as a Meta variable as illustrated by the figure 2.

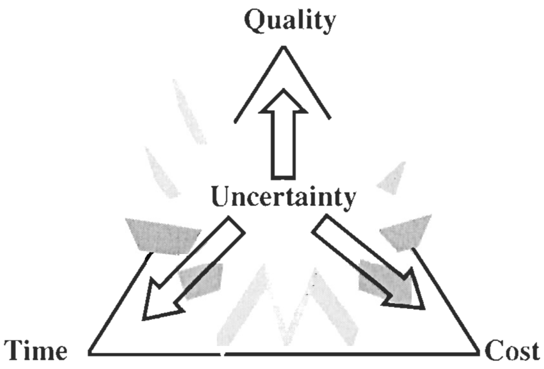


Figure 2. Risk as a Meta variable

Currently, risk management, quality management and time/cost management are managed as independent processes but recently, some exceptional papers (Hillson, 200; Paquin, Couillard and Ferrand, 2000) focus on the integration of these approaches in order to create synergy on project performance.

What shall be done most firstly in the project management is to carry out WBS analysis of project, division of work and then to analyze the quality management and risk separately. Thus, several problems will occur. Firstly, the work is done in division, which will cause disjoint problem in management. The more important step of WBS is to rectify and revise during task implementation to better finish the work. If the analysis of quality management and risk is done in division, it will cause each reversion will need to analyze the quality and risk again to inspect whether there are omits and new problems occurring. To do such is undoubtedly a kind of work of wasting and repeating. We can assume, if the quality and risk can also be analyzed at the same time of WBS, it will be greatly help to save resource and guarantee the speed of schedule.

Secondly, if quality analysis and risk management can be integrated into whole WBS, it will play a boosting action in the completion of whole project management system. The project management system is also slowly formed when people continuously integrated the management in various fields. For example, one of 9 project management function fields defined by PMI is project quality management field, and as one effective quality management method having been exited, the implementation of 6σquality management method is totally formed by a series of project. Then either project management covers quality management or quality management covers project management? Once we can integrate quality management into WBS to analyze together, such problem will not exist and project management system will be more perfect.

Thirdly, risk management can also use WBS methods to carry out management analysis of risk in level and type, which unintentionally is the soul idea of WBS. So, why not place the risk analysis into WBS to complete in one time, which not only can make the risk analysis more comprehensive but also can carry out direct risk analysis of the divided small task in WBS and complete in turn to make more easily control the risk analysis and management.

Detailed study contents are arranged as follows. In a first chapter, we'll proceed to a review of the writings in connection with the risk management, the concept of uncertainty and the ways to model it. In a second chapter, we'll present the contents and process of quality management, the methods of quality management and a special approach that we'll integrate in our proposed model, the Earned Quality Method (EQM). In a third chapter, the Earned Value Model will be presented and in the fourth chapter, we'll propose an integrated model of cost/time/quality under risk. A conclusion will complete this thesis.

Chapter I. Risk, Uncertainty and Measurement

Uncertainty is a term used in a number of fields, including philosophy, statistics, economics, finance, insurance, psychology, engineering and science and it applies to predictions of future events. It represents the gap between the information required to estimate an outcome and the information already possessed by the decision maker. In 1921, Frank Frank Knight established a distinction between risk and uncertainty. Risk is defined as uncertainty for which probability can be calculated (with past statistics for example) or at least estimated (doing projection scenarios) mathematically. Formally, Risk = (the probability that some event will occur) X (the consequences if it does occur). Uncertainty concerns, by opposition with the notion of risk, non statistical events, which are essentially unique or considered as such. These unique events can be considered as opportunities or threats for the project manager and, if risk is generally considered as a threat, one could propose that formal equation: Uncertainty = Risk + Opportunities in project management. Today, mathematicians handle uncertainty not only using probability theory, but with Dempster-Shafer evidence theory or interval or fuzzy sets theory.

In dictionary definition terms 'risk' means: ''hazard, chance of bad consequences, loss, exposure to chance of injury or loss '' (Concise Oxford Dictionary). Such definitions illustrate one problem with the term 'risk'—its ambiguous use as a synonym of probability or chance in relation to an event or outcome, the nature of an outcome, or its cause. In an entertaining and well referenced paper, entitled ''Against risk'', (Dowie, 1999) argues persuasively for abandoning use of the term 'risk' altogether. ''It is simply not needed''. Dowie argues that the term 'risk' is an obstacle to improved decision and policy making. Its multiple and ambiguous usages persistently jeopardize the separation of the tasks of identifying and evaluating relevant evidence on the one hand, and eliciting and processing necessary value judgements on the other. (The term) 'risk' contaminates all discussions of probability because of the implicit value judgement/s that the term always brings with it, just as it contaminates all discussions of value assessment because of the implicit probability judgement/s that it contains (Dowie J. 1999) .

The present authors are inclined to disagree with Dowie about abandoning use of the term 'risk' completely, but we are very sympathetic to his concerns. One of our concerns relates to the association of the term 'risk' with adversity, implying that project risks are potential adverse effects on project performance, and that sources of risk are 'things that might go wrong', or threats to the project. With this association, PRM would seem to be about identifying and managing threats to project performance. As is widely recognized, this view of PRM is restrictive because it fails to consider the management of opportunities, in the sense of 'potential welcome effects on project performance'. In any given decision situation both threats and opportunities are usually involved, and both should be managed. A focus on one should never be allowed to eliminate concern for the other. Moreover, opportunities and threats can sometimes be treated separately, but they are seldom independent, just as two sides of the same coin can be examined at one at a time, but they are not independent when it comes to tossing the coin. Courses of action are often available which reduce or neutralize potential threats, and simultaneously offer opportunities for positive improvements in performance. It is rarely advisable to concentrate on reducing threats without considering associated opportunities, just as it is inadvisable to pursue opportunities without regard for the associated threats. Recognizing this, guides published by the US Project Management Institute (PMI) and the UK Association for Project Management (APM) have adopted a broad view of risk. Their definitions of risk are very similar, as follows:

- Risk—an uncertain event or condition that, if it occurs has a positive or negative effect on a project objective (project management institute, 2000)
- Risk— an uncertain event or set of circumstances that should it occur, will have an effect on the achievement of the project's objectives (Hillson, 1997)

These definitions encompass welcome 'up-side' as well as unwelcome 'down-side' effects. In spite of this, there is still a tendency for practitioners to think of risk in largely down-side, threat terms (a tendency which the authors are not always able to resist), and PRM as primarily threat management. For example, Table 1 lists references in the PMI guide (Project Management Institute.2000) to risk in down side, threat terms which include: illustrative examples of risks as threats, terminology, descriptions of risk responses, and the use of probability impact matrices. The preponderance of such references suggests at least an emphasis, if not a pre-occupation, with threats rather than opportunities. This emphasis might reflect a difficulty in throwing off the commonly understood meaning of 'risk'.

Another of our concerns is the focus on 'events' or 'circumstances' which these definitions suggest. We suggest it is important to take uncertainty about anything that matters as the starting point of uncertainty management, defining uncertainty in the simple 'lack of certainty' sense. (Ward and Chapman, 2003)

Risk is the deviation from the expected target or benefit which is caused due to the uncertainty of object events and can be sensed by the subject during decision activities of the subject. This kind of deviation has division in size, degree and positive negative, i.e. probability of risk, serious degree of consequence and losses or profits.

The measurement of project risk can be considered in following aspects:

(1) Measure according to probability and serious degree of joint risk

This measurement can be shown with risk quantity. Risk quantity R is defined as $R = f\left(P, q\right)$, in the formula, P represents the happening probability of risk event, q is the magnitude of loss caused against project due to happening of risk event. Risk quantity is usually used to represent the magnitude of influential degree of project risk factors in the estimation of project risk factors. (Zhang Qinghui, Sha Jichang, 1996)

(2) Measure according to the serious degree of consequence and the subject's reaction

It relies on its expected target or benefit whether the subject has reaction against risk. When serious degree of consequence deviates from the subject's expectation, the subject will feel the existence of risk. This measurement can be shown with risk rate, which is represented with P with definition as $P = P\left(x < x_0\right)$, in the formula, x is the expected result estimated by project subject due to existence of risk, x_0 is the specified value or target value of project subject. Risk rate is often used in project risk evaluation.

(3) Measure according to the statistical regularity of risk events

This measurement can be shown with risk degree. The risk degree is defined as follows: □ when using average value as estimation value of some variable, the risk degree is defined as $FD = \dfrac{\sqrt{DX}}{EX}$ □ when average value is not adopted to be as the estimation value of this variable due to some cause, assumed estimation value is X_0, then the risk degree is defined as $FD = \dfrac{\sigma - \left(EX - X_0\right)}{\sqrt{DX}}$, in the formula, EX is average value, DX is variance and σ is standard deviation. The more large risk degree is, which shows the more little confidence to future, and the more large risk is. Risk degree is not so important to some single scheme, which had better is used to compare different schemes to list the magnitude of relative risk to provide reference for decision makers .

An important component of risk management relates to project schedule uncertainty. In project management, and in particular in scheduling problem, we can distinguish several approaches to deal with uncertainty (Herroelen and Leus, 2005): stochastic scheduling, scheduling under fuzziness, reactive scheduling and proactive (robust) scheduling. The stochastic project scheduling problem aims at scheduling project activities with uncertain durations in order to minimize the expected project duration. This difficulty has been noticed very early by the authors that introduced the PERT (Malcolm, Rosenboom, Clark, Fazar, 1959) approach and there is an extensive literature on probabilistic PERT. The advocates of the fuzzy theory argue that probability distributions for the activity durations are unknown due to the lack of historical data and that activity durations have to be estimated by human experts, with judgmental statements that are vague and imprecise. In those situations, which involve imprecision rather than uncertainty, the fuzzy set scheduling literature recommends the use of fuzzy numbers for modelling activity durations (Slowinsky and Hapke, 2000), rather than stochastic variables. Instead of probability distributions, these quantities make use of membership functions, based on possibility theory. Recently, Dubois et al. (2005) tackled the simplest form of uncertainty representation for activity duration, the interval. Assigning some time interval to activity duration means that the actual duration of this activity will take some value within, but it is not possible at present to predict which one. Reactive scheduling does not try to cope with uncertainty in creating the baseline schedule but revises or re-optimizes the baseline schedule when an unexpected event occurs (Sabuncuoglu and Bayiz, 2000, Vieira et al., 2003). The last approach, which is gaining increasing popularity among project management practitioners, is the Goldratt's critical chain methodology (Goldratt, 1997) and refers to a proactive scheduling. In fact, to tackle the uncertainty, a buffer insertion approach is used. It's a renewal in project scheduling but some oversimplifications have been revealed recently (Herroelen et al. 2001; Herroelen at al. 2002, Giard, 2003).

This type of uncertainty, referring to estimating uncertainty, is generally integrated in the planning process through the Monte Carlo analysis. Monte Carlo simulation is the most useful technique to take account of variability in uncertain parameters as duration or cost estimate simulation and is more commonly used to estimate the criticality of different activities and paths, as well as the probability distribution of the project duration.

Monte Carlo simulation of project networks is a standard project-modeling technique. However, much of this analysis is inadequate, as project managers always take action to recover late-running projects, which is ignored in most models.(Terry, 2004)

Time analyses of projects are nearly always based on the network (PERT or CPM) concept (Moder, 1988). In more recent years, project time-risk analysis using Monte Carlo simulation, including uncertainty in the networks, has become a standard technique in the project manager's toolbox. While CPM served well to structure a network and provide point estimates for the duration of a project, the increasing complexity of projects and the increasing availability of computer power has brought Monte Carlo simulation into common usage.

A Guide to the Project Management Body of Knowledge (PMBOK® Guide) (Project Management Institute, 2000) describes Monte Carlo analyses of networks in Chapter 11, where it states: Project simulation uses a model that translates the uncertainties specified at a detailed level into their potential impact on objectives that are expressed at the level of the total project. Project simulations are typically performed using the Monte Carlo technique. For a schedule risk analysis, the Precedence Diagramming Method (PDM) schedule is used.

In its Glossary, the PMBOK® Guide defines Path Convergence as: The node in the schedule where parallel paths merge or join. At that node, delays or elongations on any converging path can delay the project. In quantitative risk analysis of a schedule, significant risk may occur at this point.

The UK project management community is in general agreement. The Project Risk Analysis and Management (PRAM) Guide (Hillson, 1997) says that "The PERT technique has been superseded by the more powerful Monte Carlo simulation modeling supported by computer-based tools, and PERT is no longer considered to be a suitable risk analysis technique"; in Appendix A3.3, it details how to undertake such analyses by simply listing the risks and opportunities for each task, setting up a Monte Carlo model and populating it with data, running the simulation analysis to determine the total duration of the project, and presenting the results.

This technique can now be considered as common usage. It has for some time been described in texts that could be considered standard Wideman, 1992 and Pritchard, 1997). Extensions to network scheduling software that can carry out such analyses can be found through various sources, including Palisade Corporation (a), Primavera Systems Inc., ProjectGear Inc., and Welcom Software Technology (Terry W 2004)

In project management, we generally address another type of risks, namely the discrete risks. Generally, discrete risks are tackled by the traditional project risk approach with contingency plans and techniques like conditional and probabilistic branching (Hulett and Hillson, 2005) as in GERT (Pristker and Happ, 1966) are considered as a good way to model the effect of discrete risks on project time and cost. It's essential to take into account these contingency plans because the uncertainty could change the scope of the project, as illustrated in figure 3. For example, if the activity 2 had suddenly failed, then instead of carrying out the activities (4 and 8), we would carry out the activities (6-7 and 8).

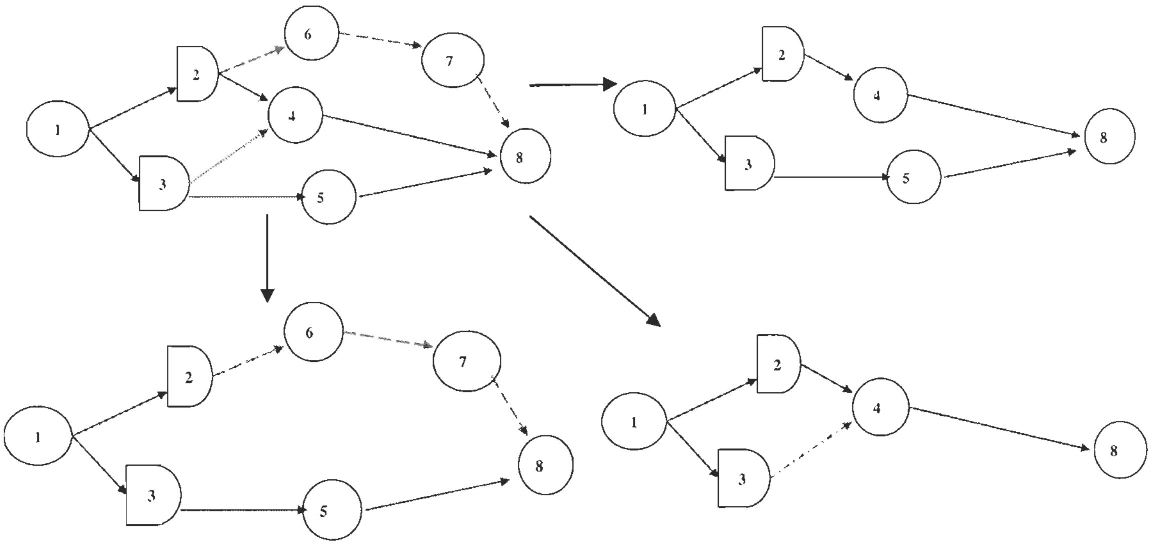


Figure 3. Contingency plans

One can also model this problem using a "decision tree" representation (figure 4).

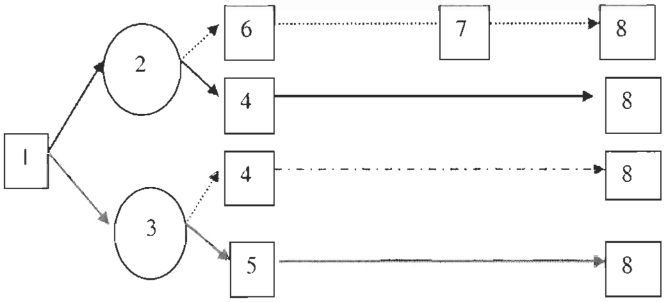


Figure 4. Decision tree representation

In this thesis, theses two types of risk and theirs consequences about the objectives (time/cost/quality) of the project will be considered.

Uncertainty management

To emphasize the desirability of a balanced approach to opportunity and threat management, the term 'uncertainty management' is increasingly used in preference to the more established terms 'risk management' and 'opportunity management'. However, uncertainty management involves rather more than the combination of risk management and opportunity management.

Uncertainty management is not just about managing perceived threats, opportunities and their implications. It is about identifying and managing all the many sources of uncertainty which give rise to and shape our perceptions of threats and opportunities. It implies exploring and understanding the origins of project uncertainty before seeking to manage it, with no preconceptions about what is desirable or undesirable. Key concerns are understanding where and why uncertainty is important in a given project context, and where it is not. This is a significant change in emphasis compared with most PRM processes.

The scope of uncertainty

The scope for uncertainty in any project is considerable, and most project management activities are concerned with managing uncertainty from the earliest 'Conception' stage to the final 'Support' stage of the project life cycle (PLC) (Chapman and Ward, 1997), clarifying what can be done, deciding what is to be done, and ensuring that it gets done. Uncertainty in the plain English sense of 'lack of certainty' is in part about 'variability' in relation to performance measures like cost, duration, or quality.

It is also about 'ambiguity' associated with lack of clarity because of the behavior of relevant project players, lack of data, lack of detail, lack of structure to consider issues, working and framing assumptions being used to consider the issues, known and unknown sources of bias, and ignorance about how much effort it is worth expending to clarify the situation.

In a project context these aspects of uncertainty can be present throughout the PLC, but they are particularly evident in the conception, design, plan and allocate stages. Here these aspects of uncertainty contribute to uncertainty in five areas: the variability associated with estimates of project parameters, the basis of estimates of project parameters, design and logistics, objectives and priorities, and relationships between project parties. All these areas of uncertainty are important, but generally items become more fundamentally important to project performance as we go down the list. Potential for variability is the dominant issue at the top of the list, but ambiguity rather than variability becomes the more dominant underlying issue towards the bottom of the list. Uncertainty about variability associated with estimates involves the other four areas, each of them involving dependencies on later areas in this list. (Hillson, 1997)

Chapter II. Quality management techniques

II.1. Contents and process of quality management

In fact, for the project stakeholders with different individual standpoints, the expected quality target will also be different. If one project will be a success, what important is to get balance among each project stakeholder to satisfy their expectation but not be able to satisfy everyone fully such as a project to develop a new foodstuff. As consumers, they will surely hope it is delicious, nutritious and cheap, but for the manufacturers, they will surely consider profit first. So for the project stakeholders with consumer character, they will need much higher-quality project product and they want:

- Better performance;
- Shorter project implementation period;
- Higher technical level and standard;
- Make use of raw material and handling ability to the maximum;
- Fewer cost;
- Lower rate of defect and fewer problem happening;

For the project stakeholders including manufacturers and project team, they will also consider the impaction on the project quality by these following problems besides will consider the requirement of project stakeholders with consumer character:

- Have market: look for a balance between project quality and cost;
- Feasible: have technology and worker can be used and ability to implement project with the acceptable cost;
- Accepted by society: the conflicting degree between product and manufacturing flow and social value (safety, environment and moral etc.);
- Operability: the safety degree of project implementation and the degree to acquire reviewing and approval as well as admission;
- Usability: the possibility of the project to have satisfied performance and acquire acceptance under the given condition;

- Reliability: the possibility of the project product to suffer fault under given operation condition and operation time;
- Maintainability: the possibility of project to run without fault and meet with operational requirement after prescribed maintenance;

One project can not be accepted as success until the abovementioned conditions are satisfied, namely meet with one factor of project success— meet with or exceed the expectation of project stakeholders.

II.1.1. Contents of quality management

Quality control is the operation technique and management activities adopted to reach the standard requirement of project quality during project implementation. This type activity shall include a continuous control process to find out the quality problem and cause in time, reduce the likelihood of quality problem and guarantee the smooth implementation of project. Its final purpose is to make the project quality reach or exceed the expectation of project stakeholder for a successful project.

Quality control in an important technical aspect in project management and there are not many methods in its management, mainly the quality control by experts and general engineers with specialty in project technical field. As project management personnel, what more important is to play a supervision and management action. Even if the project management personnel (project manager etc.) are the expert in technical field, he shall not spend too much time and energy in the specific project (detail) control. To do so, problems surely will occur in other aspects.

Quality control needs project technical personnel with different technical specialty to play each role, build some techniques and procedures to guarantee the project to provide qualified outcome in each step from design to development and to implementation and outcome of each step to be in accordance with relevant quality standard and project scheme. Perfect project quality control shall realize following aspects:

- Select what to be controlled;
- Build standard (uniform standard of relevant national governments for some industries) to provide foundation for possible correct decision making;
- Have practicable measurement and inspection methods;
- Compare the actual effect with quality standard;
- Adopt action to verify the incorrect process and material to the degree in accordance with standard on the basis of meeting with collection of timely and precise information;
- Regularly manage and calibrate relevant inspection equipments;
- Build document file including all information.

II.1.2. Process of quality management

Project quality control process will start to determine project quality target and quality standard from the beginning of project (the quality standards in some industries are implemented according to the uniform specifications of industry, which generally are established by relevant national departments). There shall be relevant professionals to carry out control in the whole project lifecycle. What shall be paid attention to is: final control of the schedule and cost control as well as schedule control of project will generally be carried out by project manager and the final whole control of quality control will generally be implemented by relevant technical personnel such as general engineer etc. and the project manager will be only responsible for quality control in project team organizing structure and material supplying, they jointly form the highest decision-making level of the project team. Final general project product will be handed over to special management operation department to operate management, what to be handed over along often also includes relevant file information of project, which will be managed by project team after completion of project. For example, a building will be handed over to property department for management and daily maintenance after completion and a project of building a chain supermarket in some area will be handed over to the market department of the company to be responsible for operation after completion of supermarket.

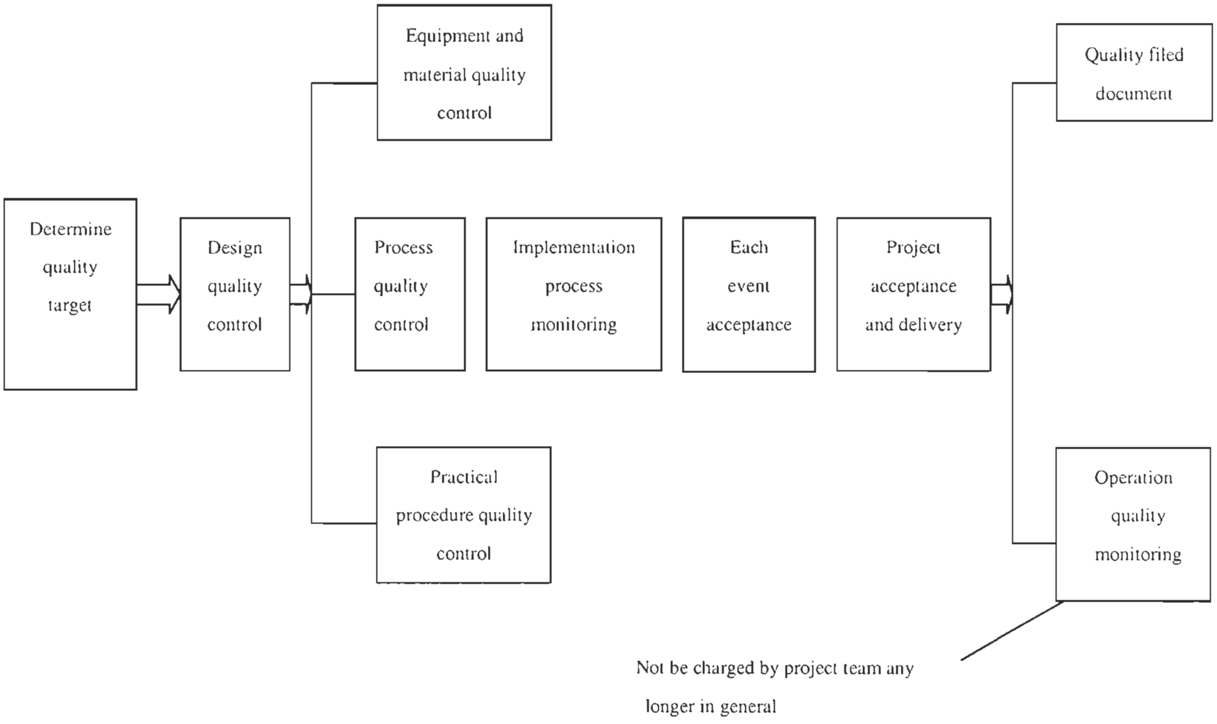


Figure 5. Schematic diagram of quality control process

II.1.3. Factors affecting quality management

The factors affecting project quality control mainly include: project stakeholder, raw and auxiliary material supply, machinery equipment, methods and project operation environment.

(1) Project stakeholder. It is undoubted that project stakeholder will have an impact on various aspects of project, impact on some aspects can be neglected or adopting measures for remedy, but the impact on project quality by many of them is irremediable and fatal. For example, the high-level leader of company and principals of relevant departments only have a smattering of knowledge about technology and make indiscreet remarks and criticisms according to individual preference, which will finally cause failure due to unqualified quality. Do not such examples often occur in China? Furthermore, the working attitude, sense of responsibility and quality view of project team can have impact on project quality control.

(2) Raw and auxiliary material supply. Raw and auxiliary material is the material condition of project and material basis of project product. Quality and supply channel of raw and auxiliary material can have a direct impact on the project product quality.

(3) Machinery equipment. During implementation of many projects, the project product quality will be caused problem due to the performance index, model and quality of project machinery equipment, therefore, it is necessary to control the quality, model, installation process and quality as well as debugging and running process of the machinery equipment to be used for project.

(4) Methods. Mainly consider the impact on project quality by the technical scheme, process flow, organization measure, planning and control means and inspection means of project implementation.

(5) Environment. Environmental impact mainly includes two aspects: one is external environment including social economic factor, social cultural factor, political and law factors etc. will have an impact on the determination of project quality target and quality control; the other is task environment, which refers to the environment composed by project stakeholders, such as the quality requirement of consumer, intervention in quality control by high-level departments, the supporting degree in quality control by parallel functional departments and implementation degree of project quality control by project team members will have an impact on project quality.

Quality is the core of project target factors. Undoubtedly, if the quality of one project product fails to meet with the requirement, it will make no sense even if more cost is saved and schedule is faster. Therefore, quality control has always been the focus to be paid attention to in project management.

Quality control is an aggregation of activity and technology. During this process, activity and technology aim to create and inspect specific quality character. This activity includes continuous monitoring process to identify and remove the cause for quality problem, reduce problem likelihood with certain technology and methods and finally ensure to realize the technical quality target of project.

For company and project team, quality is always the focus they pay attention to and there are always many theories regarding quality management and quality control. Today, what is studied and applied more frequently is Total Quality Management (TQM). This theoretical method can also be applied in project quality management. This theory has been much more mature, so the writer will not make discuss hereby. For the character that the quality data and information in project are much large, some methods of statistics can be tried to apply into project quality control. These methods of statistics are mainly used for collection and analysis of project quality data and information. For specific quality control, it shall still apply current more mature management science knowledge (such as TQM etc.)

II.2. Methods of quality management

II.2.1. Causal analysis

It is necessary to analyze causes when quality problem is found out. Sometime, causal relation is fuzzy and large amount of analysis will often need to be made in order to determine one or several specific causes of one problem. Causal analysis is to determine the relation of cause and effect according to diagram technology. Figure 6 shows the six factors affecting project product quality and this diagram is called fishbone diagram.

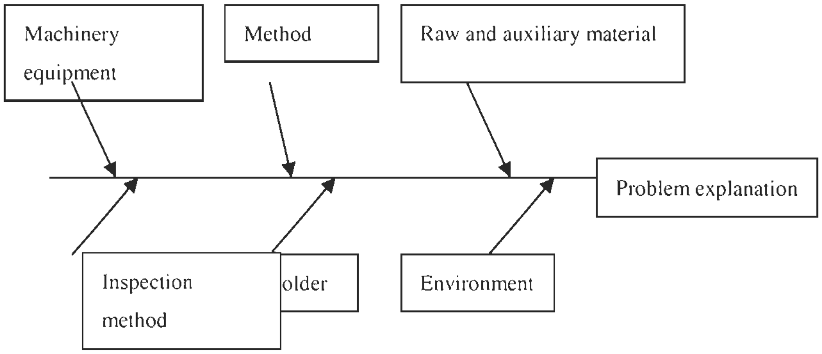


Figure 6. Fishbone diagram of impact factors of project quality

Six steps will be need for causal analysis in general:

- Determine problem. Problem must firstly be determined before analysis of cause. This process will involve other techniques which will be mentioned in following discussion. A simple and clear description of problem will be obtained through these processes.
- Select experts to form problem-solving team. Define the required technology, analysis and management knowledge according to the determined problem and employ experts in these aspects to form special problem-solving team.
- Draw schematic diagram. The schematic diagram is for problem explanation of causal analysis. The main arrowhead is taken as classification basis of main type.
- Determine specific classification of the cause of problem. For example, determine six aspects when analyzing the factors affecting quality.
- Discriminate the cause of problem. After determining problem, it can determine a series of causes relevant to each cause. There are many methods to determine these causes, but the writer thinks that it had better firstly center on one main type according to the possibility and importance of generation and turn to next more important type after completion. For example, if thinking the cause of problem A most possible (or the factor that most possible affect quality A) is machinery equipment, it can firstly make analysis of it as shown in Figure 7. Of course, you can select a type in random, then make analysis one by one, or analyze the cause of problem according to some order of specific project. The writer thinks it also can work.

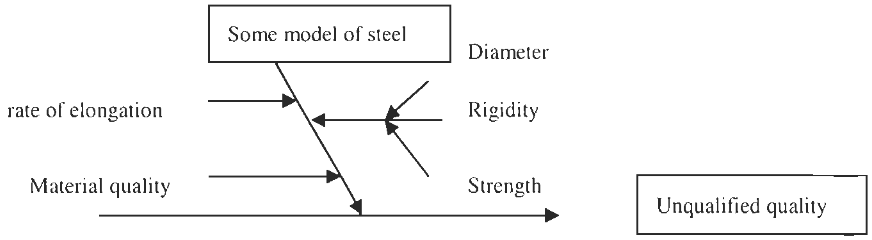


Figure 7. Methods to discriminate the cause of problem

- Determine correction and remedy measures. After finding out cause of problem, it shall look for correction and remedy measures. Fishbone diagram can also be adopted to show the generation of correction and remedy measures as shown in Figure 8.

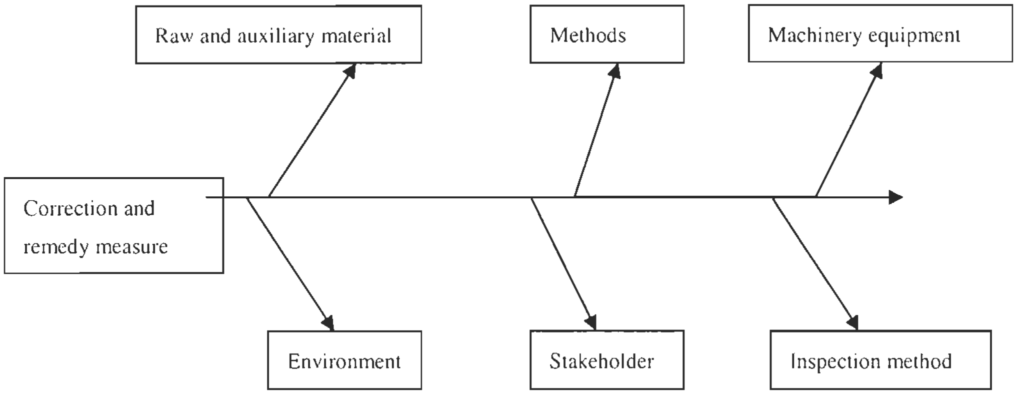


Figure 8. Fishbone diagram of correction and remedy measures

Adopting causal analysis method can determine the cause of problem as well as correction and remedy measures, but it is not difficult to find that it only limit on words to great extent. Correction and remedy measures can be resolved by problem-solving team formed by experts, but the problem description and cause seeking shall be obtained through analysis according to collected quality information and data. It also can resolve these problems with some methods of statistics.

II.2.2. Data list

Adopt simple and intelligible data list to show data and information relevant to project quality and make classification to provide possibility to further analyze problem and find out problem. Assumed that there are four supplier for one project, if analyzing the possibility that problem happens to material and further affects quality, firstly it need to list the problem data list of supplier's material as shown in Figure 9.

Each mistake in the table can be understood in such way:

- Mistaken delivery list. The model, grade and quantity of material in delivery list is not in accordance with ordering list;

- Mistaken storage. The material storage is not in accordance with delivery list;
- Material breakage. The material is refused to receive due to breakage caused by transportation etc.;
- Mistaken filed documents. For example, some relevant factory qualification certificate and test material etc. required by material is short or mistaken.

Mistake	Supplier				
	A	B	C	D	Total
Mistaken delivery list	3	2	1	1	7
Mistaken storage	4	1	2	2	9
Material breakage	5			3	8
Mistaken filed documents	1	3	4	2	10
Total	13	6	7	8	34

Figure 9. Material inspection and checking data list

II.2.3. Control chart

All abovementioned several method applying statistics are for finding out mistakes and making correction and remedy. Besides finding out mistake, what effective control needs more is to nip in the bud and avoid mistake before it occurs. During examination and approval as well as implementation of project, how to give attention to both economy and efficiency has always been the problem for project stakeholder to pay attention to and it is a more bothersome problem to further correct the arisen mistake, so it can adopt control chart in statistics process to prevent mistake form occurring further to reduce cost and improve efficiency.

Control chart and normal distribution. The building, application and combination of control chart are on the basis of normal distribution as shown in Figure 10.

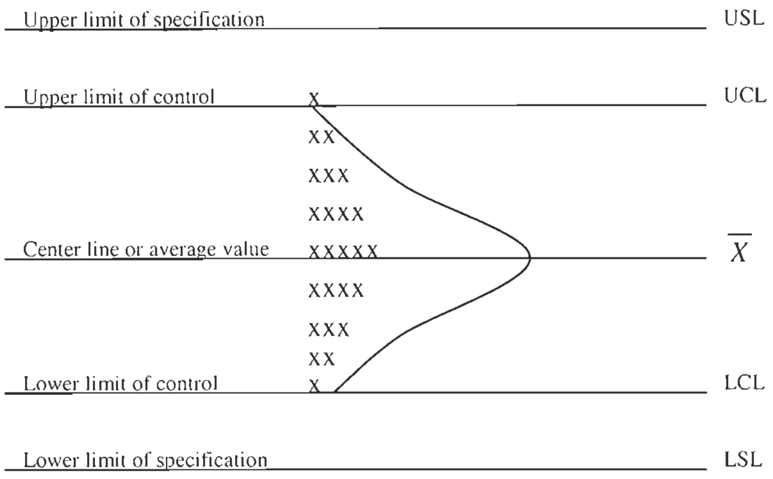


Figure 10. Control chart and normal distribution curve

The center line of control chart represents the average value of data (X). The upper and lower limits of control chart (UCL, LCL) separately represent the average value plus and minus 3 times of standard deviation ($X \pm 3\delta$). For example, the known normal distribution is symmetrical with respect to center line. 99.93% of the measurement value of normal distribution is located between $X+3\delta$ and $X-3\delta$, so the control chart boundary is called 3δ boundary.

However, it is known that many large international companies adopt 6δ boundary such as Motorola and GE. The cause is that it will need expensive cost even if maintaining 6δ boundary by taking into account the cost factor and even if 6δ boundary is satisfied, it is enough to guarantee the quality of project product.

Control chart analysis can determine whether the internal process variation and process average value of project product is in stable level and find out one of them or both of two are outside of statistics (problem happens). The other purpose of using control chart is to distinguish process internal and random variation as well as the special variation causing special cause. The origin of random variation generally is taken as common cause, which will not change at will when the project process is without change, and special variation shall be determined according to process situation.

- General variation (common cause causes variation). It generally happens in any production process of same one project and is internal of project, which will not be corrected until supervisor changes main project process or some basic factors.
- Special variation. This variation can be controlled in the local part of project or some layer and some unit element of WBS. Special variation can be removed through correction or change of some part.

In order to effectively apply process control to analyze data, variation must be understood definitely. Just as what everyone knows, there are no two totally same products or processes, because any one process is full of variation, only some of these variations are larger and some are so small that it is unable to be observed or measured. However, it is undeniable that this variation exists. Some variation in process may have impact on the quality of project product, such as quality change of raw material and difference in level of skilled workers etc., some variations may cause the change of project product quality, such as normal abrasion of machinery equipment.

In order to control and improve process, it must track the whole variation till its origin. Similarly its origin is also different due to common cause and special cause. Common cause is the origin of variation in statistics range and special cause is the origin of variation outside the statistics range. They will affect the project implementation in an unpredictable way, unless all cause of special cause are determined and corrected.

The main factors affecting project quality having been mentioned above include: project stakeholder, raw material supply, machinery equipment, method, inspection method and environment. Variation may be from the internal or special cause of these factors in process.

Control chart element. All control charts have its common character (as shown in Figure 11). Each control chart has a center line, statistics control limit and control data. Of course, some control charts have their own special limit, which does not belong to the discussion range hereby.

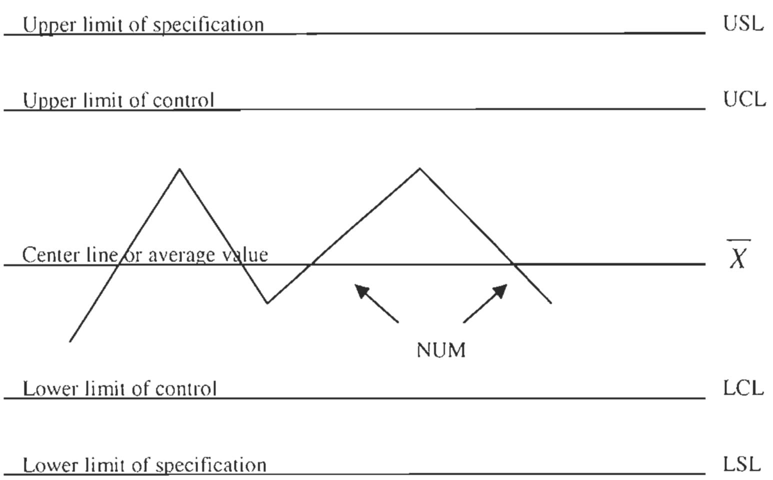


Figure 11. Control chart and normal distribution curve

Center line generally represents the average value of all data. In normal situation, data shall be controlled between upper and lower limits. When project process and operation have specific requirement, special parameter shall be adopted. The elements of control chart may be a little different with the different specific project.

The change and types of control chart can have many different explanations. If the explanation is correct, it is believed that control chart can show many things but not simply whether the implementation process can be controlled. This is just the reason why the writer uses control chart to make analysis. The following figure 12 shows several possible distributions of control chart.

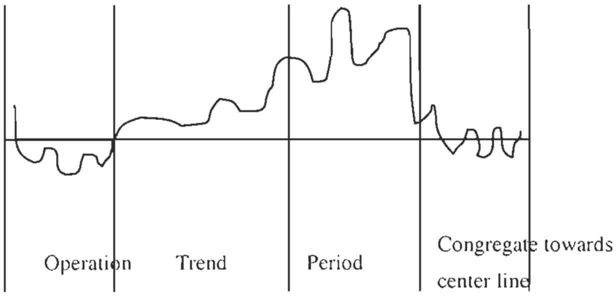


Figure 12. Control chart explanation

For the explanation of these kinds of operation means of control chart, there are relevant knowledge in statistics, it will not be described one by one hereby.

Control chart explains when problem will occur or problem is about to occur, however, only depending on it will not be able to find out where the problem will occur or the reason of problem. In fact, one of its larger advantages is that it can explain there will not require human intervention in project operation process under what situation. When the project is in operation, the project process may be caused variation due to error operation of some member of project team or tiny change.

Use of control chart method can find out the trend of data point and prevent mistake in certain extent, which also can find out the combination of problems, determine the location of problem and further complete causal analysis method.

As supplement of control chart application for quality control, simply explain process capability hereby, process capability refers to the ability to produce project product in accordance with design development standard. Since the implementation process of the basic project target control methods changes every day, process capability is the description of consistency of project product (project implementation process). Measure process capability C_p with the quality character of project product (may be one activity, unit element) with mathematical expression formula as follows:

C_p=(USL-LSL)/ 6δ

Generally, $C_p>1$, which represents the limit of 3δ can meet with requirement. Generally, C_p meets with following character:

· $C_p>1.33$, process fully meets with limit requirement.

· $1.33>C_p>1.0$, process narrowly meets with requirement but can not fully meet with requirement, it requires to improve the process.

· C_p<1.0, process can not be accepted and must be improved.

For the specific knowledge of process capability, please refer to relevant information, it will not introduce one by one hereby. The introduction of this concept is help to apply control chart method to analyze quality data.

II.2.4. Implementation of 6δ criterion

6δ is the criteria used in the field of market's innovation and was advocated firstly by Motorola in 90s, which afterwards was successfully applied for quality control of their products by GE and Sony and this method made their products with more excellent quality and lower price than the rivals. They applied this principle into one after one project simultaneously and also applied 6δ method to increase profit and train employee. Former CEO of GE Jack Welch described 6δ as the pioneer measure with most challenge and most payoff potential adopted by GE, who applied it into quality control of many projects.

II.2.5. Project risk analysis and quality analysis based on WBS

The principle parts of project control are schedule, cost and quality. The main aspects of risk control are schedule and cost. The satisfied quality always conflicts with cost and schedule control. In order to meet with the ever-changing requirement of customer, the project may be delayed indefinitely and investment has already exceeded budget, therefore, the final plan of project shall look for a balance among the three parts, which needs to clearly define quality and smartly deal with schedule and cost risk control program.

As shown in Figure 13, a possible WBS-based risk quality control program could be based on two aspects: the breakdown structure system of risk and the breakdown structure system of quality, but the key of final program forming is the compromise of conflict. It'll be the idea we'll develop later in our propose methodology.

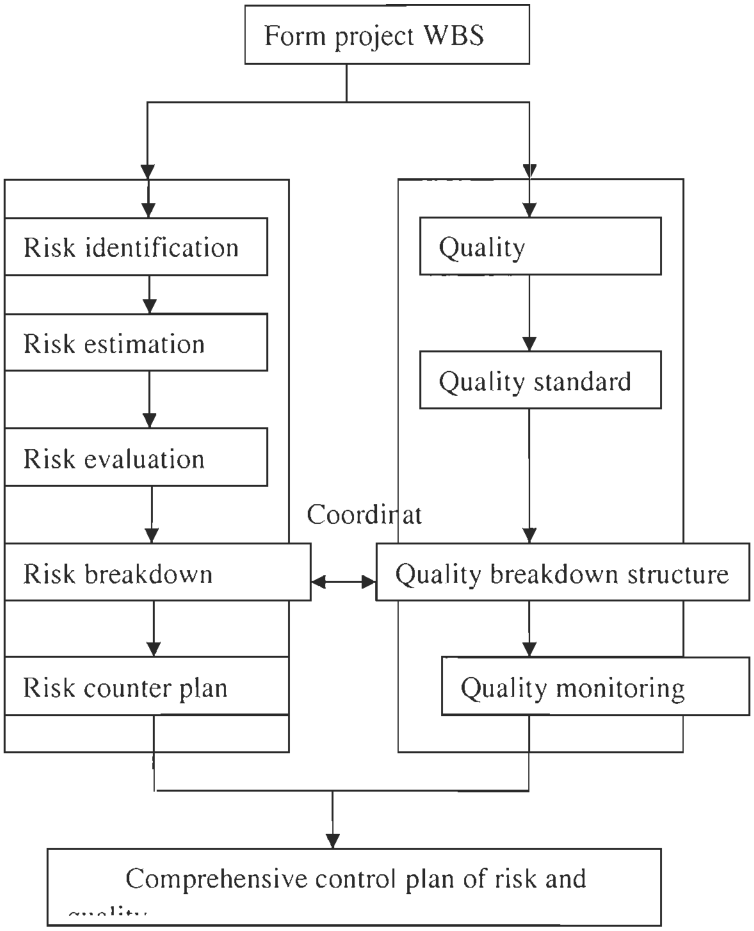


Figure 13. WBS-based risk quality control program process

II.3. The Earned Quality Method (EQM)

Quality is key to project success and ISO 8402 defines it as '...the totality of features and characteristics of a product or a service that bear on its ability to satisfy the stated and implied needs'. So, it's achieved if the client's expectations and needs are obtained by the project end product. In this context, Paquin, Couillard and Ferrand (2000) proposed the EQM, a general approach to assist project managers in assessing and controlling the quality of the project end product. Their method rests on two assumptions: the quality is a measurable concept and quality is accrued progressively through the achievement of the project.

Quality is achieved to the extent that a project end product meets the client's needs and expectations. The fundamental issues relating to the periodic assessment and control of the quality of the end product of a project are addressed. The proposed earned quality method enables project managers to assess and control the quality of the end product throughout the project's life cycle. Using a multicriteria approach, EQM allows project managers to deal in a formal and quantitative fashion with the client's stated and implied needs. By comparing earned quality and planned quality of the work performed, EQM enables project managers to detect quality deviations and initiate early corrective actions.(Paquin , Couillard and Ferrand, 2000)

To apply this method, the project manager needs the following data: a work breakdown structure (a list of all tasks broken down in a hierarchical structure), a project master schedule (a Gantt chart of what task will be done when and by whom), a quality breakdown structure (a list of quality criteria which measure the client's needs) and for each quality criteria, a value function which determine the client's value function over all possible results and a measure of the relative contribution of each activity of the project to the quality of the end product of the project.

The EQM can be described by the following steps.

- Explicit the client's needs and quality expectations and Aggregate the client's values with respect to quality

In this step, the project manager and the client determine the QBS (figure 14) and the weights wj (relative importance of criterion j to the overall quality Q). If we want to calculate the weights, we could use for example the AHP method. (Saaty, 1980) or the Simos modified method (1998).

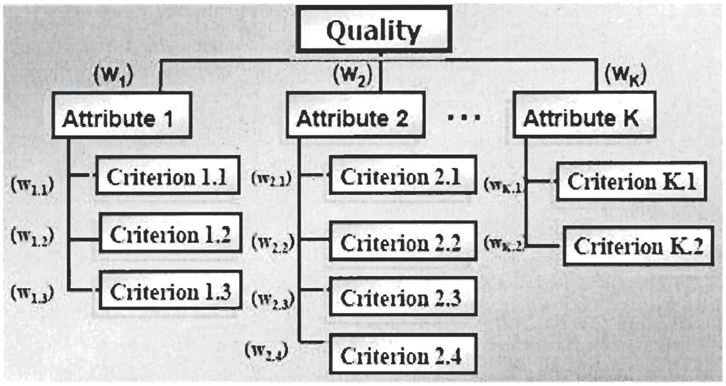


Figure 14. Quality Breakdown Structure (Paquin et al. 2005)

Now, for each criterion, the project manager must determine how the client's satisfaction will be assessed. It's obtained using criterion value functions $\Phi(Xj)$ (monotonically non-decreasing and set arbitrarily to 1, figure 15 for examples).

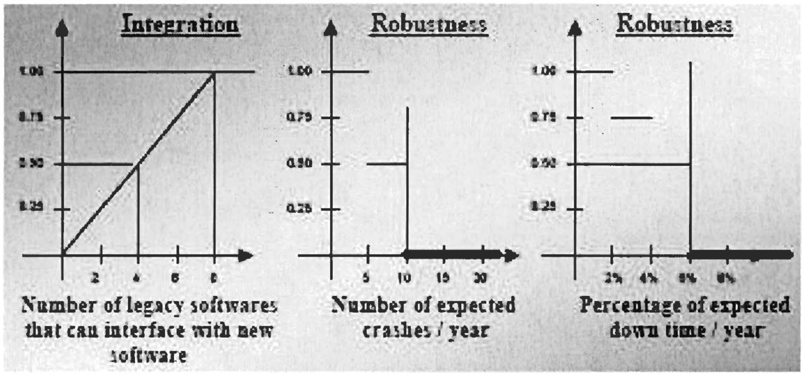


Figure 15. Examples of value functions (Paquin et al. 2005)

Henceforth, it's possible to aggregate the client's values with respect to quality and determine the overall quality Q by this equation: $Q = \Sigma wj.\Phi(xj)$.

- Assess the earned quality

Once the WBS and the QBS have been established, it's possible to link them (figure 16) and to obtain the relations between the activities of the project and the quality criteria of the end product of the project. These relations are modeled by the rij, estimated relative contribution of activity (i) to quality criterion (j).

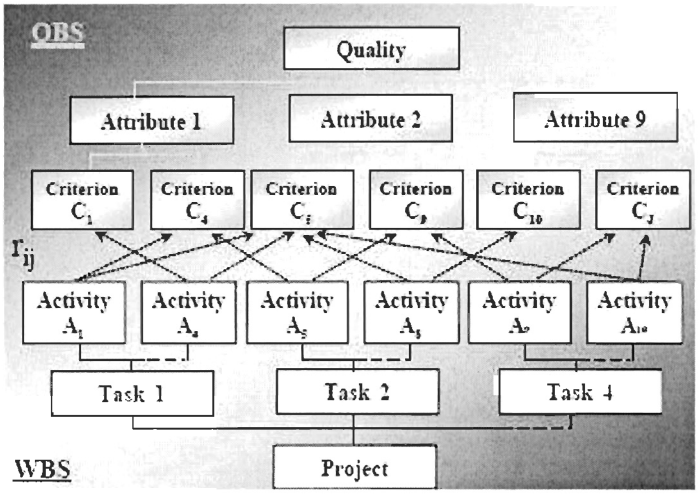


Figure 16. *WBS and QBS relation (Paquin et al. 2005)*

As in the EVM, the EQM (figure 17) relates the quantity of work identified in the WBS to the quality of work defined by the QBS.

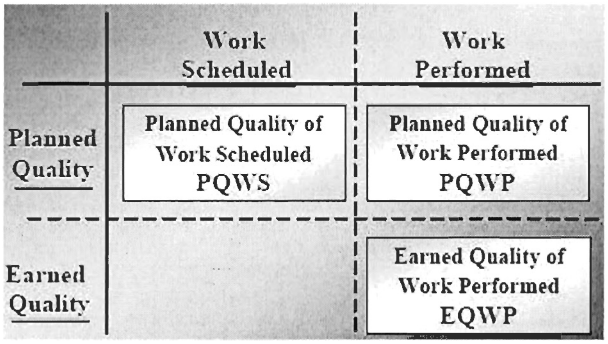


Figure 17. *EQM definition (Paquin et al. 2005)*

More specifically, one can define these different measures by the following equations (Paquin et al., 2000).

$$PQWS = \sum_i \sum_j w_j \Phi\left(x_j^*\right) \quad r_{ij}^*(t)$$

where x_j^* = planned result for the criterion j of the work planned at time t; and $r_{ij}^*(t)$ is the planned contribution to the expected result x_j^* as measured by criterion j attributable to the work scheduled for activity i at time t

$$PQWP = \sum_i \sum_j w_j \Phi\left(x_j^*\right) r_{ij}(t)$$

where $r_{ij}(t)$ is the planned contribution to the expected result x_j^* as measured by criterion j attributable to the work performed on activity i at time t

$$EQWP = \sum_i \sum_j w_j \Phi\left(\hat{x}_j\right) \hat{r}_{ij}(t)$$

where $\hat{x}_j$ = the actual result achieved with regard to the criterion j of the work performed at time t; and $\hat{r}_{ij}(t)$ is the estimated contribution to the actual result $\hat{x}_j$ as measured by criterion j attributable to the work performed on activity i at time t

- ➢ Measure quality deviations

By comparing the Earned Quality of Work Performed EQWP(t) with the Planned Quality of Work Performed PQWP(t), we obtain the Quality Deviation (QD) at time (t) Quality QD(t) = EQWP(t) – PQWP(t) and a quality performance index (PQI) at time (t) or a Percentage of Completion is calculated by QPI(t) = (EQWP(t) / PQWP(t)) x100.

EQM requires that a relationship between the WBS and the QBS be established and a Gantt chart to measure at time (t) the quality deviation and to initiate appropriate corrective actions. EVM needs the WBS and the project master schedule to calculate performance indices on cost and delay and to initiate corrective actions in terms of budget or schedule. So, it seems interesting to integrate EVM and EQM for estimating how a project is doing in a three dimensional perspective: budget, schedule and quality and use this information to predict the future outcomes for the project in an integrated manner as illustrated by the figure 18.

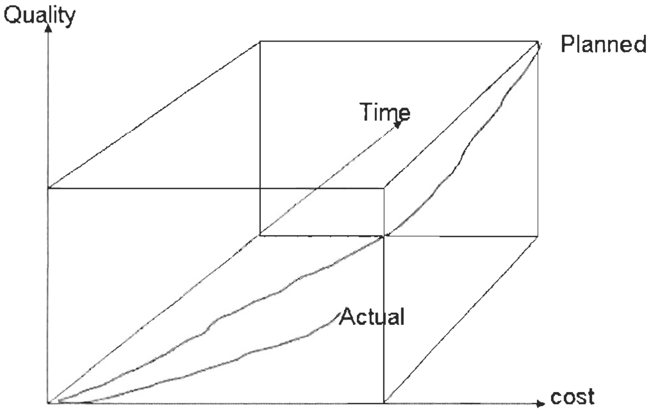


Figure 18. EVM/EQM integrated representation

Now, in presence of uncertainty, this integration becomes more complex but not infeasible and essential because it's the realty of many projects. We propose a time/cost/quality risk model to tackle this situation and we'll present the model using a little didactic example.

Chapter III. The time/cost/quality risk model

III.1. Introduction

In today's uncertain business environment, there is a growing pressure to improve the quality, the value of decision-making at all levels in the organisation and in particular at the project level. In project management, one of the leading approaches developed to tackle this concern is risk management (RM). Another important approach, used in time and cost a priori analysis, is earned value management (EVM). It is actually the alone method which integrates time and cost in a general framework. More recently, in order to manage quality throughout the project lifecycle, the earned quality method (EQM) has been proposed. These approaches contribute altogether to the performance of projects and in turn, to performance in programmes, portfolio and organisation.

We propose a general framework that can be implemented to combine EVM, EQM and RM in order to 'maximise' the likelihood of achieving project objectives (time/cost/quality). After a brief presentation of the EVM, we'll develop our proposed model, using a didactical example.

III.2. The Earned Value Management (EVM)

Earned value management is a well known project management technique (for estimating how a project is doing in terms of its budget and schedule. Earned value compares the work finished so far with the estimates made in the beginning of the project. This gives a measure of how far the project is from completion and a quantitative measure of work performance. By extrapolating from the amount of work already put into the project, the project manager can get an estimate on how much resources the project will have used at completion. This technique is related to the critical path concept and to apply it, the project manager needs the following data: a work breakdown structure (a list of all tasks broken down in a hierarchical structure), a project master schedule (a Gantt chart of what task will be done when and by whom), activities durations and activities costs (Since integrated control of cost and schedule is the core of EVM, it is desirable that cost accounts be identical to elements activities in the network schedule) and, at each control point in time, actual cost of work produced (ACWP) or effort spent. The project manager can then calculate the following measures (illustrated in figure 19):

Budgeted[1] cost of work scheduled (BCWS) or planned value (PV)

Budgeted cost of work produced (BCWP) or earned value (EV)

Cost Variance (**CV**)

$$\begin{aligned} CV &= BCWP - ACWP \\ &= EV - AC \end{aligned}$$

Schedule Variance (**SV**)

$$\begin{aligned} SV &= BCWP - BCWS \\ &= EV - PV \end{aligned}$$

Cost Performance Index (**CPI**)

$$CPI = \frac{BCWP}{ACWP}$$

Schedule Performance Index (SPI)

$$SPI = \frac{BCWP}{BCWS}$$, greater than 1 is good

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[1] Generally, the Planned Values are based on labour costs only, and the Earned Values and Actual Costs are calculated on the same basis.

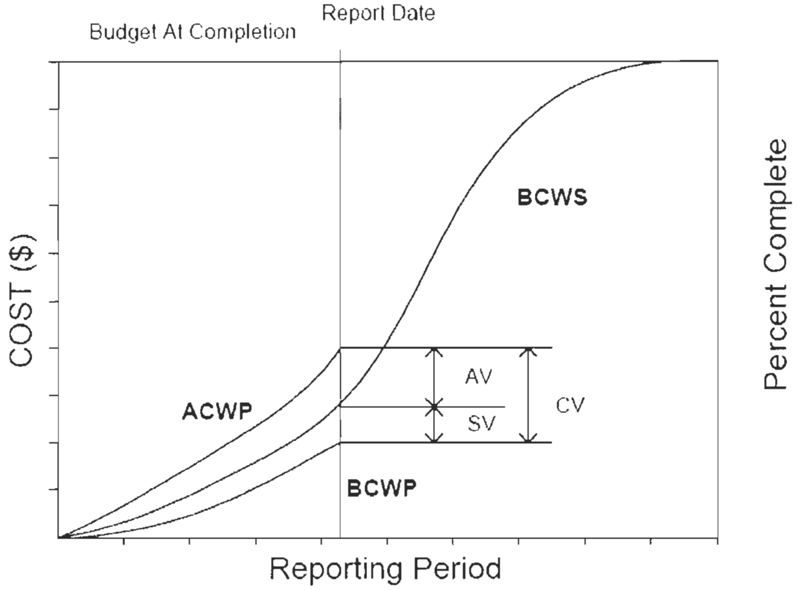


Figure 19. EVM illustration

Schedule performance indicators SV and SPI have limited utility near the end of a project and to address this limitation, an extension of EVM called Earned Schedule has been proposed (Lipke, 2003).

III.3. The time/cost/quality risk model

III.3.1. Didactical example: the project background

To illustrate our model, we'll take the simplified example presented by Paquin et al. (2000) that will be extended to take into account uncertainty. The project consists to design a new cruise liner. It involves three activities: design hull (A), design propulsion systems (B) and design steering systems (C). We assume that the quality of this end product can be measured by three criteria: C1 is the amenity, C2 is the speed and C3 is the manoeuvrability. The weights wj (relative importance of criterion j to the overall quality Q) are w_1=0.20, w_2=0.30, w_3=0.50.

We face discrete risks and variability in this problem. So, we consider that it's possible that we'll have to choose B' instead of B and C' instead of C. These activities (B' and C') represent contingency plans for the activities B and C. Moreover, there is an estimating uncertainty in the evaluation of the activities duration. For the illustration of our method, we'll consider an interval for the possible durations of the different activities. So, for each activity, there are two values, a minimum and a maximum duration. For simplicity, the cost for each activity will be a constant cost per week. (Figure 20)

activity	Duration Min (weeks)	Duration Max (weeks)	Cost/week
A	7	9	1000
B	4	6	800
B'	6	8	700
C	3	5	1200
C'	4	6	1200

Figure 20. Project information

A, around 8 weeks, can be done, every week cost 1000$, the quickest takes 7 weeks no later than 9 weeks.

B, 5 weeks can be done, start on the sixth week before the completion of A, every week cost 800$, the quickest can be done in 4 weeks no later than 6 weeks. Or we can choose B' project will takes 7 weeks to complete, every week cost 700$, the quickest takes 6 weeks and no later than 8 weeks.

C, 4 weeks can be done, start on the last week before the completion of B, every week cost 1200$, the quickest takes 3 weeks to complete, no later than 5 weeks. Or we can choose C' project which takes 5 weeks to complete, every week cost 1200$, the quickest is 4 weeks no longer than 6 weeks.

Note that this simple example is already complex as illustrated in figure 21.

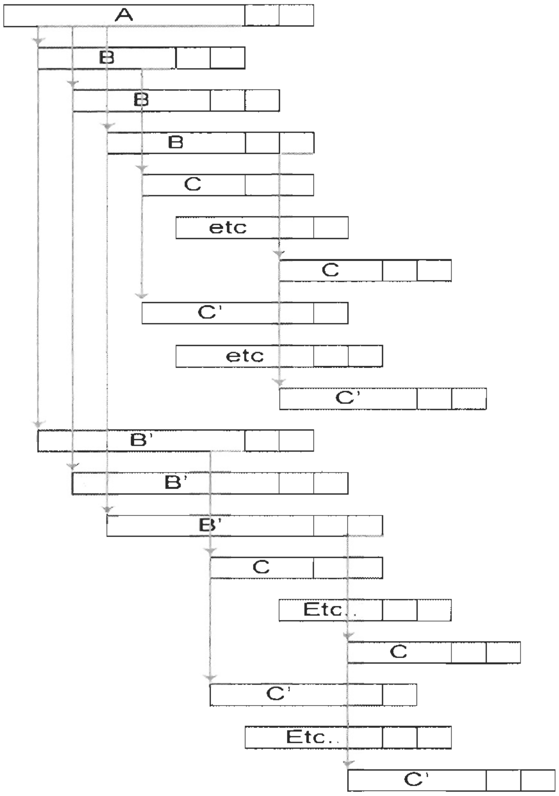


Figure 21. Combinatorial aspect of a simple example

Actually, our situation is, until the completion of the project, we chose A-B'-C, for A every week cost 1100$, completed in 8 weeks. B' every week cost 720$, completed in 7 weeks. C every week cost 1300$ and completed in 4 weeks.

To take into account these two types of uncertainty, our model predicts a range of possible outcomes in terms of time, cost and quality. In fact we conduct integrated analysis based on EVM and EQM for each scenario and these outcomes correspond to the value obtained for the possible extreme scenarios for the project. In this example, there are eight extreme scenarios, each scenario corresponding to a combination of activity and duration, as resumed in figure 22. We present the extreme scenarios because all possible combinations are included in this cube.

	ABC	AB'C	AB'C'	ABC'
Duration minimum	1	2	3	4
Duration maximum	5	6	7	8

Figure 22. Extreme scenarios

In this project, the quality influence is divided in 3 factors, C1, C2 and C3. C1 is design hull of the new automobile, C2 is design speed of the new automobile, and C3 is design maneuverability of the new automobile. By the way C1 is influenced by A, counts 100%. C2 is influenced by B and C, B counts 70% and C 30%. C3 is influenced by A,B and C together. Which A counts 50%, B 10% and C 40%.

If we switch B for B', C1 is still influenced by A, no change, counts 100%. C2 is influenced by B' and C, B' counts 80%, C 20%. C3, A counts 50%, B' 20% and C 30%.

The value function Φ(Xj) for each criterion, determined by the client and the project manager, are in figure 23 and the Gantt chart of one of the possible scenarios is depicted in figure 23.

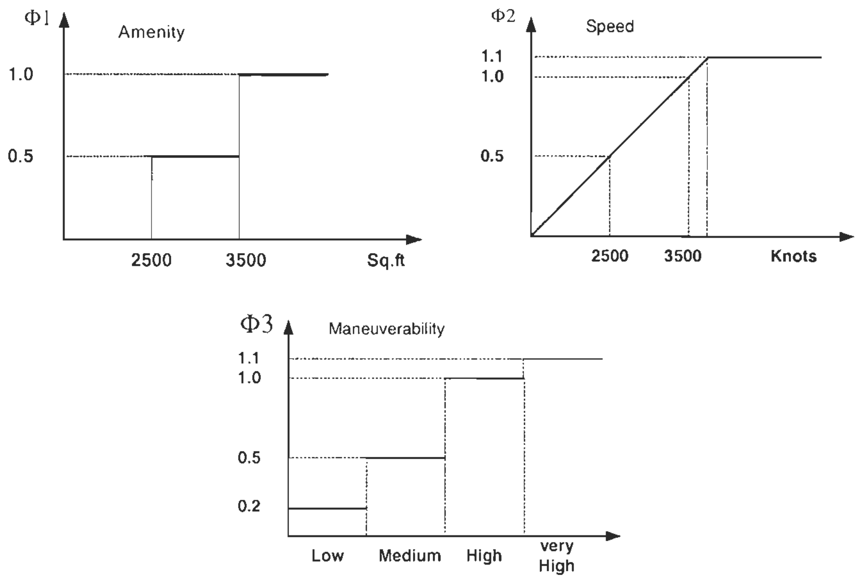
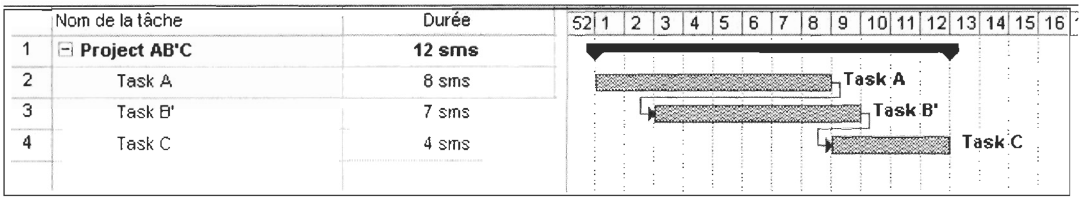


Figure 23. Value functions for the quality criteria (adapted from Paquin al., 2000)



	Nom de la tâche	Durée
1	⊟ **Project AB'C**	**12 sms**
2	Task A	8 sms
3	Task B'	7 sms
4	Task C	4 sms

Figure 24. Gantt chart of a specific scenario

The relative contribution[2] (w_j) of the criteria to the overall quality and the relative contribution (r_{ij}) of the activities to the quality criteria are presented in figure 25 and in the WBS-QBS model of the figure 26.

w_j	.30	.20	.50
activity	Amenity	Speed	Manoeuvrability
A	1	0	.50
B	0	**.70**	**.10**
B'	0	**.80**	**.20**
C	0	.30	.40
C'	0	.20	.30

Figure 25. Contribution of the activities to the quality

We assume that the work scheduled is such that its result will meet the client's expectations, that is to say the quality (PQWS) will be obtained at 100%. In this example, we assume that if the work scheduled is (ABC), the overall quality will be equal to 100%. But, if we scheduled the activity (B') instead of the activity (B), there is an increase of quality on the criteria 2 and 3.

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[2] These weights could be easily assessed using for example AHP (Saaty, 1980) or the Simos method for eliciting weigths in the Electre method (Roy et al., 1998).see appendix AHP

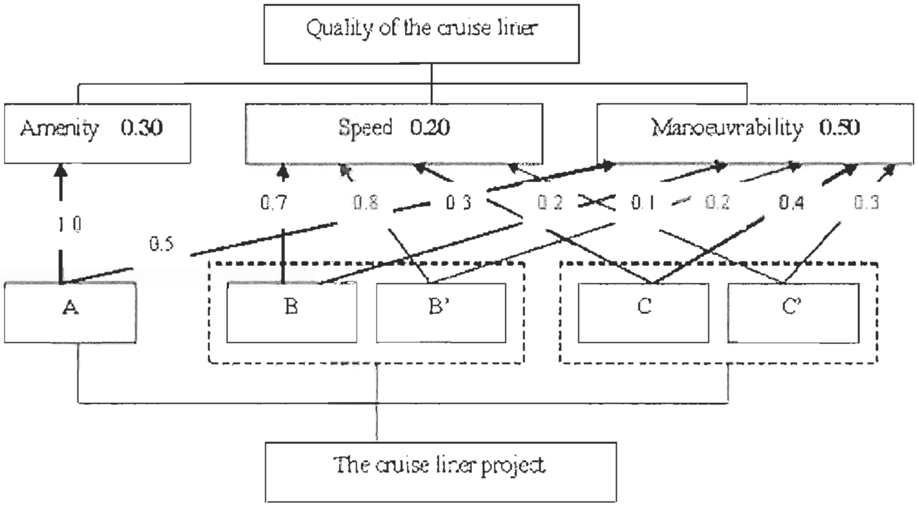

Figure 26. WBS-QBS model (adapted from Paquin et al. 2000)

Note that if it's the schedule (AB'C) instead of (ABC) which is realized, the planned quality will be different. For (ABC) the planned quality is PQWS = (1.0*0.3 + 0.5*0.5)+(0.7*0.2 +0.1*0.5)+(0.3*0.2+ 0.4*0.5)=100% and for (AB'C), PQWS = (1.0*0.3 + 0.5*0.5)+(0.8*0.2 +0.2*0.5)+(0.3*0.2+ 0.4*0.5)=107% . But that increase of the overall quality has a cost. In this case, the planned duration is 2 weeks more and the planned cost is, at minimum, 800$ more for (AB'C). This simple analysis can show the effect of a specific risk on project performance and it gives an idea of the value of the information about the uncertainty.

Now, we also need to know where are the quality control points for our different activities. In our example, we will consider the following points of control. It means that, for example for the activity A, at time 4, 50% of the total quality for A is planned to be reached.

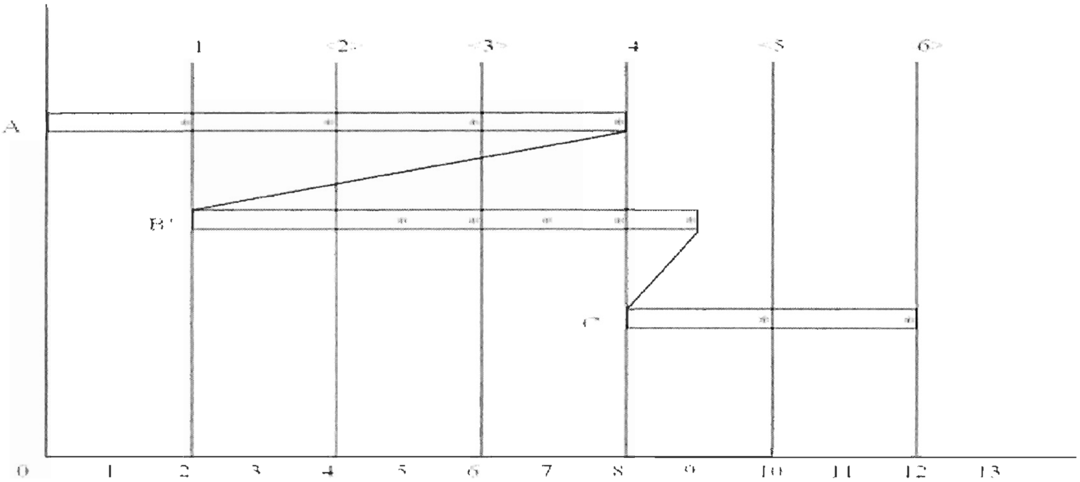

Figure 27. Activities quality control points

III.3.2. Didactical example: the project analyze

We will illustrate our didactical example at different control points.

We choose the 2nd day to be the first control line, because we are not sure if we will use B or B'. So we get A-B-C; A-B'-C; A-B-C' and A-B'-C', and four different situations have to be analyzed.

First, we will calculate PQWP and EQWP in order to get IPQ=EQWP/PQWP

On the Control line, A's Φ is 0, so

EQWP=0

PQWP(C)=0.1375

PQWP(C')=0.13125

IPQ=0

Because the first part A design hull does not affect the speed. So Φ2 certainly don't have any function. PQWP is only decided to select C or C' two kinds of situation.

For complete calculations, you can see appendix 1.

Because the existence of risk, we can't certainly confirm A's final completed date which is the quickest of 7 weeks or the longest of 9 weeks, then we have to calculate Amin and Amax.(figure 27)

CBTP=2000 and CRTE=2200

CBTE-Ai=1750 where(Ai=Amini) and CBTE-Ax=2250 where (Ax=Amax)

As IPC=CBTE/CRTE and IPS=CBTE/CBTP

Then: IPC-Ai=79.55% and IPC-Ax=102.27%

IPS-Ai=87.50% and IPS-Ax=112.50%

	1-Ai	2-Ax
IPS (%)	87.5	112.5
IPQ (%)	0	0
IPC (%)	79.55	102.27

Figure 28. IPS/IPQ/IPC Ai-Ax

We choose now the 4th day to be the Control line and we confirm that we will use B', so we will only analyze the two situations (A-B'-C) and (A-B'-C').

We obtain PQWP-C=0.2750, PQWP-C'=0.2625 and EQWP=0. So, IPQ=0

Calculations are in appendix 1 (form3)

In the following calculations of IPC and IPS, because they involve A and B', so we have to calculate 4 situations (figure 28). 1AiB'i, 2AiB'x, 3AxB'i, 4AxB'x.

CBTP=1000*4+700*2=5400

CRTE=1000$4+720*2=5840

CBTE1=1000*7*4/8+700*6*2/7=4700

CBTE2=1000*7*4/8+700*8*2/7=5100

CBTE3=1000*9*4/8+700*6*2/7=5700

CBTE4=1000*9*4/8+700*8*2/7=6100

	1-AiB'I	2-AiB'x	3-AxB'I	4-AxB'x
IPS (%)	87.04	94.44	105.56	112.96
IPQ (%)	0	0	0	0
IPC (%)	80.48	87.33	97.6	104.45

Figure 29. IPS/IPQ/IPC AiBi-AxB'x

The 3rd Control line is calculated on day 6.

Because C or C' are not confirmed, so we have 2 situations to analyze IPQ

PQWP-C=0.5293

PQWP-C'=0.47895

EQWP-C=0.36995

EQWP-C'=0.35418

IPQ-C=69.89%

IPQ-C'=73.95%

See calculations in appendix 1 (form5)

CBTP=1000*6+700*4=8800

CRTE=1100*6+720*4=9480

CBTEii=1000*7*6/8+700*6*4/7=7650 (CBTEii=CBTE A min B' min)

CBTEix=1000*7*6/8+700*8*4/7=8450 (CBTEix=CBTE A min B' max)

CBTExi=1000*9*6/8+700*6*4/7=9150 (CBTExi=CBTE A max B' min)

CBTExx=1000*9*6/8+700*8*4/7=9950 (CBTEix=CBTE A max B' max)

	1-AiB'I-C	2-AiB'x-C	3-AxB'I-C	4-AxB'x-C	5-AiB'I-C'	6-AiB'x-C'	7-AxB'I-C'	8-AxB'x-C'
IPS (%)	86.93	96.02	103.98	113.07	86.93	96.02	103.98	113.07
IPQ (%)	69.89	69.89	69.89	69.89	73.95	73.95	73.95	73.95
IPC (%)	80.7	89.14	96.52	104.96	80.7	89.14	96.52	104.96

Figure 30. IPS/IPQ/IPC AiB'iC-AxB'xC'

The 4th point, closure on day 8 with A done and C is going to start, but we are still not sure is C or C'.

PQWP-C=0.7836 and PWQP-C'=0.6954

EQWP-C=0.6924 and EQWP-C'=0.6326

IPQ-C=88.74% and IPQ-C'=90.97%

See calculations in appendix 1 (form7)

CBTP=1000*8+700*6=12200

CRTE=1100*8+720*6=13120

CBTEii=1000*7*8/8+700*6*6/7=10600

CBTEix=1000*7*8/8+700*8*6/7=11800

CBTExi=1000*9*8/8+700*6*6/7=12600

CBTExx=1000*9*8/8+700*8*6/7=13800

	1-AiB'I-C	2-AiB'x-C	3-AxB'I-C	4-AxB'x-C	5-AiB'I-C'	6-AiB'x-C'	7-AxB'I-C'	8-AxB'x-C'
IPS (%)	86.89	96.72	103.28	113.11	86.89	96.72	103.28	113.11
IPQ (%)	88.74	88.74	88.74	88.74	90.97	90.97	90.97	90.97
IPC (%)	80.79	89.94	96.04	105.18	80.79	89.94	96.04	105.18

Figure 31. IPS/IPQ/IPC AiB'iC-AxB'xC'

Closure on day 10, A and B' are completed and we confirmed to use C. Here, we choose to do our 5th control line.

PQWP=0.941 and EQWP=0.842

So, IPQ=EQWP/PQWP=89.48%

Calculations: appendix1 (form9)

CBTP=1000*8+700*7+1200*2=15300 and CRTE=1100*8+720*7+1300*2=16440

CBTEiii=1000*7*8/8+700*6*7/7+1200*3*1/2=13000

CBTEiix=1000*7*8/8+700*6*7/7+1200*5*1/2=14200

CBTEixi=1000*7*8/8+700*8*7/7+1200*3*1/2=14400

CBTEixx=1000*7*8/8+700*8*7/7+1200*5*1/2=15600

CBTExii=1000*9*8/8+700*6*7/7+1200*3*1/2=15000

CBTExix=1000*9*8/8+700*6*7/7+1200*5*1/2=16200

CBTExxi=1000*9*8/8+700*8*7/7+1200*3*1/2=16400

CBTExxx=1000*9*8/8+700*8*7/7+1200*5*1/2=17600

	iii	iix	ixi	ixx	xii	xix	xxi	xxx
IPS (%)	84.97	92.81	94.12	101.96	98.04	105.88	107.19	115.03
IPQ (%)	89.48	89.48	89.48	89.48	89.48	89.48	89.48	89.48
IPC (%)	79.08	86.37	87.59	94.89	91.24	98.54	99.76	107.06

Figure 32. IPS/IPQ/IPC AiBiCi-AxBxCx1

Finally, on day 12, the project is done; we have to do the last calculations.

PQWP=1.040 and EQWP=1.040

IPQ=EQWP/PQWP=1

See calculations in appendix 1 (form11)

CBTP=1000*8+700*7+1200*4=17700 and CRTE=1100*8+720*7+1300*4=19040

CBTEiii=1000*7*8/8+700*6*7/7+1200*3*4/4=14800

CBTEiix=1000*7*8/8+700*6*7/7+1200*5*4/4=17200

CBTEixi=1000*7*8/8+700*8*7/7+1200*3*4/4=16200

CBTEixx=1000*7*8/8+700*8*7/7+1200*5*4/4=18600

CBTExii=1000*9*8/8+700*6*7/7+1200*3*4/4=16800

CBTExix=1000*9*8/8+700*6*7/7+1200*5*4/4=19200

CBTExxi=1000*9*8/8+700*8*7/7+1200*3*4/4=18200

CBTExxx=1000*9*8/8+700*8*7/7+1200*5*4/4=20600

	iii	iix	ixi	ixx	xii	xix	xxi	xxx
IPS (%)	83.62	97.18	91.53	97.69	94.92	108.47	102.82	116.38
IPQ (%)	1	1	1	1	1	1	1	1

IPC (%)	77.73	90.34	85.08	97.69	88.24	100.84	95.59	108.19

Figure 33. IPS/IPQ/IPC AiBiCi-AxBxCx2

So, in an a priori analysis (planning step), this time/cost/quality risk model can be used by the project manager in managing the trade-offs between quality, time and cost. For example, the model can perform scenario analysis showing the possible results for the project performance for particular discrete risks or uncertainties and allows identification of the most significant risks or uncertainties to be addressed as a priority. Figure 33 presents, in 3D, the planned quality and budgeted cost of work scheduled for a specific scenario and the quality/cost/time cube for the eight extreme scenarios.

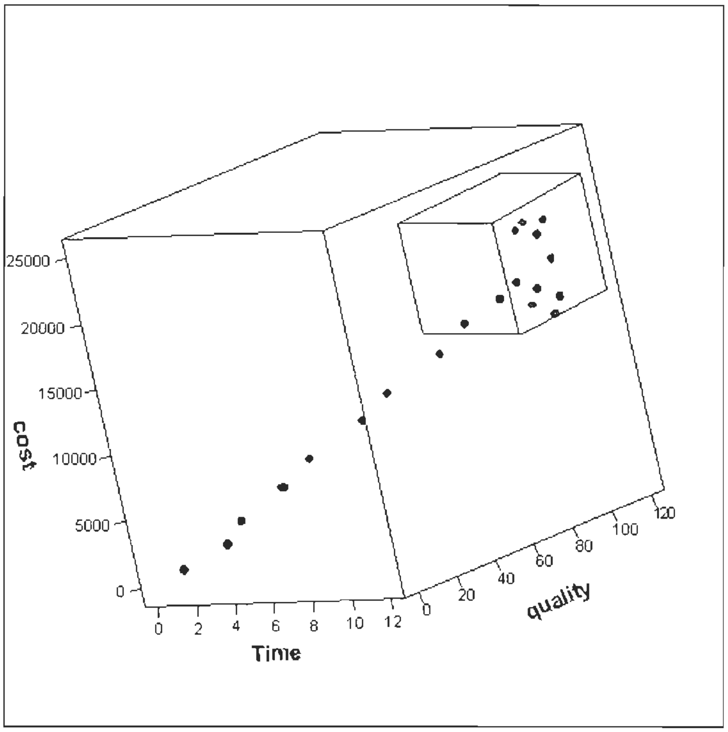

Figure 34. The quality/cost/time cube

These results can be shown as a set of two related S-curves (BCWS and PQWS), as in Figure 33, which take account of both estimating uncertainty (variability in planned events) and discrete risks. The 'ellipse' at the end of the curves represents the envelope of all possible calculated project outcomes delimited by the extreme scenarios.

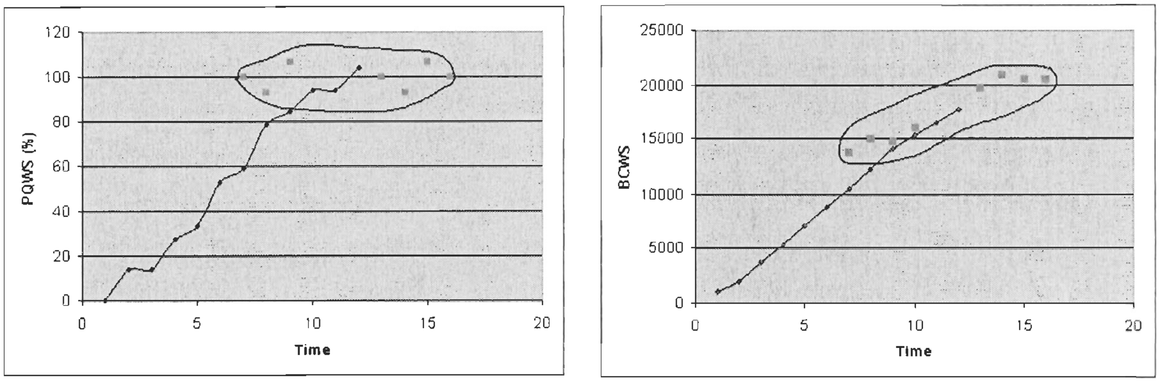

Figure 35. EVM and EQM S-Curves

The existence of this set of possible project outcomes raises the question of where the baseline profile for EVM and EQM should be set. This question is still open but it could be determined, for each control point, by the gravity center of these extreme scenarios.

This model permits also, during the execution of the project or in a control step, to take better decisions taking account of pasty performance. Just to illustrate this point, suppose that we are on week 8 since the beginning of the project: A is done, and due to some problem during A, we choose to plan (B'), which is not yet finished, C is going to start but we are still not sure if it will be C or if we'll have to choose C'. So, to help the project manager, we can calculate quality, cost or schedule performance indices as in Figure 35.

scenario	1	2	3	4	5	6	7	8
SPI (%)	86.89	96.72	103.28	113.11	86.89	96.72	103.28	113.11
QPI (%)	88.74	88.74	88.74	88.74	90.97	90.97	90.97	90.97
CPI (%)	80.79	89.94	96.04	105.18	80.79	89.94	96.04	105.18

Figure 36. Performance indices at time 8

If we had chosen a baseline profile, we'll obtain three indices (one for each dimension). Here, as no choice has been made for the baseline profile, the calculations of these indices must take into account the uncertainty of the project. So, the values of the indices may vary with the extreme scenarios 1 to 8 of Figure 36.

	A duration minimum and C	A duration maximum and C	A duration minimum and C'	A duration maximum and C'
B' duration Minimum	1	3	5	7
B' duration Maximum	2	4	6	8

Figure 37. duration 1-8

In figure 37, some of these indices are plot and each triangle represents an extreme scenario. We plot two specific scenarios (in addition to scenarios 5,7 and 8), the objective-scenario with all indices equal to 100% and a Minimum Objective with all indices equal to 85%.

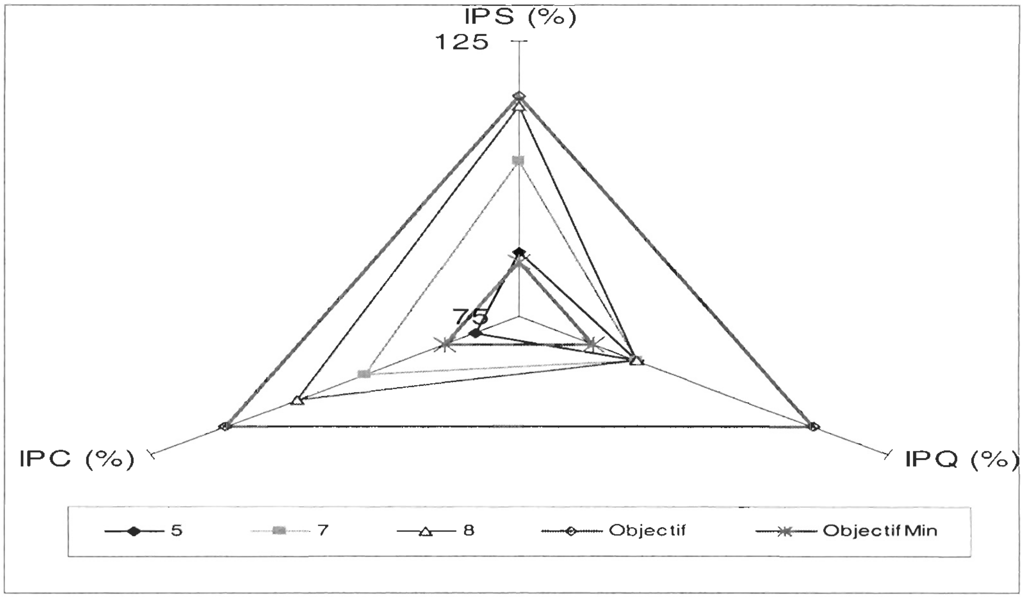

Figure 38. Radar graphic of performance indices for scenario 5, 7 and 8

We can present these indices in another way as in figure 38. One can see that among all the scenarios, just two of us are outside the limits established at 115% and 85%.

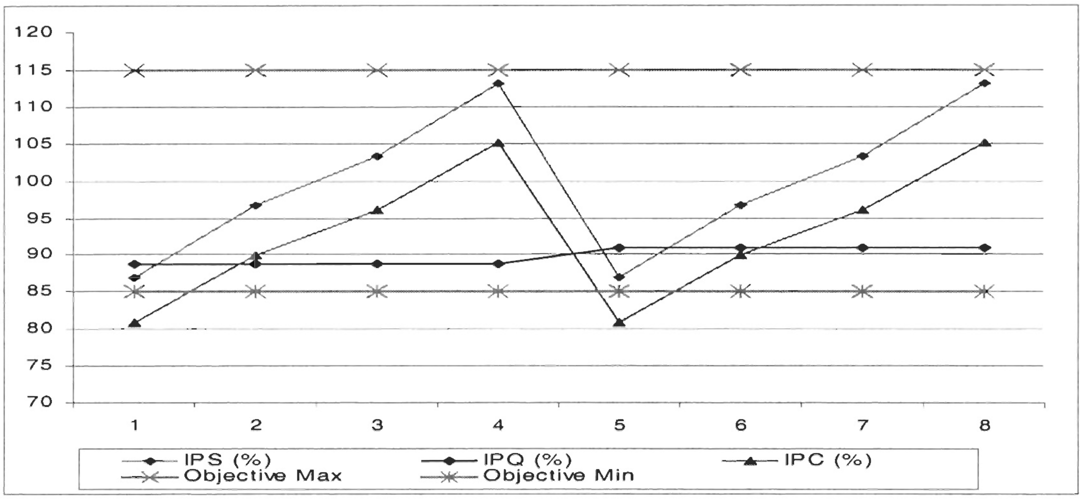

Figure 39. Performance indices for all extreme scenarios

In this last figure, the project manager may think that his project is under control even if he doesn't make an a priori choice for the baseline. This illustrates the fact that, if the activities (A) and (B') were realized at her minimum[3] durations, the CPI (cost performance index) only could be under our minimum limit. The deepening of this analysis is the most interesting aspect. We keep all the variability of the possible outcomes and of the indicators through the different scenarios instead of using an a priori choice or a mean value which mask the possible reality in the future.

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[3] Note that scenarios 1 and 5 could have been not considered in our analysis because at time 8, durations if activities (A) and (B') are already more than their minimum values.

Conclusion

With the rapid progress of technology, economy and society, each social field has more and more realized the importance of project management. This thesis summarizes the origin, development and current situation of study of project management as well as definition, usage, decomposition Principle, studies on Process, method and model of project risk analysis as well as content, process and method of quality management.

EVM and EQM share a focus on project performance. They propose performance indices (CPI, SPI ands QPI) looking back at past performance and have the same purpose of developing effective actions to correct unwanted trends in order to achieve project objectives. RM looks ahead at possible influences on future project outcomes by formalizing the uncertainty in terms of discrete risks or in term of estimating uncertainty and so on. Uncertainty has an effect on the outcomes of a project and on the objectives of the project. Our goal, in this thesis, was to propose a general model which could give to the project manager a dynamic view of where his project stands and which effective actions we'll have to take in order to achieve project objectives in terms of cost, time and quality. Integration of Cost/Time and Quality is often discussed in project management but we didn't found an integrated model taking into account these three dimensions. We propose a way to do that and the integration is based on the WBS and the Gantt chart. Our model has some limits. First, it addresses an end product project. It's not an important constraint because the approach could nevertheless be adapted to other type of project. Another limit to our model could be the difficulty to obtain the information about the quality criteria from the client. It could be difficult also to treat a too large amount of information resulting of the scenario approach that we propose to tackle the uncertainty (discrete risks or estimating uncertainty). Nevertheless, we are developing basic algorithm to be able to tackle problems of real size. Moreover, It could be interesting in the future study to the estimating uncertainty considered in this thesis (interval value) to situations where it's possible to have more information about the uncertainty, for example, probabilities or membership functions. It's also interesting to consider the possibility to have more information about the discrete risk, for example an interval of probabilities, and to use this information to help the project manager. We just validated our model through a didactical example, but it will be important to implement it on a real life situation. Finally, this model can be considered as a planning decision aid model under uncertainty and it will be interesting to add a robustness analysis in order to discuss the stability of the different planning to ensure the project management in his choice of a particular baseline.

In conclusion, we thought that this integrated model provides management information to assist the project manager in predicting the future outcomes of the project in term of quality, time and cost and to generate sound basis for decisions and actions.

Appendix 1

A-C					
	w1=	0.3	w3=	0.5	
	r11=	1	r13=	0.5	
t	Φ1=	1	Φ3=	1	TOTAL
1		0		0	0
2		0.25		0.125	0.1375
A-C'					
	w1=	0.3	w3=	0.5	
	r11=	1	r13=	0.5	
t	Φ1=	1	Φ3=	0.9	TOTAL
1		0		0	0
2		0.25		0.125	0.13125

Form1-1-PQWP (total=w1*r11*Φ31*(2)+w3*r13*Φ3 *(2))

A-C					
	w1=	0.3	w3=	0.5	
	r11=	1	r13=	0.5	
t	Φ1=	1	Φ3=	1	TOTAL
1		0		0	0
2		0.25		0.125	0.1375
3		0.25		0.125	0.1375
4		0.5		0.25	0.275
A-C'					
	w1=	0.3	w3=	0.5	

	$r_{11}=$	1	$r_{13}=$	0.5	
t	$\Phi_1=$	1	$\Phi_3=$	0.9	TOTAL
1		0		0	0
2		0.25		0.125	0.13125
3		0.25		0.125	0.13125
4		0.5		0.25	0.2625

Form3-2-PQWP

A-C							**B'-C**						
	$w_1=$	0.3	$w_3=$	0.5				$w_2=$	0.2	$w_3=$	0.5		
	$r_{11}=$	1	$r_{13}=$	0.5				$r_{22}=$	0.8	$r_{23}=$	0.20		
t	$\Phi_1=$	1	$\Phi_3=$	1		TOTAL	t	$\Phi_2=$	1.2	$\Phi_3=$	1		TOTAL
1		0		0		0	1		0		0		0
2		0.25		0.125		0.1375	2		0		0		0
3		0.25		0.125		0.1375	3		0		0		0
4		0.5		0.25		0.275	4		0		0		0
5		0.5		0.25		0.275	5		0.16		0.04		0.0584
6		0.75		0.375		0.4125	6		0.32		0.08		0.1168

ACT	1	2	3	4	5	6
A	0	0.1375	0.1375	0.275	0.275	0.4125
B'	0	0	0	0	0.0584	0.1168
C	0	0	0	0	0	0
PQWP	0	0.1375	0.1375	0.275	0.3334	0.5293

Form5-3-PQWP-c

A-C'							B'-C'						
	$w_1=$	0.3	$w_3=$	0.5				$w_2=$	0.2	$w_3=$	0.5		

	r11=	1	r13=	0.5				r22=	0.7	r23=	0.1		
t	Φ1=	1	Φ3=	0.9		TOTAL	t	Φ2=	1.2	Φ3=	0.9		TOTAL
1		0		0		0	1		0		0		0
2		0.25		0.125		0.13125	2		0		0		0
3		0.25		0.125		0.13125	3		0		0		0
4		0.5		0.25		0.2625	4		0		0		0
5		0.5		0.25		0.2625	5		0.14		0.02		0.0426
6		0.75		0.375		0.39375	6		0.28		0.04		0.0852

ACT	1	2	3	4	5	6
A	0	0.13125	0.13125	0.2625	0.2625	0.39375
B'	0	0	0	0	0.0426	0.0852
C'	0	0	0	0	0	0
PQWP	0	0.13125	0.13125	0.2625	0.3051	0.47895

Form5-3-pqwp-c'

A-C							**B'-C**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.8	r23=	0.2		
t	Φ1=	1	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL
1	0	0	0	0		0	1	0	0	0	0		0
2	0	0.25	0	0.125		0	2	0	0	0	0		0
3	0	0.25	0	0.125		0	3	0	0	0	0		0
4	0	0.5	0	0.25		0	4	0	0	0	0		0
5	1	0.5	0	0.25		0.15	5	0.8	0.16	0	0.04		0.0256
6	1	0.75	0.5	0.375		0.31875	6	0.8	0.32	0	0.08		0.0512

ACT	1	2	3	4	5	6

A	0	0	0	0	0.15	0.31875
B’	0	0	0	0	0.0256	0.0512
C	0	0	0	0	0	0
EQWP	0	0	0	0	0.1756	0.36995

Form5-3-eqwp-c

A-C							**B'-C’**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.7	r23=	0.1		
t	Φ1=	1	Φ3=	0.9		TOTAL	t	Φ2=	1.2	Φ3=	0.9		TOTAL
1	0	0	0	0		0	1	0	0	0	0		0
2	0	0.25	0	0.125		0	2	0	0	0	0		0
3	0	0.25	0	0.125		0	3	0	0	0	0		0
4	0	0.5	0	0.25		0	4	0	0	0	0		0
5	1	0.5	0	0.25		0.15	5	0.8	0.14	0	0.02		0.0224
6	1	0.75	0.45	0.375		0.309375	6	0.8	0.28	0	0.04		0.0448

ACT	1	2	3	4	5	6
A	0	0	0	0	0.15	0.309375
B’	0	0	0	0	0.0224	0.0448
C’	0	0	0	0	0	0
EQWP	0	0	0	0	0.1724	0.354175

Form5-3-eqwp-c’

A-C							**B'-C**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.8	r23=	0.2		
t	Φ1=	1	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL

1		0		0		0	1		0		0		0
2		0.25		0.125		0.1375	2		0		0		0
3		0.25		0.125		0.1375	3		0		0		0
4		0.5		0.25		0.275	4		0		0		0
5		0.5		0.25		0.275	5		0.16		0.04		0.0584
6		0.75		0.375		0.4125	6		0.32		0.08		0.1168
7		0.75		0.375		0.4125	7		0.48		0.12		0.1752
8		1		0.5		0.55	8		0.64		0.16		0.2336

ACT	1	2	3	4	5	6	7	8
A	0	0.1375	0.1375	0.275	0.275	0.4125	0.4125	0.55
B'	0	0	0	0	0.0584	0.1168	0.1752	0.2336
C	0	0	0	0	0	0	0	0
PQWP	0	0.1375	0.1375	0.275	0.3334	0.5293	0.5877	0.7836

Form7-4-pqwp-c

A-C'							**B'-C'**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.7	r23=	0.1		
t	Φ1=	1	Φ3=	0.9		TOTAL	t	Φ2=	1.2	Φ3=	0.9		TOTAL
1		0		0		0	1		0		0		0
2		0.25		0.125		0.13125	2		0		0		0
3		0.25		0.125		0.13125	3		0		0		0
4		0.5		0.25		0.2625	4		0		0		0
5		0.5		0.25		0.2625	5		0.14		0.02		0.0426
6		0.75		0.375		0.39375	6		0.28		0.04		0.0852
7		0.75		0.375		0.39375	7		0.42		0.06		0.1278
8		1		0.5		0.525	8		0.56		0.08		0.1704

ACT	1	2	3	4	5	6	7	8
A	0	0.13125	0.13125	0.2625	0.2625	0.39375	0.39375	0.525
B'	0	0	0	0	0.0426	0.0852	0.1278	0.1704
C'	0	0	0	0	0	0	0	0
PQWP	0	0.13125	0.13125	0.2625	0.3051	0.47895	0.52155	0.6954

Form7-4-pqwp-c’

A-C							**B'-C**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.8	r23=	0.2		
t	Φ1=	1	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL
1	0	0	0	0		0	1	0	0	0	0		0
2	0	0.25	0	0.125		0	2	0	0	0	0		0
3	0	0.25	0	0.125		0	3	0	0	0	0		0
4	0	0.5	0	0.25		0	4	0	0	0	0		0
5	1	0.5	0	0.25		0.15	5	0.8	0.16	0	0.04		0.0256
6	1	0.75	0.5	0.375		0.31875	6	0.8	0.32	0	0.08		0.0512
7	1	0.75	0.5	0.375		0.31875	7	0.8	0.48	0.5	0.12		0.1068
8	1	1	1	0.5		0.55	8	0.8	0.64	0.5	0.16		0.1424

ACT	1	2	3	4	5	6	7	8
A	0	0	0	0	0.15	0.31875	0.31875	0.55
B'	0	0	0	0	0.0256	0.0512	0.1068	0.1424
C	0	0	0	0	0	0	0	0
EQWP	0	0	0	0	0.1756	0.36995	0.42555	0.6924

Form7-4-eqwp-c

A-C'							**B'-C'**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.7	r23=	0.1		
t	Φ1=	1	Φ3=	0.9		TOTAL	t	Φ2=	1.2	Φ3=	0.9		TOTAL
1	0	0	0	0		0	1	0	0	0	0		0
2	0	0.25	0	0.125		0	2	0	0	0	0		0
3	0	0.25	0	0.125		0	3	0	0	0	0		0
4	0	0.5	0	0.25		0	4	0	0	0	0		0
5	1	0.5	0	0.25		0.15	5	0.8	0.14	0	0.02		0.0224
6	1	0.75	0.45	0.375		0.309375	6	0.8	0.28	0	0.04		0.0448
7	1	0.75	0.45	0.375		0.309375	7	0.8	0.42	0.45	0.06		0.0807
8	1	1	0.9	0.5		0.525	8	0.8	0.56	0.45	0.08		0.1076

ACT	1	2	3	4	5	6	7	8
A	0	0	0	0	0.15	0.309375	0.309375	0.525
B'	0	0	0	0	0.0224	0.0448	0.0807	0.1076
C'	0	0	0	0	0	0	0	0
EQWP	0	0	0	0	0.1724	0.354175	0.390075	0.6326

Form7-4-eqwp-c'

A							**B'**							**C**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.8	r23=	0.2				r32=	0.2	r33=	0.3		
t	Φ1=	1	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL
1		0		0		0	1		0		0		0	1		0		0		0
2		0.25		0.125		0.1375	2		0		0		0	2		0		0		0
3		0.25		0.125		0.1375	3		0		0		0	3		0		0		0
4		0.5		0.25		0.275	4		0		0		0	4		0		0		0

5		0.5		0.25		0.275	5		0.16		0.04		0.0584	5		0		0		0
6		0.75		0.375		0.4125	6		0.32		0.08		0.1168	6		0		0		0
7		0.75		0.375		0.4125	7		0.48		0.12		0.1752	7		0		0		0
8		1		0.5		0.55	8		0.64		0.16		0.2336	8		0		0		0
9		1		0.5		0.55	9		0.8		0.2		0.292	9		0		0		0
10		1		0.5		0.55	10		0.8		0.2		0.292	10		0.1		0.15		0.099

ACT	1	2	3	4	5	6	7	8	9	10
A	0	0.1375	0.1375	0.275	0.275	0.4125	0.4125	0.55	0.55	0.55
B'	0	0	0	0	0.0584	0.1168	0.1752	0.2336	0.292	0.292
C	0	0	0	0	0	0	0	0	0	0.099
PQWP	0	0.1375	0.1375	0.275	0.3334	0.5293	0.5877	0.7836	0.842	0.941

Form9-5-pqwp

A							**B'**							**C**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.8	r23=	0.2				r32=	0.2	r33=	0.3		
t	Φ1=	1	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL
1	0	0	0	0		0	1	0	0	0	0		0	1	0	0	0	0		0
2	0	0.25	0	0.125		0	2	0	0	0	0		0	2	0	0	0	0		0
3	0	0.25	0	0.125		0	3	0	0	0	0		0	3	0	0	0	0		0
4	0	0.5	0	0.25		0	4	0	0	0	0		0	4	0	0	0	0		0
5	1	0.5	0	0.25		0.15	5	0.8	0.16	0	0.04		0.0256	5	0	0	0	0		0
6	1	0.75	0.5	0.375		0.31875	6	0.8	0.32	0	0.08		0.0512	6	0	0	0	0		0
7	1	0.75	0.5	0.375		0.31875	7	0.8	0.48	0.5	0.12		0.1068	7	0	0	0	0		0
8	1	1	1	0.5		0.55	8	0.8	0.64	0.5	0.16		0.1424	8	0	0	0	0		0
9	1	1	1	0.5		0.55	9	1.2	0.8	1	0.2		0.292	9	0	0	0	0		0
10	1	1	1	0.5		0.55	10	1.2	0.8	1	0.2		0.292	10	0	0.1	0	0.15		0

ACT	1	2	3	4	5	6	7	8	9	10
A	0	0	0	0	0.15	0.31875	0.31875	0.55	0.55	0.55
B'	0	0	0	0	0.0256	0.0512	0.1068	0.1424	0.292	0.292
C	0	0	0	0	0	0	0	0	0	0
EQWP	0	0	0	0	0.1756	0.36995	0.42555	0.6924	0.842	0.842

Form9-5-eqwp

A							**B'**							**C**						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.8	r23=	0.2				r32=	0.2	r33=	0.3		
t	Φ1=	1	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL
1		0		0		0	1		0		0		0	1		0		0		0
2		0.25		0.125		0.1375	2		0		0		0	2		0		0		0
3		0.25		0.125		0.1375	3		0		0		0	3		0		0		0
4		0.5		0.25		0.275	4		0		0		0	4		0		0		0
5		0.5		0.25		0.275	5		0.16		0.04		0.0584	5		0		0		0
6		0.75		0.375		0.4125	6		0.32		0.08		0.1168	6		0		0		0
7		0.75		0.375		0.4125	7		0.48		0.12		0.1752	7		0		0		0
8		1		0.5		0.55	8		0.64		0.16		0.2336	8		0		0		0
9		1		0.5		0.55	9		0.8		0.2		0.292	9		0		0		0
10		1		0.5		0.55	10		0.8		0.2		0.292	10		0.1		0.15		0.099
11		1		0.5		0.55	11		0.8		0.2		0.292	11		0.1		0.15		0.099
12		1		0.5		0.55	12		0.8		0.2		0.292	12		0.2		0.3		0.198

ACT	1	2	3	4	5	6	7	8	9	10	11	12
A	0	0.1375	0.1375	0.275	0.275	0.4125	0.4125	0.55	0.55	0.55	0.55	0.55
B'	0	0	0	0	0.0584	0.1168	0.1752	0.2336	0.292	0.292	0.292	0.292

C	0	0	0	0	0	0	0	0	0	0.099	0.099	0.198
PQWP	0	0.1375	0.1375	0.275	0.3334	0.5293	0.5877	0.7836	0.842	0.941	0.941	1.04

Form11-6-pqwp

A							B'							C						
	w1=	0.3	w3=	0.5				w2=	0.2	w3=	0.5				w2=	0.2	w3=	0.5		
	r11=	1	r13=	0.5				r22=	0.8	r23=	0.2				r32=	0.2	r33=	0.3		
t	Φ1=	1	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL	t	Φ2=	1.2	Φ3=	1		TOTAL
1	0	0	0	0		0	1	0	0	0	0		0	1	0	0	0	0		0
2	0	0.25	0	0.125		0	2	0	0	0	0		0	2	0	0	0	0		0
3	0	0.25	0	0.125		0	3	0	0	0	0		0	3	0	0	0	0		0
4	0	0.5	0	0.25		0	4	0	0	0	0		0	4	0	0	0	0		0
5	1	0.5	0	0.25		0.15	5	0.8	0.16	0	0.04		0.0256	5	0	0	0	0		0
6	1	0.75	0.5	0.375		0.31875	6	0.8	0.32	0	0.08		0.0512	6	0	0	0	0		0
7	1	0.75	0.5	0.375		0.31875	7	0.8	0.48	0.5	0.12		0.1068	7	0	0	0	0		0
8	1	1	1	0.5		0.55	8	0.8	0.64	0.5	0.16		0.1424	8	0	0	0	0		0
9	1	1	1	0.5		0.55	9	1.2	0.8	1	0.2		0.292	9	0	0	0	0		0
10	1	1	1	0.5		0.55	10	1.2	0.8	1	0.2		0.292	10	0	0.1	0	0.15		0
11	1	1	1	0.5		0.55	11	1.2	0.8	1	0.2		0.292	11	0	0.1	0	0.15		0
12	1	1	1	0.5		0.55	12	1.2	0.8	1	0.2		0.292	12	1.2	0.2	1	0.3		0.198

ACT	1	2	3	4	5	6	7	8	9	10	11	12
A	0	0	0	0	0.15	0.31875	0.31875	0.55	0.55	0.55	0.55	0.55
B'	0	0	0	0	0.0256	0.0512	0.1068	0.1424	0.292	0.292	0.292	0.292
C	0	0	0	0	0	0	0	0	0	0	0	0.198
EQWP	0	0	0	0	0.1756	0.36995	0.42555	0.6924	0.842	0.842	0.842	1.04

Form11-6-eqwp

Références

Bai Sijun, 2003, Modern Project Management (volume 1) Beijing, Publishing house of the mechanical industry.

Betts, M., Lansley, P. , 1995, International journal of project management: A review of the first ten years, International Journal of Project Management,.Vol.13, N° 4.

Chapman C, Ward S.1997 Project risk management: processes, techniques and insights. UK: John Wiley,

Cleland, D.I., 2004, The evolution of project management, IEEE Transactions on Engineering Management, Vol.51, N° 4.

Cooke-Davies, T., 2004, Project Management Maturity Models in Morris P. W. G. and J. K. Pinto (eds.), *The Wiley Guide to Managing Projects,* Hoboken, New Jersey: John Wiley and Sons.

Cooke-Davies,T.J., Arzymanow, A.,*2003,* The maturity of project management in different industries: An investigation into variations between project management models, International Journal of Project Management, Vol.21, N° 6.

Crawford, L., 2006, Developing organizational project management capability: theory and practice, project management journal.

Crawford, L., Pollack, J., Hard and soft projects: a framework for analysis , International Journal of Project Management, Vol.22, N° 8.

Crawford,L., Pollack, J., England, D., 2006, Uncovering the trends in project management: Journal emphases over the last 10 years, International Journal of Project Management, Vol.24, N° 2.

Dai, C., Wells, W., 2004, An exploration of project management office features and their relationship to project performance, International Journal of Project Management, Vol.22,

Dinsmore, P. C., 1996, Toward Corporate Project Management : Beefing Up the Bottom Line with MOBP, PM Network .

Dinsmore, P. C., 1999, Winning in Business with Enterprise Project Management, New York, AMACOM.

Dowie, J., 1999, Against risk, Risk Decision and Policy, Vol.4, N° 1, Routledge Pub., part of the Taylor & Francis Group.

Dubois, D., Fargier, H. and Fortin, 2005, Computational methods for determining the latest starting times and floats of tasks in interval-valued activity networks, Journal of Intelligent Manufacturing, 16.

Englund, R, Graham, R., 1999, From experience: Linking projects to strategy, *The* Journal of Product Innovation Management, Vol.16, N° 1.

Gareis, R., 1990, Management by projects: the management strategy of the "new" project-oriented company, Handbook of management by projects. R. Gareis. Vienne, Manz: 35-47.

Giard, V. 2003, La chaîne critique : un concept novateur ?, La Cible, revue francophone de management de projet, 96.

Goldratt, E., 1997, Critical Chain, North River Press.

Herroelen, W., Leus, R., 2001. On the merits and pitfalls of critical chain scheduling. Journal of Operations Management, 19, 559–577.

Herroelen, W., Leus, R., 2004, The construction of stable baseline schedules. European Journal of Operational Research 156.

Herroelen, W., Leus, R., 2005, Project scheduling under uncertainty: Survey and research potentials, European Journal of Operational Research 165.

Herroelen, W., Leus, R., Demeulemeester, E., 2002. Critical chain project scheduling: Do not oversimplify. Project Management Journal 33.

Hillson, D. A,. 2000, Project risks – identifying causes, risks and effects, PM Network, Volume 14 Number 9.

Hillson, D., 2004, Combining Earned Value Management & Risk Management to create synergy", Risk Doctor Position Paper.

Hobbs, B., Aubry, M., 2005.A Realistic Portrait of PMOs : The Results of an Investigation. In Actes du PMI North America Congress.

Hobbs, B., Aubry, M., 2006, Identifying the Structure that Underlies the Extreme Variety Found Among PMOs, Invited paper for PMI Research Conference 2006.

Hodgson, D., 2004, Project Work: The Legacy of Bureaucratic Control in the Post-Bureaucratic Organization, Organization, Vol.11, N° 1.

Hu Yanda, Shen Houcai, 2001 Risk Management Basis--Mathematical Method. Nangjing Southeast University Press.

Hulett, D. and Hillson,D., 2005, Branching out: Decision trees offer a realistic approach to risk analysis, PM Network , Project Management Institute, Volume 20 Number 5.

Humphrey, W.S., Sweet, W.L., 1987, *A Method for Assessing the Software Engineering Capability of Contractors*, Technical Report CMU/SEI-87-TR-23, Software Engineering Institute, Carnegie Mellon University.

Kerzner, H., 1979, Project management : a systems approach to planning, scheduling, and controlling, New York, Van Nostrand Reinhold.

Kerzner, H., 1997, Systems management and the engineer, Journal of Systems Management, Vol.28, N° 10.

Kloppenborg, T., Opfer, W., 2002, The current state of project management research: Trends, interpretations, and predictions**,** Project Management Journal, Vol.33, N° 2.

Lipke, W., 2003, Schedule is Different, The Measurable News.

Lu Youjie, Lu Jiayi, , 2000 Project Risk Management, Beijing, Publishing House of Jiehua University.

Malcolm, Rosenboom, Clark, Fazar, 1959, Applications of a technique for research and development program evaluation, Operations Research , **7** : 5.

Morris, H., 2000, Winning in Business with Enterprise Project Management **,** Project Management Journal, Vol.31, N° 2

Morris, P.W.G.,Patel, M.B., Wearne, S.H., 2000, Research into revising the APM project management body of knowledge, International Journal of Project Management, Vol.18, N° 3.

Morris, W.G., 1994 The management of Projects, Amer Society of Civil Engineers Publisher

Paquin & Couillard, 2005, OCRI Partnership Conference Series Ottawa.

Paquin, Couillard and Ferrand, 2000 , How to Assess the Value Delivered by a Project End- product: The Earned Quality Method, IEEE- Transactions On Engineering Management, 27,1.

Paulk, M., Weber, C., Curtis, B., Chrissis, M.B., 1995**,** The capability maturity model: guidelines for improving the software process, Corporate Carnegie Mellon University Pittsburgh.

Pennypacker, J., Grant, K., 2003, Project management maturity: An industry benchmark, Project Management Journal, Vol.34, N°1.

Pristker & Happ, stochastic network, 1966

Project management institute,2000 a guide to the project management body of knowledge,2000

Roy B., Figueira J., 1998, Détermination des poids des critères dans les méthodes de type ELECTRE avec la technique de Simos révisée, Université de Paris-Dauphine, Document du LAMSADE n°109

Saaty, T.L., 1980, The Analytic Hierarchy Process, McGraw Hill Company, New York

Sabuncuoglu, I., Bayiz, M., 2000. Analysis of reactive scheduling problems in a job shop environment. European Journal of Operational Research 126, 567–586.

Simon P, Hillson D, Newland K, 1997 Project risk analysis and management (PRAM)

Slowinski, R., Hapke, M. (Eds.), 2000. Scheduling under Fuzziness. Physica-Verlag, Heidelberg.

Song Mingzhe , 1984 Risk Management, Taibei Zhonghua Enterprise Development Center.

Song Zheming , 2003 Modern Risk Management, Beijing, China Textile Press.

Stretton, A., 1994, A short history of project management: part one: the 1950s and 60s and part two: the 1970s, The Australian Project Manager 14.

Terry, W., 2004, Why monte carlo simulations of project networks can mislead.

Themistocleous, G., Wearne, S.H., 2000, Project management topic coverage in journals, International Journal of Project Management, Vol.18, N° 1.

Urli, B., Urli, D., 2000, Project management in North America, stability of the concepts, Project Management Journal, Vol.31, N° 3.

Vieira, G.E., Herrmann, J.W., Lin, E., 2003. Rescheduling manufacturing systems: A framework of strategies, policies and methods. Journal of Scheduling 6.

Ward, S. & Chapman,C., 2003 Transforming project risk management into project uncertainty management, international journal of project management.

Wu Chong, Li Hanling, 2001 Fuzzy AHP Decision-Making Methods, Journal of Engineering Management.

Zhang Qinghui, Sha Jichang, , 1996 Risk Analysis, Systems Engineering and Electronics.

Zhang Qinghui, Sha Jichang, 1996

Zobel, A., Wearne, S., 2000, Project management topic coverage in recent conferences, Project Management Journal, Vol.31, N° 2.