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A DSS Using Multiple Time Periods for Measuring Project Uncertainty

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Abstract

This paper presents a decision support system based on hierarchical planning and control for the assessment of multi project management under uncertainty. The Proposed DSS contains three hierarchical levels namely the planning, management and operational level. Applying a hierarchical DSS at each level the utilization of the resources in an effective way in the long term medium and short term is achieved. Specifically at the planning level decision have to do with the strategic goals to be pursued in the system management and with the ways to achieve them: overall long term sustainable policies are set at this level. The scope of Management is the utilization of the resources in an effective way in the short and the medium term, according to the directive issued by the Planning stage. In the operational level the DSS is mostly applicable the implementation of the Management decisions in real time operation and it is generally highly structured, so that fixed rules can be applied at this level. Queuing theory is used to estimate the size of the time buffers. Some principles of development of the methodological framework are formulated. This formulation represents a significantly different view of project planning from the ones implied to traditional project management. A small computational example that focuses on maximizing the probability of successful decision making of a project based on minimizing the number of resource conflicts is presented. The problem formulated here has importance and direct application to the management of a wide variety of projects where there is significant uncertainty.

Keywords decision support systems, assessment of projects, decision uncertainty.

1. Introduction

Schedulling the project activities is often executed in a deterministic environment and under the assumption of complete information. During execution, however, the project is subject to considerable uncertainty, which may lead to numerous schedule disruptions. The variability factor in the framework involves a joint impression of the uncertainty and variability associated with the size of the various project parameters (time, cost, quality), uncertainty about the basis of the estimates (activity durations, work content), uncertainty about the objectives, priorities and available trade-offs, and uncertainty about fundamental relationships between the various project parties involved.

When dependency and variability are both low deterministic single-project scheduling methods can be used to schedule each individual project in a multi-project environment: the project can be planned and executed with dedicated resources and without outside restrictions (De Boer 1998). For case with high variability and low dependency, a detailed deterministic schedule covering the entire project will be subject to a high degree of uncertainty. Alternatively, a reactive approach can be followed: reactive scheduling revises or re-optimises the baseline schedule when unexpected events occur. Proactive schedules are schedules that are as well as possible protected against anticipated schedule disruptions that may occur during project execution. Proactive scheduling techniques can be applied to enhance the quality of objective function projections in reactive scheduling. In the high-dependency case, a large number of resources are shared and/or a large number of activities have constrained time windows. A stable plan should be set up for these activities, such that small disruptions do not propagate throughout the overall plan. Stability is a particular kind of robustness that attempts to guarantee an acceptable degree of insensitivity of the activity starting times of the bulk of the project to local disruptions; for more details on stability in scheduling we refer to Leus (2003). Satisficing may be required to obtain a feasible plan with a minimal number of (for instance resource) conflicts.

Case *of* high variability and high dependancy is best seen from a process management viewpoint (Adler 1996) : the resources are workstations that are visited by (or visit) work packages and pass these on to the appropriate successor resources after completion. A rough ballpark plan can be constructed to come up with intermediate milestones, which can be used for setting priorities for the resources in choosing the next work package to consider. Intermediate cases with moderate dependency may benefit from an identification of what we refer to as the *drum* activities: these are the activities that induce the dependency. Either they are performed by shared internal or external resources, or their start or completion time is constrained. It may make sense to adopt a two-level scheduling pass, planning the drum activities first and the remaining activities afterwards. The drum can be scheduled either efficiently or in a stable manner; the remainder activities can either be scheduled from the start or rather dispatched in function of the progress on the drum.

1.1 Information Systems

Information systems dealing with uncertainty are developed based on the PERT technique that allow an estimate of the overall duration of a project to be constructed. However, PERT has major weaknesses. It does not consider constraints on available resources and it assumes that all tasks will be completed successfully Using a PERT framework, Valadares Tavares, et al. (1998) also consider uncertainty in the resource requirements of individual tasks and the resulting effect on overall project cost, but they do not incorporate resource constraints. There is an enormous literature on resource-constrained project scheduling, but very little of that literature includes consideration of uncertainty. Hapke and Slowinski (1993; 1996), Yeh, el al. (1999) and Willis et al (1999) have proposed scheduling methods based on fuzzy number representations.

2 Hierarchical planning and control for multi-project organisations

From a review on hierarchical production planning and control frameworks one concludes that several frameworks have been proposed for shop floor oriented manufacturing environments and for project-driven organisations (Speranza and Varcellis 1993). Only few, however, actually deal with different objectives of the planning problems at different time periods and levels. Moreover, little effort has been devoted to the aspect of uncertainty in the hierarchical multi-project planning approach, the integration of technological planning and logistics planning, and the integration of material coordination and capacity planning.

Antony (1965) considers three levels. Strategic-Planning, Management-Control, and Operational-Control denoting in the following simply Planning, Management and Control.

In an other research, De Boer (1998) proposed a hierarchical project planning and control framework is proposed that is partly based on the framework that was proposed by Antony (1965) The framework was adapted to the various planning functions with respect to, three hierarchical levels: (a) the strategic level, (b) the tactical level, and (c) the operational level

It is reported that applying the hierarchical DSS with at each level the appropriate quantitative planning approach has turned out to be successful in dealing with uncertainty. However deterministic planning approaches are used to solve the problems at each level. The main motivation for this choice is the lack of adequate planning approaches that account for uncertainties.

In this research, planning techniques that account for uncertainty have been emerging and may be embedded in the DSS. In doing so the queuing theory is used to estimate the size of the time buffers according to Levy and Globerson (1997).This would allow generating robust and stable plans for this complex multi-project planning environment.

3. Model Formulation

A three-level hierarchical multi-project planning process under the assumption that a portfolio of long-term projects is to be performed. Each project has a given release date, deadline and work breakdown structure, i.e. it consists of subprojects, which include different work packages, each of which can be decomposed into individual activities. The planning level has to do with the strategic goals to be pursued in the system management and with the ways to achieve them: overall long term sustainable policies are set at this level. The scope of Management is the sustainable utilization of the resources in an effective way in the short and the medium term, according to the directive issued by the Planning stage. In the Control level where DSS is mostly applicable the implementation of the Management decisions in real time operation and it is generally highly structured, so that fixed rules can be applied at this level.At the first level (long-term) all the projects are grouped into a single multi-project network that contains all the subprojects as aggregate activities. The release date and deadlines are modelled using generalised precedence relations. The aggregate activities are to be scheduled subject to scarce key resources (e.g. experts, research equipment, special-purpose facilities). The estimated duration of an aggregate activity equals the critical path length of the corresponding subproject plus a time buffer that anticipates the time extension of the aggregate activity that will occur due to the scheduling of the disaggregated projects at the third planning level. Queuing theory is used to estimate the size of the time buffers(Levy and Globerson 1997). The key resource requirement of an aggregate activity is computed as the ratio of the total workload of the corresponding subproject and its pre-estimated duration. The capacity of the key resources is fixed by the general business strategy. The objective function is the minimization of the number of resource conflicts. The resulting schedule provides a maximum duration for every project and the resulting resource profiles provide the time-dependent resource capacities for the key resources at the second planning level as described in Dey and Tabucanon (1996). At the second level (medium-term) each project is condensed by choosing the aggregate activities to be the work packages. The durations, time lags and resource requirements are determined analogously to what happened at the first level. The objective is to level the use of these resources over the project duration. At the third level (short-term) the operational level the condensed projects are disaggregated into detailed projects with individual activities. Resource constraints are given for the key and primary resources as well as for low-cost secondary resources (tools, auxiliary resources).

3.1 Interaction of the hierarchical levels

Planning approaches on the various hierarchical levels cannot operate independently from each other. Information that is generated by other (planning) functions in the framework should be exploited to the best possible extent. More specifically, information is passed down form high to low levels and vice versa (Figure 2). Several authors have discussed the interaction between the various hierarchical planning levels with a focus on manufacturing organisations. Krajewski and Ritzman (1977) give a survey of a disaggregation approach in manufacturing and service organisations. For a multi-stage system with multiple products and nonlinear assembly trees they state that this problem is hard to solve because of its computational complexity.

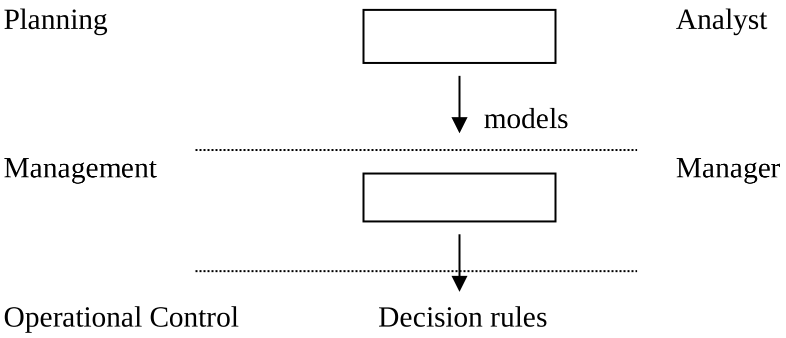

Figure 2 Levels of management of a system

4. Application

An implementation of the proposed hierarchical DSS for project planning is described in Manoliadis (1994) for the management of an irrigation organization in Crete, Greece. He argues that if organisations activities are numerous and the area is too large for coordination by simple adjustment of data, a hierarchy is needed to deal with the uncertainty. In other words, when necessary because of a large number of disruptions and exceptions, a hierarchical structure facilitates the downward delegation of responsibilities. The DSS proposes contains three hierarchical levels: a planning-level a management level and an operational level. Applying a hierarchical DSS with at each level the appropriate quantitative planning approach has turned out to be successful. Deterministic planning approaches are used to solve the operational and management problems. At the planning level the planner has first to propose different tentative interpretations of the strategic goals. Theh he has to express them in quantitative terms by appropriate performance indices and criteria, so that the long run management problem associated to each tentative interpretation can be formulated as an optimal control problem. At this stage the DSS/P plays a central role by providing a unique and consistent framework for the interaction between the planner and the analyst (Figure 2). In fact the DSS/P contains all the necessary tools to solve the optimization problems, and to design and run a simulation model for the evaluation of the effects of the obtained policies. The simulation model can be created so to describe the deferent units present and by specifying their interconnections. When necessary the parameters present in these models can be calibrated by parameter estimation procedures. The planner can also produce predictors to forecast the future course of some interesting variables.
These predictors may be required by some particular type of policy (risk adverse, average etc.).

The decision taken by the planner result, therefore in a set of that have to be implemented into the modelbase of the DSS/M and use by the manager. At the Management Level, the decision is supported by the DSS/M. At every decision step the manager take the decision by selecting one or more policies from the DSS/M Modelbase and evaluating, via simulation, their effects in the short run in presence of different scenarios produced by means of the available predictors or directly typed in by the manager on the basis of his experience.

A three level DSS as the one used here overcomes the reason that brought to the failure of the classical management approach:

- The interaction between the analyst and the planner has a logical and physical framework
- The construction and choice of a policy is transparent to both the planner and the manager.

The basic system to be controlled is to minimise the number of resource conflicts seen as a *risk aversion* problem If A_1 is the unsatisfaction of the resource demand, d_t when the availability of resources is r_t

$$A_1 = \max \{(d_t - r_t)/d_t\} \text{when } d_t > 0 \quad \text{otherwise } 0$$

And is the maximum unsatisfaction has the form of the optimization problem used in the design of the risk averse policies is formalized as follows:

$$\min \max \{A_1, B_1\} \text{subject to}$$
$$d_{i+1} = d_{t+1} + d_t - r_t$$

The prototype DSS was implemented on PC based routines (Manoliadis 1994) in an analogous application..

5. Results

In this example the modules used for this model are modified in order to present scheduling of activities in an irrigation organization. Table 1 shows the performance(number of resource conflicts obtained in three successive periods and the ones that would have been obtained if he had strictly followed the suggestion of the policy corresponding to DSS/M. As can be seen by comparing point P and M in Fig. 3 min-max constraint improves significantly the performance in terms of risk adverse objectives.The performance of the DSS confirm that the risk significantly lowers than the mean value of the preceding years.

The result as activities of the organization are presented in Figure 3.

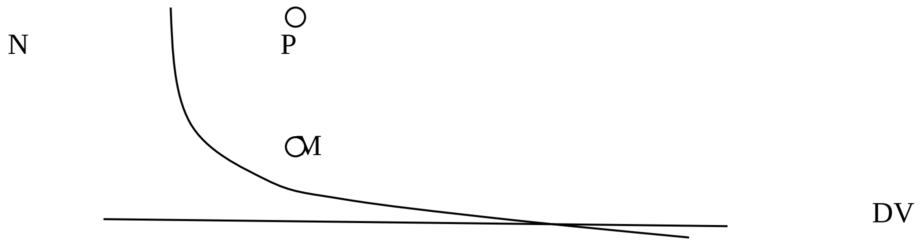

Figure 3 Time vs number of resource conflicts

Table 1. Results from comparison of historical (Guariso et al 1984) to proposed management

		First period	Second period	Third yperiod
B(day)	DSS/M	4	3	2
	Manager	10	6	4

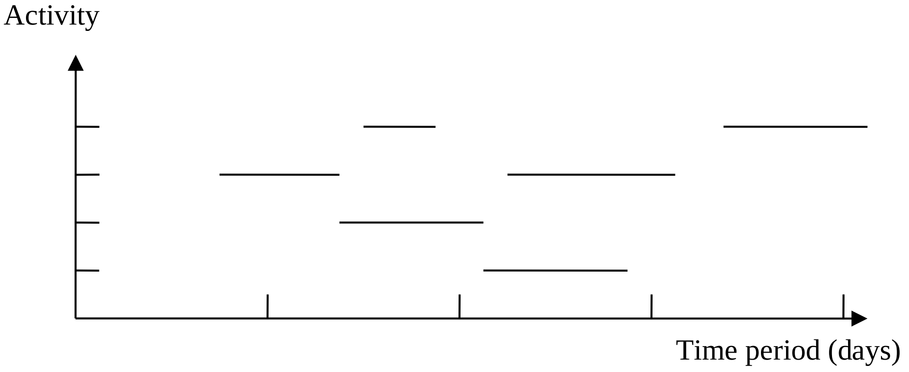

Figure 3 Schedule of activities for irrigation organization

6 Conclusions

In this article, we have proposed a classification framework for multi-project planning environments, and we have pointed out that different levels of hierarchical decision-making (planning, management and operational) require different methods and should not always be combined into one ‘monolithic’ model. The models should allow practitioners to better manage and control complex multi-project environments with uncertainty. We have also discussed the current state of the art in the research on hierarchical planning approaches, both for ‘traditional’ manufacturing organisations and for project environments. Some cases from practice have been included to illustrate the ideas that were put forward in this text. The proposed decision support model provides the decision maker a set of tools that can usefully employed to find his/her own solution. It is interesting to note that the introduction of DSS improves significantly the performance in terms of risk adverse objectives

References

Adler, P.S., Mandelbaum, A., Nguyen, V. and Schwerer, E. (1995). From project to process management: an empirically-based framework for analyzing product development time. *Management Science*, 41(3), 458-484.

Antony R.N., (1965) ‘Planning and Control Systems:a framework for analysis’ Havard Univ. Graduate School of Business Administration, Havard, Massachussets.

De Boer, R., (1998). *Resource-constrained Multi-project Management - A hierarchical decision support system*. PhD thesis, University of Twente, Enschede.

Dey, P.K. and Tabucanon, M.T. (1996). Hierarchical approach to project planning: The case of a petroleum pipeline construction. *Applied mathematical modelling*, 20, 683-698.

Krajewski, L.J. and Ritzman, L.P (1977). Dissagregation in manufacturing and service organisations: survey of problems and research. *Decision Sciences*, Vol. 8, 1-18.

Leus, R. (2003). The generation of stable project plans. Complexity and exact algorithms. *Ph.D. thesis, Katholieke Universiteit Leuven, Belgium.*

Levy, N. and Globerson, S. (1997). Improving multi- project management by using a queuing theory approach. *Project Management Journal*, December issue, 40-46.

Manoliadis O. (1994) Real Time Control for the management of an irrigation system (in Greek) PhD Dissertation National Technical University of Athens

Neumann, K., C. Scwhindt and J. Zimmermann (2003), *Project scheduling with time windows and scarce resources – Temporal resource-constrained project scheduling with regular and nonregular objective functions*, 2ndedition, Springer.

Neumann, K. and C. Schwindt (1998), A capacitated hierarchical approach to make- to-order production, *European Journal of Automation*, 32, 397-413.

Speranza, M.G. and Vercellis, C. (1993). Hierarchical models for multi-project planning and scheduling. *European Journal of Operational Research*, 64, 312-325.

Hapke, M. and R. Slowinski (1996). Fuzzy Priority Heuristics for Project Scheduling, Fuzzy Sets and Systems, 83:3, 291-299.

Valadares Tavares, L., J.A. Antunes Ferreira and J. Suva Coelho (1998). On the Optimal Management of Project Risk, European Journal of Operational Research, 107,451-469.

Willis, R.J., H.Pan and C.-H. Yeh(1999). Resource-Constrained Project Scheduling under Uncertain Activity Duration, in Computational Intelligence for Modelling, Control & Automation, M. Mohammadian (ed), 1OS Press, Amsterdam, pp. 429-434.

Yeh, C.-H., H. Pan and R.J. Willis (1999). A Heuristic Approach to Fuzzy Resource-Constrained Project Scheduling, in Computational Intelligence for Modelling, Control & Automation, M. Mohammadian (ed), IOS Press, Amsterdam, pp. 423-428.