CHALLENGES OF THE PROJECT PLANNING METHODS IN THE 21ST CENTURY

Zsolt T. Kosztyán
University of Pannonia, Hungary
E-mail: kzst@vision.vein.hu

Abstract

There are a lot of project planning (like Gantt chart (Gant, 1910)) and network-based scheduling methods (like CPM, PDM, GERT (see i.e. Kelley-Walker, 1959, Pritsker 1966)), they were developed for handling traditional (e.g. construction) projects. While these methods are appropriate for the operation level - logic planning, scheduling, cost and resource allocation - of traditional project managemet, these methods can hardly be used for agile and extreme project management. Network-based methods focus on operation level, while for strategic decisions other methods should be used.
Matrix-based methods can be used for planning agile methods (see Kosztyán-Kiss 2010-2013), however these methods also focused on operation level.
*This paper introduces an improved matrix-based method, the e**x**tended **M**ultilevel **P**roject **E**xpert **M**atrix (xMPEM) method. This method can be used not only for operation, but strategic level of project management, where typical strategic questions arise e.g. which subprojects/tasks should be completed, how to treat priorities of completion in case of defining logic planning, how to support not only traditional but agile project management approaches.*
In this paper a multilevel genetic algorithm (MLGA) will be specified in order to determine possible project scenarios and possible project structures. The introduced xMPEM and MLGA methods can serve as the connection between operation and the strategic level of the project management.

Key words: *Project Expert System, matrix-based project planning methods, multilevel project planning*.

Introduction

The network-based project-planning methods were very good base methods in project management at the operation level. Resource allocation and time/cost trade-off methods were developed by different kinds of project situation and some of these methods are implemented by Project Management Software (PMS) applications.

The methodological aspect introduced by Lynn Crawford (Crawford-Pollack, 2006) had strongly affected project management publications in the 1950s-1960s, however Kastor and Sirakoulis (Kastor-Sirakoulis, 2009) showed that very few results of these methods are implemented to PMS applications. For example heuristic methods are used for resource allocation, and resource leveling; therefore different kind PMS software determines different kind of results for the same resource-constraint scheduling problem. According to Lynn Crawford at the 1970s-1980s other aspects (like team-work, handling multi projects and project portfolios, connection between strategy and projects etc.) became more and more important, while unfortunately PMS applications very hardly supported these approaches. For instance connections and resource sharing can be handle within a multi project or a programme, but the manager cannot determine and rank different kind project scenarios, project portfolios cannot be assembled considering the company's strategy with using traditional, most frequently used PMS software (like: Microsoft Project, Primavera Project Planner).

Evaristo and van Fenema (Everisto-Fenema, 1999) demonstrated that the developed and

PROBLEMS
OF MANAGEMENT
IN THE 21st CENTURY
Volume 5, 2012

implemented resource-allocation and project planning methods were usually developed for construction projects, since according to Wysocki's (Wysoczki, 2009) recent project managers' survey, projects supported by so called traditional project management are nowadays only 20% of the whole running projects. Methods for investment and construction projects usually cannot be used directly for software development or software R&D projects managed by agile project management approaches.

Main shortcomings of the traditional PMS application are:

(1) focuses only on operation level of the project management (like scheduling, resource allocation), but does not consider the strategic approaches, like ranking different kind of possible project scenarios according to the strategic claims;

(2) supports mainly construction projects and does not handle the specialties of non-traditional projects (like: software development projects, R&D projects etc.);

(3) usually does not contain the advanced results of the research in methodologies (like: handling different kind of project variations supported by i.e. Graphical Evaluation and Review Technique (GERT method) (see i.e. Pritsker, 1966) in scheduling, trade-off methods when reduction of the project duration or exact methods for resource leveling and resource allocation).

This paper focuses on how the new matrix-based project planning method supports the strategy claims. This method can be used as an expert module of a traditional project management system.

Background of the Study

General Background of Research

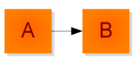
Matrix-based methods are also used for planning and scheduling mainly when new product development projects are planned. These matrix methods are based on the DSM (Design Structure Matrix/Dependency Structure Matrix) method published by Steward (1981).

Three main types of connections between activities are defined in this Dependency Structure Matrix Method (DSM): parallel, sequential, and iterative relations between two tasks (see Table 1). Sequential relation means task **B** can be started, if task **A** has finished. Iterative relation means that after finishing task **B**, task A may be executed again.

Table 1. Possible relations between task A and task B. ("X" means dependencies between task A and task B).

Sequential completion

	A	**B**
A		X
B		

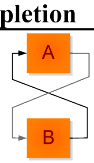


Parallel completion

	A	**B**
A		
B		

Iterative completion

	A	**B**
A		X
B	X	



At first sight one senses no novelty of this approach. Parallel and sequential connections are used in Critical Path Method (CPM) (Kelley-Walker, 1959) and Program Evaluation and Review Technique (PERT method) (Fazar, 1959) as well and Graphical Evaluation and Review Technique (GERT method) (Pritsker, 1966) can also handle cycles. But if researches of matrix-based methods are seen attentively one can find some considerable methods for detecting, and handling cycles in the project plan (see Gabala-Eppinger, 1991). One of these methods is partitioning/sequencing.

Sequencing means the reordering of the DSM rows and columns in a way that the new DSM arrangement does not contain any feedback marks, thus transforming the DSM into an upper triangular form. For complex engineering systems, it is highly unlikely that simple row and column manipulation will result in an upper triangular form. Therefore, the analyst's objective changes from eliminating the feedback marks to moving them as close as possible to the diagonal (this form of the matrix is known as block triangular).

There are several approaches used in DSM sequencing. However similar they are they vary in the identification of cycles (loops or circuits) of coupled elements. All sequencing algorithms proceed as follows:

1. Identify system elements (or tasks) that can be determined (or executed) without input from the rest of the elements in the matrix. Those elements can easily be identified by observing an empty column in the DSM. Place those elements to the left of the DSM. Once an element is rearranged, it is removed from the DSM (with all its corresponding marks) and step 1 can be repeated with the remaining elements.
2. Identify system elements (or tasks) that deliver no information to other elements in the matrix. Those elements can easily be identified by observing an empty row in the DSM. Place those elements to the right of the DSM. Once an element is rearranged, it is removed from the DSM (with all its corresponding marks) and step 2 can be repeated with the remaining elements.
3. If there are no remaining elements in the DSM after steps 1 and 2, then the matrix is completely partitioned; otherwise, the remaining elements contain information circuits (at least one).
4. Determine the circuits (i.e. with using Path Searching algorithm, see Figure 1)
5. Collapse the elements involved in a single circuit into one representative element and go to step 1.

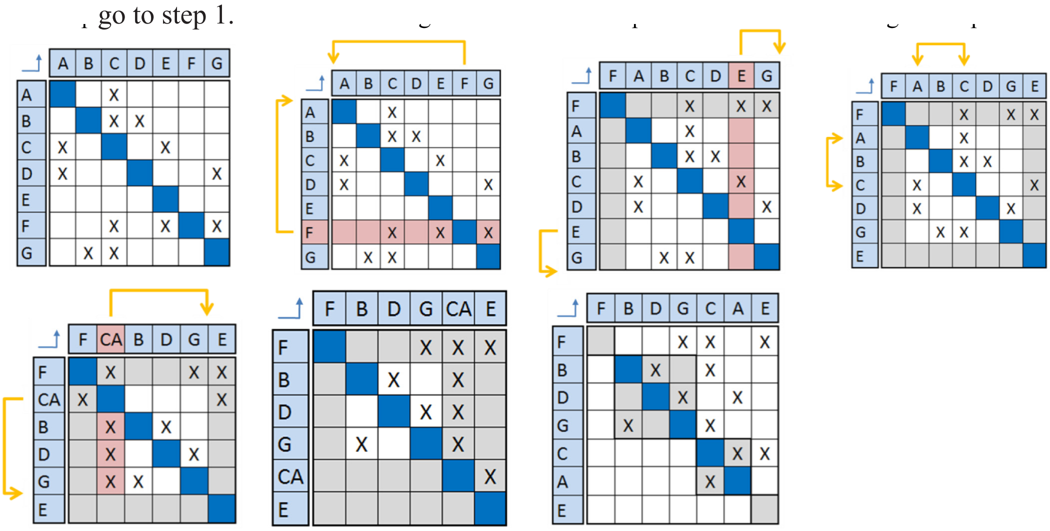


Figure 1: Partitioning (dsmweb.org) (X means dependencies between different kinds of tasks).

The other method, clustering, can be used for detect quasi-independent subprojects. The new goal is to detect subsets of DSM elements (i.e. clusters or modules) that are mutually exclusive or minimally interacting subsets. This process is referred to as "Clustering". In other words, clusters absorb most, if not all, of the interactions (i.e. DSM marks) internally and the interactions or links between separate clusters are eliminated or at least minimized. Since clustering usually has a lot of intermediate steps Figure 2 below shows only the initial and the clustered matrix (Thebeau, 2001; Meehan-Duffy, 2007). (Matlab and Excel tool for clustering can be found at the official web page of DSM, see www.dsmweb.org)

PROBLEMS
OF MANAGEMENT
IN THE 21st CENTURY
Volume 5, 2012

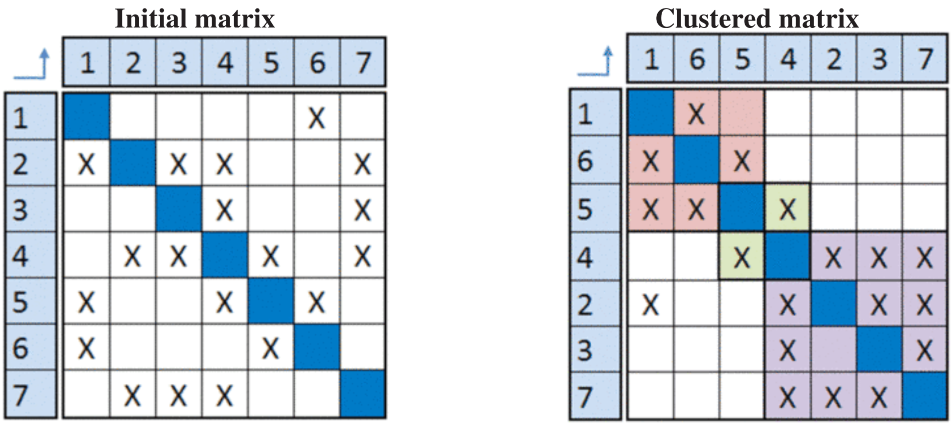


Figure 2: Clustering (dsmweb.org) (different colours/gray scale means different subprojects).

Large projects can represent sparse matrices, where scheduling can be run with quasi-linear time demands.

However these so-called (Binary) Dependency Structure Matrix ((B)DSM) representations can be used to describe strict relations between activities, there are Numerical Dependency Structure Matrix (NDSM) representations (Yassine, 1999) for describing the strength and stochastic network planning method (SNPM) for describing probability of the relations between two tasks (Kosztyán-Kiss, 2010a).

The acronym of SNPM alludes to an uncertain project network. If there is an uncertain (successive) relation between task **A** and task **B** (denoted as "?" in Table 3) there are two possible *project structures*: (1) there is a (successive) relation between task **A** and task **B**, therefore task **A** and task **B** must be realized in a sequence; or (2) task **A** and task **B** are independent from each other, therefore task **A** and task **B** can be realized paralelly (see Table 2).

Table 2. Possible Project Structures.

<table>
<tr><th>Numerical DSM/SNPM</th><th>Binary DSM
(project structures)</th><th>Activity-on-Node network
(project structures)</th></tr>
<tr><td rowspan="2">

↰	A	B
A		?
B		

</td><td>

↰	A	B
A		X
B		

</td><td>A → B</td></tr>
<tr><td>

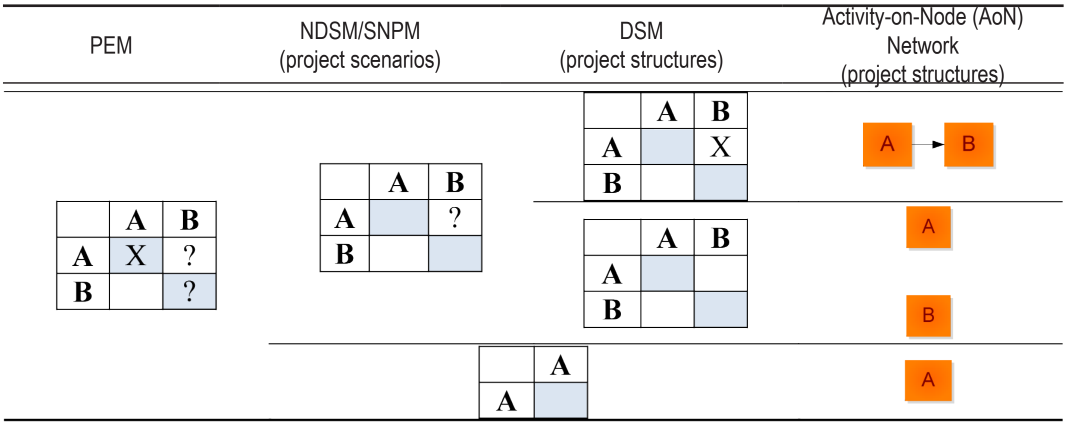
↰	A	B
A		
B		

</td><td>A

B</td></tr>
</table>

The SNPM method (Kosztyán-Kiss, 2010a, 2010b; Kiss et.al 2011) was extended, where probabilities or priorities can be assigned to the completion of the tasks, too. If the probability or priority of the completions/relations cannot be estimated, one can say that completions/relations are uncertain (denoted by "?" in the figure below). This representing method is the Project Expert Matrix (PEM).

Table 3. Evaluation of matrix-base methods.



Possible projects can be determined in two steps. First the manager should decide which tasks should be executed. Table 2 shows that completion of task **B** was uncertain. Therefore two SNPM matrices or ***project scenarios*** can be defined, where task **B** is executed and where task **B** is ignored. At the second step if the project manager decides that task **B** will be completed, he/she should decide how to execute these project scenarios: parallel or sequential. So one can say there are two ***project structures***. If task **B** will not be completed, the question of how to complete task **A** and task **B** is irrelevant, therefore only one project structure exists, where only task **A** has completed.

Uncertainty completion can mean probability or importance of task completion. The strength of dependencies can also mean probabilities, priorities or importance of dependencies between two tasks.

There is a need to differentiate between importance and probability. The decision can be based upon the type of the project and the source of the information. Probability can be used in these cases by using estimates based upon the experience of prior similar projects and/or the opinions of experts. This applies to maintenance projects (Kosztyán, Hegedűs & Kiss, 2010), as well. However, in case of IT and innovation projects it is practical to use the importance instead of the probability (Kiss & Kosztyán, 2010a, b). There are also differences in the calculation. The arithmetic average is used for the importance, and the geometric average is applied for the probability.

Figure 3 shows how to consider former project plans and theirs DSM matrices. In this very simple case the values of the PEM matrix elements will be the *relative frequency* of the occurrences of tasks and relations. The values of the Project Expert Matrix can be determined using prior experience of similar projects as shown in the left side of Figure 3, and it is possible to get all deterministic solutions based on the values of the PEM matrix with the mediation of other matrix-based methods.

The standard Project Management Systems (PMS) (like MS Project, Primavera etc.) maintain project templates, where logic networks can be stored. However these applications cannot store the occurrences of the task executions and cannot store different kinds of possible dependencies between tasks. PEM matrix can represent a stochastic project template, where different kinds of project scenarios and project structures can be specified. At the end of the evaluation process project structures are specified. Project structures can be represented by different methods, e.g. Precedence Diagramming Method (PDM), Critical Path Method (CPM) or extended Event-driven Process Chain (eEPC) (see the right side of Figure 3).

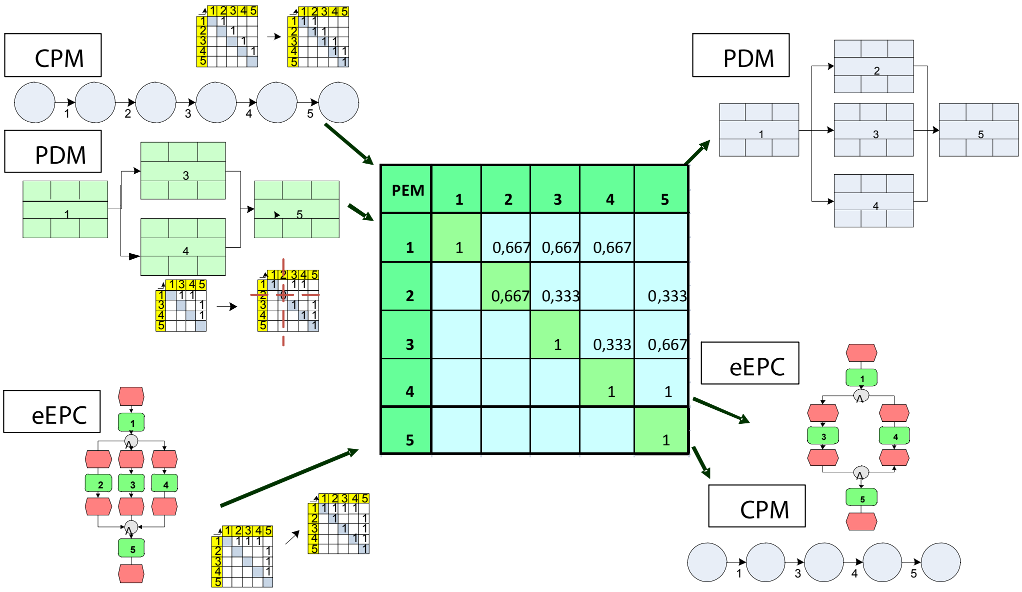


Figure 3: Previous project plans and their DSM matrices; PEM matrix contains the relative frequencies of the occurrences of the tasks and their relations; Generated possible project networks (Kosztyán & Kiss, 2010a).

Figure 3 summarizes how the Project Expert Matrix can be applied for reusing prior project plans to calculate the importance of both the task realizations and the precedence relations. Based on the values of the PEM matrix, project managers can choose ***what*** (which tasks) and ***how*** (in what kind of order) they want to implement during the project. To determine all possible project scenarios it is a combinatorial problem, the computation time can be decreased extensively by using genetic algorithms. Although this PEM method needs lots of calculations, as part of an expert system it reduces the work of project planners and managers. It can be a universal method to solve problems occurring during planning and scheduling of special projects as well.

When priorities or probabilities can be estimated project scenarios and project structures can be ranked. Despite the k uncertain completions and 2^k different kinds of project scenarios, a fast exact algorithm for ranking project scenarios and project structures is developed, the so called Agile Project Scheduling (APS) (Kosztyán-Kiss, 2011).

If matrix-based approach is used in a project expert system for selecting a project plan regarding strategic claims, the project expert matrix and also the ranking algorithms should be extend. In case of probabilities or priorities the APS method is a fast exact method for ranking project scenarios and project structures, and another counting algorithm (Kosztyán-Kiss, 2011) can be defined for different kinds of target function, like: finding minimal duration time or minimal total cost of the project etc., in strategic decisions complex target function should also be considered, where minimizing time, cost and resource demands are important at the same time. Thus counting and exact methods cannot be used for supporting complex strategic claims. Therefore in this paper genetic algorithm will be specified for ranking project structures and project scenarios instead of using exact or counting algorithms.

Instead of tasks the project portfolio manager can consider projects or subprojects in the rows/columns of the PEM matrix for characterizing multi project, project portfolio or a programme. In this way multilevel PEM matrices can also be defined similarly to defining multilevel project networks. If completions of the tasks or (sub) projects are depending on each other Boolean (and, or, exclusive or (xor) etc.) operators will be used for characterizing the dependencies of task/subproject completions. This matrix-based approach will be the ***extended Multilevel Project Expert Matrix***: xMPEM.

In this paper the extended Multilevel Project Expert Matrix will be introduced, which extend the standard Project Expert Matrix. This matrix-based method can already model complex and multilevel projects with loops or cycles.

Multilevel Genetic Algorithm (MLGA) will be specified for evaluating xMPEM for supporting different kinds of strategic claims. At the end of this paper a design of the project expert system will be specified. This project expert system can be integrated to a traditional project management system.

Methodology of Research

In this chapter the extended multilevel Project Expert Matrix (xMPEM) will be specified. Complex xMPEM matrix will be evaluated by multilevel genetic algorithm (MLGA). When evaluating xMPEM different kinds of project scenarios and after that different kinds of project structures will be determined, and ranked according to a given target function.

Extended Multilevel Project Expert Matrix xMPEM

The first main novelty of the xMPEM matrix is that this model can maintain multilevel planning. The first level is the strategic level. In this case project portfolio managers can select different kinds of multi project/project portfolio/programme structures. Rows/columns of the top-level xMPEM matrix represent projects/subprojects of a multi project/project portfolio/programme. Budget, time and resource demands, score of the completion priority can be assigned to the subprojects. After clustering the top-level xMPEM matrix different kinds of quasi-independent projects can be defined. In Table 4 three top-level xMPEM matrices are characterized. The first matrix represents a project portfolio, where projects are independent from each other (i.e. a product developing projects). The second matrix represents a multi project, where resources are common (i.e. construction multi project or a software developing project). The third matrix represents a programme or a mega project, where projects are depending from each other (like organizing Olympic Games).

Table 4. xMPEM matrices of a project portfolio, multi project, programme. (S1-S4 are the IDs of subprojects. RG=Resource Group, CPM=Chief Project Manager) (within the matrix, different colours/gray scale means different subprojects).

Project portfolio

Budget	S_3	S_1	$S_4 \rightarrow S_2$	S_2	RG
4 m€	1	1			A
2 m€		.7			A
4 m€			.8	.6	B
2 m€					C
Dur.	2	3	3	1	*CPM*

Multiproject

Budget	S_3	S_1	$S_4 \rightarrow S_2$	S_2	RG
4 m€	1	1			A
2 m€		.7			B
4 m€			.8	.6	B
2 m€					C
Dur.	2	3	3	1	*CPM*

Programme

Budget	S_3	S_1	$S_4 \rightarrow S_2$	S_2	RG
4 m€	1	1	1		A
2 m€		.7			B
4 m€			.8	.6	B
2 m€					C
Dur.	2	3	3	1	*CPM*

Probabilities/score of priorities of completion are described in the diagonal of the matrix, where 1 means certain completion. The 1st project contains S_1 and S_3 subprojects are competed sequentially, if Chief Project Manager (CPM) selects S_1 for completion. When probability/score of priority of completion subproject S_1 is 0.7, we can assign 1-0.7=0.3 probability value/score of priority of ignore subproject from a project portfolio/multi project/programme.

The second main novelty of the xMPEM is that Boolean operators can be used in case of logic planning. Boolean operators can also be used for characterizing dependencies for subproject completion. I.e. $S_4 \rightarrow S_2$ means that subprojects S_4 and S_2 can be completed or ignored, but if subproject S_4 is selected for completion, subproject S_2 also has to be completed, or if subproject S_4 is ignored, S_2 will also be ignored. "→" is the operator of *implication*; however other Boolean operators can be used for characterizing dependencies of the completion. Since result of selecting for completion of subproject S_4 implies the result of selection subproject S_2 either probability or score of priority assigned to the subproject S_4. Either score of priority or probability of the project portfolio/multi project/programme scenario can be calculated by multiplication of non-zero probabilities/score of priorities of the subprojects. Above diagonals either probability or score of priority of relations between two subprojects are represented, where 1 means certain relation between two subprojects. If either probability or score of priority of the relation between tasks are 0.6, one can say that the probability/score of priority of sequential completion is 0.6, and the parallel completion is 1-0.6=0.4. In this way the probability/score of priority of project structure can also be calculated by the multiplication of the non-zero probabilities/score of priorities of relations between tasks.

In case of project portfolio, 1st project (contains subproject S_1 and S_3) demands resource group A and 2nd project (contains subproject S_2 and S_4) demands resource group B and C, and there is no relation between two projects. However in case of multi project resource group B is common for subproject S_1 and S_4. In the third case subprojects are related to each other so one can see a megaproject where elements are the subprojects instead of tasks. In this level project scenarios called as multi project scenarios, and project structures called as multi project structures, because matrix represents subprojects instead of tasks. Table 5 below shows the possible multi project scenarios and multi project structures, time cost and resource demands in case of planning project portfolio (PP), multi project (MP) or programme (Pr).

Table 5. All possible scenarios and structures. (PP=project portfolio; MP=multi project; Pr=programme; P-value is either probability or score of priority value).

Selected sub-projects for completion	Multi project structures	Duration (month)	All budget (m€)	Resources
S_1-S_4 P=1*0.7*0.8=0.56	S_1 Pr S_3 S_4 S_2	6	12	A, B, C
	S_3 S_1 PP, S_4 S_2 MP	5		
	S_3 S_1 Pr S_2 S_4			
	S_3 S_1 S_4 PP, S_2 MP			
S_2-S_4 P=1*0.3*0.8=0.24	Pr S_3 S_4 S_2	6	10	A, B, C (Pr) B, C (PP, MP)
	S_3 PP, S_4 S_2 MP	4		
	S_3 S_4 Pr S_2	5		
	S_3 S_4 PP, S_2 MP	3		
S_1,S_3 P=1*0.7*0.2=0.14	S_3 S_1	5	6	A (PP) A, B (MP, Pr)
S_3 P=1*0.3*0.2=0.06	S_3	2	4	A

Table 5 above shows that there is no simple target function for selecting a scenario. For instance, while the first scenario has the largest *P*-value, this scenario has the largest cost and resource demands. Therefore complex target function is needed to be specified in order to rank multi project scenarios and multi project structures considering different kinds of strategic claims. A fitness=target function in a genetic algorithm can scale importance of cost, time and resource demands, thus genetic algorithm will be used for the evaluation of xMPEM matrix instead of applying counting and exact algorithms (see next chapter).

At the next level the subprojects will be planned. At this level xMPEM matrix can also be used for characterizing completion of tasks and their relations. Let we consider the project plan of subproject S_2, which is a maintenance subproject, where the budget is 2 m€, the maximal duration is 1 month=23 workdays and the demanded resource group C (4 members of maintenance). A maintenance project usually contains sequential operations, however after control and inspections operations may be released until malfunction is recovered. This means project plans may contain cycles with a probability. *The third main novelty of xMPEM method* *is that this model can maintain cycles.* The partitioning algorithm can be used for finding cycles in the project plan and similarly to the GERT method cycles can be resolved. Table 5 shows a partitioned xMPEM matrix for the subproject S_2. At the first step the cycle is reduced, and the duration and the cost demands will be recalculated. "Resolved xMPEM" matrix no contains cycles, because any cycles have been reduced (see Table 6).

Table 6. Partitioned and resolved xMPEM matrix for the subproject $S_{2.}$

Partitioned xMPEM of the subproject S_2

Cost (1000 €)	T_1	T_3	T_2	T_4	Resource
200	.8	.7			2
100		1	1		1
80			1	1	1
80			.2	1	1
Duration (wrkdys)	10	8	8	4	*C*

Resolved xMPEM of the subproject S_2

Cost (1000 €)	T_1	T_3	T_2	T_4	Resource
200	.8	.7			2
100		1	1		1
100			1	1	1
100				1	1
Duration (wrkdys)	10	8	10	5	*C*

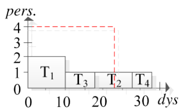
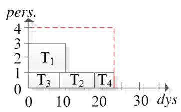
Since there is a feedback between T_2 and T_4 with probability value p=0.2, in the resolved xMPEM matrix the durations and the cost demands of T_2 and T_4 regarding GERT method can be calculated as follows: $d'=d/(1-p)$, $vc'=vc(1-p)$, where d' is the expected value of the duration, vc' is the expected value of the (variable) cost demand of the task in the resolved xMPEM, while d and vc are the original duration time/(variable) cost of task in the partitioned xMPEM. I.e. right side of the Table 5: $d'_{T_2}=d_{T_2}/(1-p)=8/(1-0.2)=10$ workdays.

Project scenarios and project structures can be determined after cycles are reduced (see right side of the Table 7). After reducing cycles, project scenarios and project structures can be specified. Table 7 shows the possible project scenarios, project structures and their time/resource and cost demands.

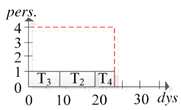
Table 7. Possible project scenarios, project structures, time/cost/resource demands of the subproject $S_{2.}$

<table>
<tr><th>Project scenario</th><th>Project structure</th><th>Duration (workdays)</th><th>Costs (1000 €)</th><th>Resource graph
Schedule: As Soon As Possible (ASAP)</th></tr>
<tr><td rowspan="2">

S_2	T_1	T_3	T_2	T_4
T_1		.7		
T_3			1	
T_2				1
T_4				

***P*=0.8*1*1=0,8**</td><td>T_1 – T_3 – T_2 – T_4
p=0.7*1*1=0.7</td><td>33</td><td rowspan="2">500</td><td></td></tr>
<tr><td>T_3 – T_2 – T_4
T_1
p=0.3*1*1=0.3</td><td>23</td><td></td></tr>
<tr><td>

S_2	T_3	T_2	T_4
T_3		1	
T_2			1
T_4			

***P*=0.2*1*1=0,2**</td><td>T_3 – T_2 – T_4
p=1*1=1</td><td>23</td><td>300</td><td></td></tr>
</table>

Similarly to the evaluation of the top-level xMPEM matrix a simple target function is very hard to define. Since the first project scenario has the largest P-value, and within the first project scenario has the largest probability value (p-value), this project structure cannot be completed within the time constraint. Only two feasible project structures satisfy the time and resource constraints. Both of them can be completed within 23 workdays. However cost and resource demands are different.

It is worth to remark, that this method can also support the agile project management approach, where regarding a budget, time and resource constraints as many task as possible will be completed. In traditional project management there is no way to exclude tasks from a project, therefore any value of the diagonal should be 1. However at the top level also in case of traditional project management approach, subprojects can be excluded or postponed to the later multi project.

When defining a target function for ranking project scenarios or project structures time, resource, cost demands and probability/priority of completion can be important at the same time. In the next subchapter it will be showed how to define a target function regarding different kinds of viewpoints.

Define a Multilevel Genetic Algorithm (MLGA) for Ranking Project Scenarios and Project Structures

In this case ‘multilevel’ means that first project scenarios and within different kinds of project scenarios, different kinds of project structures have to be ranked. Target function contains different kinds of components in different kinds of levels. For example, the cost demands in the low level, or the budget in the top level planning can be calculated when we determine different kinds of scenarios, but structures within a scenario contains the same cost demands/budgets. A target function in the different kinds of levels can contain four components: (1) *P*-values/*p*-values (*P*), (2) duration (*D*), (3) cost demands/budget (*C*), (4) resource demands (*R*) of the project structure/project scenario (see Table 8 below). In this case the target function has maximum four parameters, and can be defined as a t (P, C, D, R) function.

Table 8. Components of the target function.

	***P*-values/*p*-values**	**Cost demand/ Budget**	**Duration**	**Resource demands**
Project scenarios	X	X		(In case of different kind of resource demands)
Project structure	X		X	X

With *P*-values probability/priority/importance of completion can be taken into consideration. According to the time/cost/resource demands, target function may minimize these demands when selecting a scenario or a structure. At the evaluation low-level xMPEM constraints can be handled by special target function. In this case the value of target function will be infinite if constraints are exceeded.

Using genetic algorithm, a so-called ‘fitness function’ should be defined. In this case the target function will be the fitness function, which has to be minimised/maximised. f=min t (P, C, D, R), f=max t (P, C, D, R).

When generating initial population of project scenario uncertain completion will be considered. Diagonal values between 0 and 1 will be 0 or 1. 0 means that this task/subproject will be ignored; in contrast 1 means task/subproject will be completed at this scenario. In this way the uncertain completion will be certain completion, or certain exclusion. This operation is the ***realization of project scenario***. The realizations of uncertain task/subproject completion of the project scenario give a vector, where elements of this vector are 0 or 1, and the number of elements of this vector is the number of uncertain task completion. For instance in 2 by 2 xMPEM matrix, where the *P*-value of the first task/subproject 0.3 and the second one is 0.7, the possible realization vectors are (0,0); (0,1); (1,0) and (1,1). The realization vector can be called as the genome of the project scenario.

Table 9. Different kind of project scenarios.

<table>
<tr><th></th><th>(x)PEM</th><th>1st scenario</th><th>2nd scenario</th><th>3rd scenario</th><th>4th scenario</th></tr>
<tr><td>Matrix</td><td><table><tr><td></td><td>S₁</td><td>S₂</td></tr><tr><td>S₁</td><td>.3</td><td>1</td></tr><tr><td>S₂</td><td></td><td>.7</td></tr></table></td><td><table><tr><td></td><td>S₁</td><td>S₂</td></tr><tr><td>S₁</td><td></td><td>1</td></tr><tr><td>S₂</td><td></td><td></td></tr></table></td><td><table><tr><td></td><td>S₁</td></tr><tr><td>S₁</td><td></td></tr></table></td><td><table><tr><td></td><td>S₂</td></tr><tr><td>S₂</td><td></td></tr></table></td><td>–</td></tr>
<tr><td>Realization vector</td><td></td><td>(1,1)</td><td>(1,0)</td><td>(0,1)</td><td>(0,0)</td></tr>
</table>

P-values can also be used for generating initial population, where initial population contains more completed uncertain tasks, where *P*-values are larger.

Similarly to generating population of a project scenario, the population of project structure within a project scenario can be generated. In this case the realization vector contains the realized/ignored relation between two tasks/subprojects.

Realizations with high/low *fitness function* will be selected. This operator is the so-called selection operator and defines a $\mathbf{P}^s$ subset of population $\mathbf{P}$.

If at least two genomes of project structure/project scenario are determined, than the operator of *recombination* can be described in a very easy way. Let $\mathbf{r}_1$ and $\mathbf{r}_2$ be two realization vectors of either a project scenario or a project structure within a project scenario. Since number of elements of $\mathbf{r}_1$ and $\mathbf{r}_2$ are equal, the recombined new $\mathbf{r}$ vector has the same number of elements as $\mathbf{r}_1$ and $\mathbf{r}_2$, and the i^{th} element of vector $\mathbf{r}$ are the same the i^{th} element of $\mathbf{r}_1$ or $\mathbf{r}_2$. For example let $\mathbf{r}_1=(0,1,1,1,0,1)$ and $\mathbf{r}_2=(0,1,0,0,0,1)$ then possible recombination excluding $\mathbf{r}_1$and $\mathbf{r}_2$ are (0,1,1,0,0,1) and (0,1,0,1,0,1). The set of recombination with large fitness values will be denoted as $\mathbf{P}^r$.

When applying *mutation operator* an element of a genome will be switched either from 0 to 1 or from 1 to 0. (i.e. $(0,1,1,0,0,1)\rightarrow(0,0,1,0,0,1)$). The set of mutated genomes with large fitness value will be denoted as $\mathbf{P}^m$.

The next population ($\mathbf{P}$') will be the union of selected ($\mathbf{P}^s$), recombined ($\mathbf{P}^r$) and mutated ($\mathbf{P}^m$) sets. The algorithm will iterate generating new population until a maximal iteration number or a convergence will not be reached. Convergence means the values of target function within a population are closer together than $\varepsilon>0$.

Results of Research

Since scheduling problem can be solved by fast algorithms, and the mean of the resource demands, which can be a target function for the resource constraint scheduling problem, can be determined very fast, and also the cost demands of a given project scenario can be solved very quickly, therefore one can focus on how to generate realization vectors for project scenarios and project structures. Table 9 shows the results of different sizes of realization vectors. The initial project plan contains 500 activities, 2500 dependencies between tasks and 8 different kinds of renewable resource demands. The selection ratios for setting certain task completions and certain task relations into uncertain values were 1%, 5%, 10% and 15% of the activities/relations. The time constraint for computation was 30 minutes.

The target function minimises (time/cost/resource) demands, and maximises the priority/probability of project scenarios and project structures. In one hand, when minimising project demands activities and/or dependencies from the project plans can be ignore. On the other hand, when maximising either priorities or probabilities of the project scenarios/project structures, we want to keep important/probable completion of activities/dependencies as much as possible. Parallelised project structures required less time, but more resource demands.

Table 10. Results of the simulation.

Project scenarios			Project structures			
% Uncertainty of task completion	Mean of % realized task completion	Mean of relative cost demands	% Uncertainty of task dependencies	Mean of % realized task dependencies	Mean of relative time demands	Mean of relative resource demands
1	99.5	99.2	1	99.4	90.4	104.5
			5	98.2	85.5	108.5
			10	90.5	80.2	110.4
			15	87.6	74.2	125.1
5	97.4	97.1	1	94.7	88.4	100.2
			5	91.2	83.1	104.3
			10	87.5	78.6	107.7
			15	81.7	71.2	111.2
10	95.1	93.8	1	82.3	84.1	98.7
			5	77.8	80.1	100.1
			10	71.2	77.7	104.4
			15	69.9	70.1	107.9
15	90.6	88.2	1	68.4	81,9	92.4
			5	64.7	74.5	98.1
			10	61.8	71.2	100.6
			15	58.7	67.2	105.5

Discussion

The introduction described some shortcomings of the traditional project planning methods. Although these methods are very effective at the operation level of the project management, matrix-based methods are more appropriate in strategic level. In this paper a new matrix-based project modelling and planning method was introduced. This chapter it is shows, how the traditional project management system and the new methods into a project expert system put together. Figure 4 shows the possible connection between Project Expert System and the Project Management System.

After evaluating a multilevel xMPEM matrix, which can describe a multi project, project portfolio or a programme, the project manager can give project structures, which can be characterized and managed by using a traditional project management system. However before the final step, where a network plan will be specified, the project manager can decide which subprojects/task should be completed considering the project budgets. After this the manager can decide how to complete these tasks/subprojects according to the time and resource constraints. In the course of the evaluation three matrix-based methods are used: multilevel xMPEM for characterizing multilevel projects; SNPM for describing a project scenario and a DSM for presenting a project structure. Since there are huge number of variations of different kinds of project scenarios and project structures, genetic algorithm should be used for selecting adequate project scenarios and project structures considering the management claims.

PROBLEMS
OF MANAGEMENT
IN THE 21st CENTURY
Volume 5, 2012

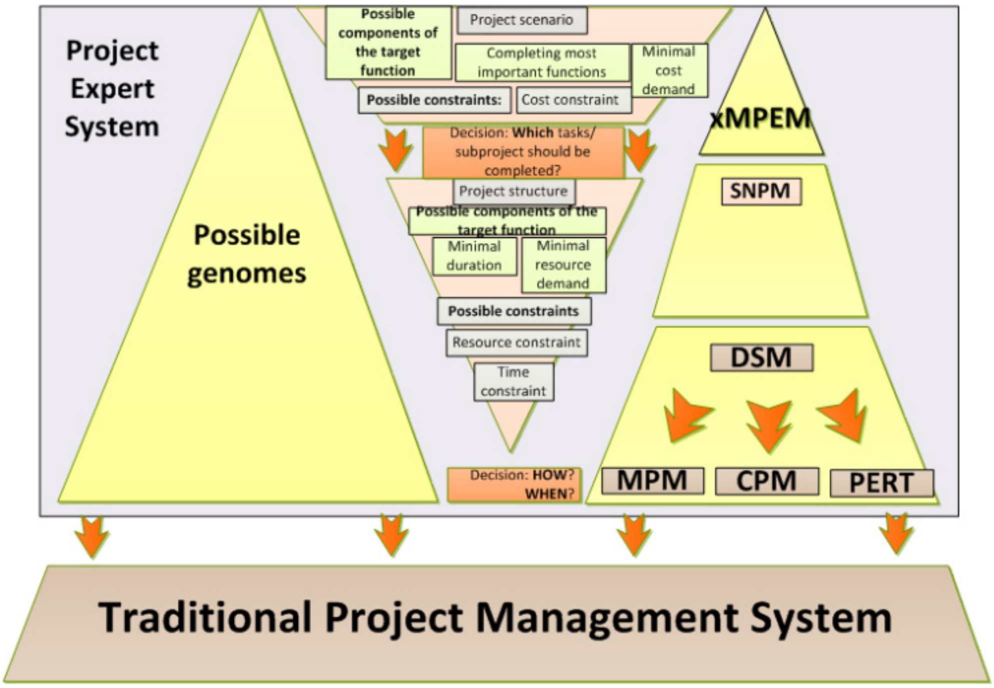


Figure 4: Architecture of the project expert system.

Conclusions

Although the project expert system is rather a fictitious currently, than the fact now, developed matrix based methods and introduced multilevel genetic algorithms may be important components of a project expert system. The introduced methods support the agile project management approach beside the traditional project management. Different kinds of target functions adapted to the management claims can be used for selecting an adequate project plan.

Acknowledgements

This paper was made under the project TÁMOP-4.2.2/B-10/1-2010-0025.

Note

This paper is a revised and enhanced version of a submitted conference paper: "Project Expert System – Fact or Fiction?" submitted to the 2nd World Congress on Information Technology 2012. Barcelona, Spain, (not published).

References

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*, *24* (2), 175-184. http://dx.doi.org/10.1016/j.ijproman.2005.10.005

Evaristo, R., & van Fenema, P. C. (1999). A typology of project management: emergence and evolution of new forms. *International Journal of Project Management*, *17* (5), 275-81. http://dx.doi.org/10.1016/S0263-7863(98)00041-6

Fazar, W. (1959). Program Evaluation and Review Technique. *The American Statistician*, *13* (2), 10.

Gantt, H. L. (1974). *Work, Wages and Profit*. Published by The Engineering Magazine, New York, 1910; republished as Work, Wages and Profits, Easton, Pennsylvania, Hive Publishing Company.

Gebala, D. A., & Eppinger, S. D. (1991). Methods for analyzing design procedures. *Proceedings of 3rd International ASME Conference on Design Theory and Methodology*, 227-233.

Kastor, A., & Sirakoulis, K. (2009). The effectiveness of resource levelling tools for Resource Constraint Project Scheduling Problem. *International Journal of Project Management*, *27* (5), 493-500. http://dx.doi.org/10.1016/j.ijproman.2008.08.006

Kelley, J. E., & Walker, M. R. (1959). Critical-Path Planning and Scheduling. *1959 Proceedings of the Eastern Joint Computer Conference*, 160-173.

Kiss, J., Kosztyán, Zs. T., Németh, A., & Bognár, F. (2011). Matrix-based methods for planning and scheduling maintenance projects. *Proceedings of the 13th International DSM Conference**, Cambridge, MA, USA, 14-15 September 2011, Carl Hanser Verlag, Munich, 421-434.

Kosztyán, Zs. T., & Kiss, J. (2010a). Stochastic Network Planning Method. *Advanced Techniques in Computing Sciences and Software Engineering* (edited by Khaled Elleithy) Springer Netherlands, 2010. 263-268. DOI 10.1007/978-90-481-3660-5_44

Kosztyán, Zs. T., & Kiss, J. (2010b). PEM - A new matrix method for supporting the logic planning of software development projects. *12th International Dependency and Structure Modelling Conference*, DSM'10, 22-23 July 2010, Cambridge, UK.

Kosztyán, Zs.T., Hegedűs, Cs. & Kiss, J. (2010). Developing Expert System for Managing Maintenance Projects, *2nd International Conference on Software, Services and Semantic Technologies*, Varna, Bulgaria, 11-12 September 2010. 218-225 Printed by Demetra EOOD, Sofia.

Kosztyán, Zs. T., & Kiss, J. (2011). Matrix-based project planning methods. *Problems of Management in the 21st Century*, *1* (1), 67-85.

Kosztyán, Zs. T., & Kiss, J. (2013). Matrix-based Methods for Supporting Logic Planning of IT Projects. *Emerging Trends in Computing, Informatics Systems Sciences, and Engineering* (edited by Khaled Elleithy)*, Lecture Notes in Electrical Engineering, 151*, 311-318. DOI: 10.1007/978-1-4614-3558-7_25.

Meehan, J. S., Duffy, A. H. B., & Whitfield, R. I. (2007). Supporting 'Design for Re-use' with Modular Design. *Concurrent Engineering*, *15*, 141-155.

Pritsker, A. A. B. (1966). (PDF). *GERT: Graphical Evaluation and Review Technique*. RM-4973-NASA. National Aeronautics and Space Administration under Contract No. NASr-21 (08). RAND Corporation, Research Memorandum, Santa Monica, California.

Steward, D. (1981). *System Analysis and Management: Structure, Strategy, and Design*. New York: Petrocelli Books

Thebeau, R. E. (2001). *Knowledge Management of System Interfaces and Interactions for Product Development Processes*. Master's Thesis, Massachusetts Institute of Technology, Cambridge, MA, System Design and Management Program

Wysocki, R. K., & McGary, R. (2009). *Effective Project Management: Traditional, Adaptive, Extreme*. 3rd Edition, Wiley and Sons Inc.

Yassine, A., Falkenburg, D., & Chelst, K. (1999). Engineering design management: An information structure approach. *International Journal of Production Research*, *37* (13), 2957-2975. DOI:10.1080/002075499190374.

Advised by Constantin Bratianu, Academy of Economic Studies, Bucharest, Romania

Received: *September 29, 2012*　　　Accepted: *October 28, 2012*

Zsolt T. Kosztyán	PhD., Associate Professor, Department of Quantitative Methods, University of Pannonia, 10 Egyetem Street, 8200 Veszprém, Hungary. E-mail: kzst@vision.vein.hu Website: http://englishweb.uni-pannon.hu/