UPON MULTI-PARAMETRICAL OPTIMIZATION IN RISK MANAGEMENT

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In order to demonstrate the role and the place of the harmonization modelling theory [12–14], we have to show its utilization in certain management areas. It can be well-recognized that harmonization models are applicable mostly to organization systems under random disturbances. This, in turn, enables analyzing various sources of uncertainty, e.g. reliability values including hazardous failures, various environmental parameters, etc. We will examine henceforth two important cases of project management: large-scale complicated projects and medium-level public service projects.

Keywords: project risk analysis; risk assessment models; public service projects; on-line control models; trade-off project optimization models

1. Using harmonization modelling for managing large projects

It can be well-recognized from [13–14] that the input information for the developed harmonization modelling in Project Management comprises a PERT-COST activity-on-arc network project \(G(N,A)\) with budget values \(c_{ij}\) assigned to all activities \((i,j) \in A \subseteq G(N,A)\) with restricted upper and lower bounds \(c_{ij,\text{min}} \leq c_{ij} \leq c_{ij,\text{max}}\). Each activity duration \(t_{ij}\) is a random value with a probability density function depending parametrically on the assigned budget \(c_{ij}\). Thus, uncertainty in scheduling results in random time delays of the total project's duration which translates directly into an uncertainty in cost. Those uncertainties may cause certain risks in the course of managing the project.

From the other side the projects to be considered in Harmonization Modelling (HM) do not deal with system's engineering aspects, since all the input information is presented in a formalized shape. Harmonization model is regarded as a generalized cybernetic problem which deals with multi-parametric optimization in order to calculate system's utility estimates. Harmonization models, thus, are not linked with such risk factors as technology, complexity and integration, design changes, supportability, marketing, etc., although they usually comprise probabilistic parameters which may affect those risk factors.

Taking into account [2], a conclusion can be drawn that projects of such type have not to be managed by use of regular risk analysis models, e.g. of SCERT and RAER types [2]. Such projects usually perform the duties of public service projects, e.g., by building new populated areas, schools, hospitals, bridges, factories, etc. In our opinion, those projects also have to be properly managed and controlled.

Since harmonization modelling techniques are based on trade-off optimization models which can be used in planning and controlling stochastic network projects as well [8,9], we suggest to unite in one person the harmonization models' analyzing function as well as the analyst responsible for undertaking on-line control for PERT-COST projects. In our opinion, most of the conclusions drawn from harmonization modelling can be implemented in on-line control procedures including decision-making.
However, even in the case of highly complicated large projects with new changing technologies and with tendencies for the latter to become obsolete, harmonization models may prove to be useful. In certain cases the alternatives and scenarios to be determined in the course of risk analysis, on the stage of optimization and refinements of alternatives [2, 17], may be passed to harmonization analysts in order to obtain basic parameters to optimize the corresponding utilities. Those scenarios may be in the form of PERT-COST network projects which is one of the most general forms in Project Management. Thus, a general conclusion can be drawn as follows:

I. For projects under random disturbances which:
   - do not deal either with advanced technological uncertainty or with capital investments to be returned from marketing;
   - may involve certain risks caused by overrunning pre-given due dates or project's costs,
     - harmonization techniques can serve both for evaluating the project's utility and as regulation models in the course of planning and controlling the project.

II. For highly complicated and large projects which have to be managed by the use of risk analysis, harmonization techniques can be used in risk assessment, by systems analyzing and modelling (usually in the form of possible alternatives and scenarios).

Thus, harmonization models can be regarded as an important auxiliary technique to support and facilitate risk management. If, e.g. the management is faced with two different alternatives (scenarios) to manage an organization system, both alternatives have to be analyzed from the point of risk management. Those alternatives may eventually boil down to different system's models with different basic parameters. To implement a trade-off analysis between the two alternatives, the methodology of harmonization modelling may be applied.

The interconnection between risk management and harmonization techniques may be put as follows: at all critical time points in the life cycle of a project (changing the market requirements, needs for developing a new software package, new contingency plans that cut expenses and development time at the cost of lower performance, etc.), risk management analysts form the updated input information of alternative scenarios for harmonization modelling. The new input information comprises [12–14]:

- the updated and renewed alternative's model (e.g. in the form of PERT-COST sub-networks);
- n basic parameters entering the model;
- new partial utility coefficients \( \alpha_k \) as well as values \( R_{k0} \) and \( R_{k00} \), \( 1 \leq k \leq n \).

On the basis of the obtained information in the course of harmonization modelling, proper decision-making has to be undertaken and implemented in monitoring the organization system. This has to be carried out by risk management analysts.

In other words, harmonization modelling, similarly to make tree analysis, fault tree models, contingency evaluation and review techniques, etc., may be regarded as special auxiliary technique to improve the system's monitoring. Thus, harmonization modelling, like any generalized cybernetic modelling, may serve as technique in risk assessment.

2. Harmonization models for managing PERT-COST public service projects

We will consider in greater detail the case when a medium-size PERT-COST activity-on-arc network project serves as a system's model in order to undergo harmonization. The project \( G(N,A) \) comprises activities \((i,j) \subset A \subset G(N,A)\) of random durations \( t_{ij} \) with pre-given p.d.F. depending parametrically on the budget value \( c_{ij} \) assigned to each activity \((i,j)\). It is assumed that for each activity \((i,j)\) its p.d.F. \( p(t_{ij}/c_{ij}) \) satisfies the beta-distribution

\[
p(t_{ij}/c_{ij}) = \frac{12}{(b_{ij} - a_{ij})^2} \left( t - a_{ij} \right) \left( b_{ij} - t \right), \tag{1}
\]

where \( a_{ij} = \frac{A_{ij}}{c_{ij}} \), \( b_{ij} = \frac{B_{ij}}{c_{ij}} \), \( A_{ij} \), \( B_{ij} \) – constants, and \( c_{ij} \) satisfies restrictions.
\[ c_{ij} \min \leq c_{ij} \leq c_{ij} \max , \]  

(2)

with pre-given values of \( c_{ij} \min \) and \( c_{ij} \max \).

Given the total project's budget \( C \geq \sum_{ij} c_{ij} \min \) and the due date \( D \), the problem is to evaluate the project's optimal utility value given in the linear form

\[ U = \max_{C,D,R} \left\{ \alpha_C(C_0 - C) + \alpha_D(D_0 - D) + \alpha_R(R - R_0) \right\}, \]  

(3)

where \( C_0 \), \( D_0 \) and \( R_0 \) are the least permissible budget, due date and reliability values which can be implemented in a PERT-COST project, while values \( C \), \( D \) and \( R \) are current values for the project under consideration. Linear rates \( \alpha_C \), \( \alpha_D \) and \( \alpha_R \), i.e., the partial utilities, are pre-given as well. It has been shown in [12-14] that reliability value \( R \) is obtained by means of optimizing the partial harmonization model \( PHM[C,D] = R \) as follows:

\[ \text{determine } c_{ij}^{(opt)} \text{ to maximize the objective} \]

\[ \max_{\{c_{ij}\}} \left[ \Pr\left\{ T[G/c_{ij}] \leq D \right\} \right] \]  

(4)

subject to (2) and

\[ C = \sum_{ij} c_{ij}^{(opt)}, \]  

(5)

\[ C_00 \leq C \leq C_0, \]  

(6)

\[ D_00 \leq D \leq D_0, \]  

(7)

\[ R_0 \leq R \leq R_00. \]  

(8)

Undertaking a relatively simple look-over in the two-dimensional area of \( C \) and \( D \) and determining for each couple \( (C,D) \) the corresponding \( R = PHM[C,D] \) in order to maximize objective (3) enables establishing the project's utility \( U \).

In case when project \( G(N,A) \) is represented in a formalized shape and activities \( (i,j) \in G(N,A) \) do not bear any engineering definitions and have an abstract meaning, we suggest using harmonization modelling as the project's planning and control technique. Note that undertaking harmonization modelling for the project under consideration results in optimal budget reallocation among the project's activities. This basic assertion will be used later on, by implementing the project's on-line control.

We suggest a step-wise procedure to control the PERT-COST public service network project by means of harmonization as follows:

**Step 0.** Given the input information:
- PERT-COST project \( G(N,A) \);
- Pre-given values \( c_{ij} \min \), \( c_{ij} \max \), \( A_{ij} \) and \( B_{ij} \) for each activity \( (i,j) \subset A \subset G(N,A) \);
- Pre-given partial utilities \( \alpha_C \), \( \alpha_D \) and \( \alpha_R \);
- Pre-given admissible intervals \([C_00, C_0]\), \([D_00, D_0]\) and \([R_0, R_00]\).

**Step 1.** Undertake harmonization modelling for \( G(N,A) \) beforehand, i.e., before the project actually starts to be carried out. Denote the corresponding optimized values which define the maximal project's utility, by \( C^*, D^* \) and \( R^* \). Note that restrictions

\[ \begin{cases} 
C_00 \leq C^* \leq C_0 \\
D_00 \leq D^* \leq D_0 \\
R_0 \leq R^* \leq R_00
\end{cases} \]  

(9)

hold, otherwise harmonization cannot be accomplished.
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**Step 2.** If budget value $C^*$ is accepted, reassign $C^*$ among the project's activities according to values $c_{ij}^{(opt)}$ obtained in the course of undertaking harmonization at Step 1. Afterwards the project starts to be carried out.

**Step 3.** In [8,9], a control model for PERT-COST projects is outlined. The model determines planned trajectories, observes at each control point the progress of the project and its deviation from the planned trajectory, and establishes the next control point. This control model has to be implemented at Step 3, in order to determine the routine control point $t > 0$.

**Step 4.** At each control point $t$ the progress of the project is observed, i.e., network graph $G(N,A)$ has to be updated at point $t$, as well as the remaining budget $C^*$. Denote those values by $G_t(N,A)$ and $C^*_t$, correspondingly.

**Step 5.** At each routine control point $t > 0$ solve harmonization problem in order to reallocate later on the remaining budget $C^*_t$ among remaining activities $(i,j) \in A_t \subseteq G_t(N,A)$. Denote the corresponding optimal budget values by $c_{ij}^{(opt)}$.

**Step 6.** Reallocate, if necessary, budget $C^*_t$ among activities $(i,j) \in A_t$ according to the results of Step 5. Note that implementing numerous budget reallocations is actually the only control action in the course of performing on-line control. Go to Step 3.

**Step 7.** The algorithm terminates after inspecting the project at the due date $D$, i.e., at the last control point.

It can be well-recognized that, besides undertaking on-line procedures, the suggested step-wise algorithm comprises both harmonization modelling and risk analysis models. Indeed, the latter are not similar to traditional risk management methods which involve technological risks, uncertainties in products' marketing, etc. However, optimal budget reallocation serves actually as a regulation model under random disturbances and can be regarded as a risk analysis element.

Note that in the course of the project’s realization certain parameters entering the input information may undergo changes, e.g. restriction values $C_0$, $C_{oo}$, $R_0$, $R_{oo}$, $D_0$, $D_{oo}$, as well as partial utility values $\alpha_C$, $\alpha_D$ and $\alpha_R$ [12-14]. New values have to be implemented in the harmonization model in order to facilitate optimal budget reallocation among the remaining project’s activities at Step 5 of the algorithm. If the problem (4-8) has no solution, the decision-making to be undertaken at the company level results either in obtaining additional budget value $\Delta C$ or in increasing the due date by $\Delta D$. Both values can be determined by means of harmonization.

**3. Harmonization models for analyzing alternatives and scenarios**

We will consider the case of a large complicated project with a high level of uncertainty both in technology and at the marketing stage of the project’s life cycle. To manage such projects risk analysis methods similar to RAER or SCERT [2] have to be implemented. Those methods, which we will use henceforth as benchmarks, deal with analyzing various alternatives or scenarios which may be presented in the form of deterministic network sub-projects of CPM type. On the basis of those sub-projects “time – cost” trade-offs outlined in [17], are usually carried out. We will henceforth call those deterministic trade-offs the CPM-COST projects.

We suggest, if possible, to present those scenarios in the form of stochastic PERT-COST network projects and to substitute the former “time – cost” trade-off by a harmonization model. We will demonstrate that the newly developed trade-off optimization model is more effective than the former CPM-COST ones.

In order to perform a proper comparison we have to use similar input information. Since an overwhelming majority of both researchers and practitioners accept the beta-distribution as a probability law for random activities' durations [see, e.g. 1, 3-7, 10-11, 15-16, 18-20] with the p.d.f. of the activity time $t_{ij}$

$$f_{ij}(t) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) \Gamma(\beta)} \left( t - a_{ij} \right)^{\alpha-1} \left( b_{ij} - t \right)^{\beta-1}, \quad a < t < b, \quad \alpha, \beta > 0,$$

where $a_{ij}$ stands for the optimistic time and $b_{ij}$ is the pessimistic time. 

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In order to simplify the model the p.d.f. in the PERT statements can be modified [5-7, 9] to

\[ f_{ij}(t) = \frac{12}{(b_{ij} - a_{ij})^2} (t - a_{ij}) (b_{ij} - t)^2 \]  

with the mean \[ \mu_{ij} = 0.2(3a_{ij} + 2b_{ij}) \].

Thus, introducing the assumption about the p.d.f. (10) and taking into account that (10) depends on \( c_{ij} \) parametrically, relations (1,2) hold.

The simplified time – cost trade-off model for a CPM network [17] is as follows:

given a CPM graph \( G(N,A) \) together with functions \( t_{ij} = f_{ij}(c_{ij}) \), \((i,j) \in G(N,A)\), and values \( c_{ij\min} \) and \( c_{ij\max} \), determine:

- the minimal total project direct costs \( C \),
- the optimal assigned budget values \( c_{ij}^{opt} \), subject to

\[ T_{cr} \left\{ t_{ij} = f_{ij}(c_{ij}^{opt}) \right\} \leq D \]  

\[ \sum_{(i,j)} c_{ij}^{opt} = C \]  

\[ c_{ij\min} \leq c_{ij}^{opt} \leq c_{ij\max} \]  

where \( D \) stands for a pre-given due date.

Since trade-off models in RAER [2] are based on deterministic time – cost trade-offs for CPM-COST models (13-16), the similarity of input information for both models (harmonization and RAER) can be provided by setting

\[ t_{ij} = \frac{0.6A_{ij} + 0.4B_{ij}}{c_{ij}} \]  

for

\[ c_{ij} = \begin{cases} c_{ij\min} & \\ 0.5(c_{ij\min} + c_{ij\max}) & \\ c_{ij\max} & \end{cases} \]  

where values \( A_{ij}, B_{ij}, c_{ij\min}, c_{ij\max} \) are similar to those outlined in (1), and (17) are obtained by substituting the p.d.f. (11) by its mean value (12).

Let us compare the "time – cost" trade-off CPM-COST model (13-16) and the harmonization model (4-8), taking into account that actually activity durations \( t_{ij} \) are random variables. It is widely known [see, e.g. 5, 8, 9, 16, 17 etc.] that substituting all p.d.f. activities by their mean values results in essential statistical bias errors for optimization models' objectives (sometimes up to 40-50%). Those errors underestimate the objective, e.g. the critical path's duration. Underestimating planning budget values of any project results in underestimating local budgets assigned to partial project's activities. Such errors might result in increasing the duration of those activities and, thus, decreasing the project's reliability. This, in turn, would affect the life cycle, the cost and the ultimate success of the entire project. As a matter of fact, substituting deterministic trade-offs by harmonization modelling prevents this shortcoming.

Second, implementing harmonization modelling by means of PERT-COST network projects enables decision-making by using reliability parameter \( R \) which is difficult to be analyzed by means of solving
CPM-COST problem (13-16). And, third, by using CPM-COST trade-offs of type (13-16) only several scenarios can be examined (since no risk analyst can take into account numerous alternatives), as distinct from harmonization models when the whole spectrum of possible couples \((C; D)\) is looked through and later on optimized. This, in turn, enables more reasonable and realistic decision-making. Thus, harmonization procedures when considered a risk assessment technique are more effective than the former similar risk assessment by means of CPM-COST network models.

Conclusions

The following conclusions can be drawn from the study:

1. Besides optimizing and calculating the system's utility, harmonization models are used in determining various reliability parameters. Thus, those models can be regarded as newly developed operation research models which can be implemented in risk assessment analysis.

2. Harmonization models can be applied directly to all kinds of PERT-COST network projects with uncertainties associated with activities' durations but without either technological risks or uncertainties on the stage of marketing the project's products. Such projects usually refer to the public service area, like constructing new hospitals, schools, stadiums, theatres, bridges and tunnels, new urban areas, factories, etc. In our opinion, those projects represent an overwhelming majority of existing projects and, thus, require good quality monitoring. For such projects we suggest to use the newly developed harmonization techniques both for estimating the project's utility and for introducing regulating control actions at inspection points to enhance the progress of the project in the desired direction. Thus, harmonization modelling enables certain on-line control procedures for projects under random disturbances. Being a regulation model, harmonization can be implemented (in a random disturbances environment) as a risk assessment tool as well. Thus, for this class of projects, harmonization, controlling and risk assessment actually meet.

3. A comparative analysis of multi-parametrical trade-off optimization models in harmonization and the existing trade-off optimization techniques in CPM-COST risk assessment leads to the conclusion that the newly developed model is more effective for project risk analysis than former trade-off models. The latter usually cover only time – cost trade-offs for deterministic projects while harmonization techniques can be applied to any number of optimized parameters for projects under random disturbances.

4. For highly complicated projects with technological risks, design changes and risks in future marketing, we suggest to apply harmonization modelling for analyzing alternatives and scenarios on condition that the latter may be presented in the form of PERT-COST network projects. This enables undertaking a more effective risk assessment.

Acknowledgement

This research has been partially supported by the Paul Ivanier Center on Robotics and Production Management, Ben-Gurion University of the Negev.

References


Received on the 1st of August 2006