A MULTI-OBJECTIVE PROJECT PORTFOLIO FORMATION MODEL: CASE STUDY OF LITHUANIAN TRANSPORT SECTOR

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Abstract. The paper is devoted to develop a decision support system based on multi-objective constrains and implementation of Lean and Six Sigma concepts for project portfolio formation problem in transport sector. A multi-objective model, that facilitates the formation of the efficient project portfolio based on the set of objectives pursued by the organization as well as on the variety of constraints and limitations of projects implementation, was suggested. The importance of Lean and Six Sigma methodologies deployment in the project portfolio formation process is accentuates in the paper. Lean and Six Sigma methodologies play an important role in nowadays’ business environment, as companies are embracing these initiatives to support cost reductions and quality improvements in order to be competitive market players. To implement these developments decision makers face with the problem of efficient project portfolio selection that would meet the multiple objectives and satisfy variety of constraints. The suggested methodology is tested in a case study of Lithuanian transport sector and exemplifies the practical application of this model. The robustness of the methodology can be tested by conducting several case studies in other Lithuanian industries. The article is relevant to both industry practitioners and researchers.

Keywords: lean, six sigma, multi-objective model, project portfolio selection, Pareto frontier, decision support system.

1. Introduction

Becoming more mature in Six Sigma programs, enterprises are demanding more and more benefits with less resource being ensured that at same time their methods utilized will bring as much beneficial financial gains as possible. For this reason they are combining several methodologies in order to better develop their performance. Transport and logistics sector’s companies in recent years have successfully started their practices implementing Lean and Six Sigma methodologies for their development projects, because the marriage between Lean Manufacturing and Six Sigma has proven to be a powerful tool for cutting waste, value creation, revenue growth (Muir 2005) and improving the organization’s operations. Therefore, Lean and Six Sigma as a quality improvement framework have been gaining considerable attention in recent years and are recognized among the most significant threads of development in the technology and quality measurement domain (Walker 2005).

The goal of the paper is to propose the multi-objective model for project portfolio formation which introduces the multi-objective approach and implementation of Lean and Six Sigma concepts. The main idea proposed by the authors is that the weights of the multiple objectives and constraints can be flexibly determined by the decision makers who are mostly concerned about both the benefit and the cost of project portfolio selection. In addition, the suggested model is novel in the aspect of the benefit objective function which is quite new in similar multi-objective and project selection models. Moreover, a novel interactive graphical decision-making method that allows the decision-maker quickly down-select to a small subset of efficient portfolios was discussed.

The rest of the paper is organized as follows. Section 2 introduces a background of a multi-objective project selection model formulation. It includes a short scenario description, multiple objective functions, model constraints and solution techniques. In section 3, Lithuanian transport sector case study is presented to illustrate the application of the model formulation in practice. The paper is concluded in section 4 with major remarks and suggestions.

2. Multi-objective project selection model

Both Lean and Six Sigma lend distinctive disciplines and tools to logistics and transport sector. Utilizing these disciplines and tools will allow an organization to uncover and deal with wastes and inefficiencies. Although Lean and Six Sigma tools are very powerful, it is necessary to remember that for Lean and Six Sigma to work in transportation and logistics requires firstly begin to make decisions based on the concept of “total costs”, and second, to eliminate waste in its various forms (Goldsby, Martichenko 2005).
At this point a problem of multiple objectives arises in the company. Therefore, a decision support system based on various multi-objective methods and models has been widely observed recently. Brauers, Zavadskas, Turskis, Vilutienė (2008) demonstrated that modelling and multi-objective analysis allow us to find a way to meet the goals of the participants of different process and to choose an optimal solution as well as the ways to implement it.

Moreover, multi-attribute decision making can be classified as follows:

a) Multi-attribute decision making (MADM) for the sorting or the ranking of alternatives according to several attributes;

b) Multi-objective decision making (MODM), for driving a vector optimization-based design process to a solution (Colson, Bruyn 1989).

A number of authors (Gabriel, Kumar, Ordonez, Nasserian 2006, Thawesaengskulthai, Tannock 2008, Hu, Wang, Fetch, Bidanda 2008, Brauers 2008, Ginevičius, Podvezko 2008) have considered the issues involved in business improvement trends, especially in the area of multiple criteria decision-making (MCDM) methods suggesting variety of multi-objective models with competing objectives for project selection in order to implement those improvements.

A decision support system based on multi-objective constrains and implementation of Lean and Six Sigma concepts for project portfolio selection problem was developed and discussed in the paper. The brief concept and the illustration of the model is provided in Fig. 1.

2.1. Scenario description

The multi-objective project portfolio formation model is developed for the economic sector, which has a list of N projects with the goal to develop its performance and considering the implementation of the Lean and Six Sigma concepts. Each project is different and may include different sub-goals, budgets, resource consumption, as well as belongs to one or another pre-specified category. However, all listed projects can not be implemented because the sector has a limited budget and various risks, limited resources and plenty of other constraints. Here, the problem of project portfolio selection arises – how the projects should be chosen from the list in order to satisfy two different objectives: to minimize the investment and at the same time maximize the benefit of the sector. The multiple objectives are met by different alternative solutions or projects of a discrete or a continuous origin (Zavadskas 2008).

The outcome of the problem mentioned would provide with success of the Lean and Six Sigma concepts implementation: the sector benefits translate into enhancing performance, productivity and profitability by alleviating defects, waste, lead time through improving product quality and reliability (Hu, Wang, Fetch, Bidanda 2008).

2.2. Multiple objective functions

Considering the Lean and Six Sigma implementation and having the main two objectives (to maximize the overall sector’s benefits and minimize the total cost of the project portfolio), a Pareto optimal frontier chart was applied. It provides with the flexibility in making decisions – to pick the specific project portfolio based on the weights of different objectives.

Implementing project portfolio, the minimization of the total cost can be defined as:

\[ \text{Min} A(x_1, x_2, ..., x_n) = \sum_{i=1}^{n} a_i x_i, \]  

where, \( A(x_1, x_2, ..., x_n) \) is the total cost of the project portfolio, where \( a_i \) is the cost of the \( i \)-th project, \( x_i \) is a binary variable, if \( x_i = 1 \), then the \( i \)-th project is selected; if not, then \( (x_i = 0) \).
The maximization of the potential benefits in the same case is the simple summation of the utility or benefit from each selected project. As some interactions among projects during implementation may exist, there is suggested another kind of function that characterizes the total integrated benefit:

\[
Max(R(x_1, x_2, ..., x_n) = \sum_{i=1}^{M} w_i \left[ 1 - \prod_{j=1}^{N} (1 - d_{ij})^{x_i} \right],
\]

where \(d_{ij}\) is the normalized performance score for the \(j\)-th Lean and Six Sigma sub-goal of the \(i\)-th project proposal, and \(w_i\) is the weight of the \(j\)-th sub-goal in the achievement of the ultimate goal which is determined by the decision makers which may be called management group; in our case they are entitled as institution group. The normalized performance score \(d_{ij}\) is calculated from the project evaluation data from the decision makers.

\[
d_{ij} = \frac{s_j}{\sum s_i},
\]

where \(s_i\) is evaluation score of \(i\)-th project proposal in \(j\)-th category. The the integrated performance score for the \(j\)-th Lean and Six Sigma sub-goal of the chosen project portfolio is

\[
1 - \prod_{i=1}^{M} (1 - d_{ij})^{x_i}. \tag{4}
\]

The weights and the benefits from each Lean and Six Sigma sub-goal were incorporated and the integrated benefit function was derived.

As the function of benefit maximization is nonlinear, because of Lean and Six Sigma sub-goal function, when \(N\) increases, let us simplify the benefit function to make it computationally approachable. For this reason the exponential part of function is replaced by a logarithmic summation, and the benefit objective formula looks like this:

\[
B(x_1, x_2, ..., x_n) = \sum_{i=1}^{M} w_i \sum_{j=1}^{N} x_j \log(1 - d_{ij}). \tag{5}
\]

The less the benefit index, the larger potential benefit is gained from the implementation of the project portfolio.

### 2.3. Model constraints

The functions introduced above have several groups of constraints:

1. **Resource constraints.** Each company’s, sector’s, government’s, country’s decision makers have limited available resources (human resources, capacity, etc.) to implement some projects of development. In Lean and Six Sigma projects’ case limited resources are typically led by ‘black belts’. The quantity of projects a decision maker can implement may be limited by the number of ‘black belts’ at that company, sector, government or country. Resource constraints are defined:

\[
\sum_{i=1}^{N} g_{ij} x_i \leq G_j; \ j \in J ,
\]

where \(g_{ij}\) is the requirement of resource for the \(j\)-th resource by \(i\)-th project, \(G_j\) is the limit for \(j\)-th resource and \(J\) is the set of critical resource.

2. **Diversity constraint.** The decision makers do not have to select all projects in the same Lean and Six Sigma implementation level, however the project portfolio should be feasible and involve all stakeholders and as much projects as possible to develop variety of company’s aspects. Therefore, this constraint should be included in the integration of various aspects for waste reduction and quality improvement that are the goal of Lean and Six Sigma.

\[
\sum_{i=1}^{\#D_k} x_i \leq D_k ,
\]

where \(D_k\) is the set of projects in \(k\)-th category and \(D_k\) are pre-specified constants.

3. **Institution constraints.** Limitation on the number of projects that an institution group is responsible for:

\[
\sum_{i=1}^{\#IM_i} x_i \leq I_p ,
\]

where \(IM_i\) is the set of projects which will be managed by \(p\)-th management group and \(I_p\) are pre-specified constants.

4. **Risk constraint.** The decision making model includes the parameters that are not completely known at the current point of time, when the decision has to be taken (Pranevicius, Sutienė 2008). Therefore, a variety of risk factors (such as uncertainty, etc.) as a constraint are included by decision makers to this multi-objective model. The decision makers agree the specific level of risk that will be allowed for projects in order to be chosen to the portfolio and select projects for Lean and Six Sigma implementation only those projects that fit to agreed level.

\[
\sum_{i=1}^{\#C_r} x_i \leq R_r ,
\]

where \(C_r\) is the set of projects in \(r\)-th category and \(R_r\) are pre-specified constants.

The problem of Lean and Six Sigma project portfolio selection is adopted into a multi-objective model with linear objective that are de-
fined in the (1) and (4) formulas and linear constraints defined in the (5), (6), (7) and (8) ones (Fig. 2).

![Multi-objective model for project selection for Lean and Six Sigma implementation.](image)

**Fig. 2.** Multi-objective model for project selection for Lean and Six Sigma implementation.

The detailed analysis and approval of the proposed model is based on Lithuanian transport sector’s case and is described below.

### 3. The case study of Lithuanian transport sector

To illustrate the practical application of introduced multi-objective model for solving portfolio project selection problem implementing Lean and Six Sigma initiatives, Lithuanian transport and logistics sector which seeks to get the financial support from European Union funds were analysed. The proposed multi-objective model could help to select the projects to the portfolio which is financed by EU structural assistance for Lithuania for the period 2007–2013.

Each managing institution has a limited budget and has to decide how to allocate this sum of money among projects applied. Each project is ranked according to the various criteria and points (scores) assigned. Projects are chosen sequentially based on these points until the budget limit is reached. However, according to Hu *et al.* (2008) there are some criteria that cannot be assigned into the overall score. Depending on environment, on conditions, on a subject of concern, in our case, depending on a sector, that is being analyzed, there can be identified several categories that characterize the constraints and limitations of the assignment mentioned. They include: the diversity, human resource and management coordination issues. Even if the score system is accurate enough to comprehensively characterize the project features, this simple scoring and ranking project selection mechanism may not provide the ‘best’ choice for the decision maker (Hu, Wang, Fetch, Bidanda 2008). Risk as an additional constraint was included, and its impact on the project selection is accentuated mostly in our model.

Considering Lithuanian transport sector case study, the projects applied for EU structural support during 2007–2009 were analyzed. The portfolio formation decision was concentrated on the managing institution Transport Investment Directorate as it is responsible for development of transport sector projects in Lithuania. There were received 119 projects related with transport and logistics development initiatives in Lithuania in this period. They applied for 2584 million LTL. However, the budget is limited and amounts only 2343.41 million LTL. Therefore, the appropriate allocation of the obtained financial resources should be ensured, taking into account the size and category of aid granted through the EU structural funds (Ginevičius, Podvezko, Bruzgė 2008). In addition, the effect of the aid should be properly evaluated.

In our research, 2343.41 millions LTL refers to transport projects’ contracts signed during the period of 2007–2009. This is the overall available budget to implement the Lean and Six Sigma concepts in our case. The problem is how to select the most valuable projects to be financed? Which projects should be rejected, why and how?

Let us analyze how this possible budget of EU financial support for transport sector projects can be allocated among Lithuanian transport and logistics projects according multi–objective model for solving project portfolio selection in order to implement Lean and Six Sigma concepts, having in mind that investment minimization and potential Lithuanian transport sector benefit maximization are the two primary objectives of this project selection problem.

#### 3.1. Data analysis

The main data categories required for this analysis and that are of the most importance to decision makers that allocate projects to the portfolio based on multi-objective model include project expenses, benefit index, Lean and Six Sigma category determined by the decision makers group and institution group information. Having collected these data of Lithuanian transport sector projects applied for the EU structural support, we draw the table, which was a background for our further analysis. Here the potential benefit index for a single project was defined as:

$$BI(x_i) = \sum_{j=1}^{M} w_j \lg(1 - d_j),$$  \hspace{1cm} (9)

where $w_j$ and $d_j$ are determined in the group discussion of the decision makers.
To compare the relationship between a single project cost and the potential benefit index the chart was drawn which is presented in Fig. 3.

Fig. 3. Single project cost (LTL) vs. benefit index.

The less single project cost, the better potential benefit index. The $x$-axis is the expense for a single project and the $y$-axis is the potential benefit index if implemented. Analyzing projects based on these characteristics, the project can be categorized into four groups: high potential projects, low potential projects and two neutral project regions.

Figure 4 shows the categories for the projects suggestions. Projects that appear in the bottom left quadrant are the most effective projects as they have low costs and high potential benefits.

Fig. 4. Categories for project proposals

3.2 Numerical results and analysis

To form the optimal project portfolio for implementing the Lean and Six Sigma concepts, the practical application of the multi-objective model is introduced as a solution to this problem. Since there are 91 project proposals analysed, there are $2^{91}$ possible choices of the project portfolio. The first step in this analysis is the formation of Pareto frontier chart of the ranked portfolios (Fig. 5).

The ranked portfolios were obtained by setting the project portfolio budget at different levels and solving the integer program model summarized in section 2. Each point on the frontier represents the possible optimal project portfolio. However, the final optimal project portfolio is selected depending on the priority determined by the decision maker. The two axes denote the two objectives being considered: the project portfolio cost and the integrated portfolio benefit index (the less, the better).

Fig. 5. Pareto frontiers of project portfolio cost (LTL) vs. benefit index.

The second step in this analysis – the comparison of risk of projects chosen in the Pareto frontier set. The main point in this analysis is addressed to the relationship between the optimal portfolio sets and the individual projects. There should be made the remark that the Pareto portfolio choice is more sensitive to the portfolio cost than to the benefit index, since the line of portfolio cost does not change significantly with the change of the benefit index, but it decreases dramatically with the increase of the project cost.

Figure 6 demonstrates the cumulative portfolio risk of potential projects chosen in the Pareto frontier portfolios.

Fig. 6. Cumulative portfolio risk of projects chosen in the Pareto frontier.
has been chosen. The higher the line increases the more risky project has picked in the Pareto frontier portfolio set.

Another observation is that the risk is not monotonically increasing with the increase of the cost or the decrease of the potential benefit (the increase of the benefit index). The explanation is that the diversity and institutional group limit constraints exclude these simple monotonic properties. On other hand, the obtained result could be treated as an advantage of the proposed multi-objective model decision support system. The non-monotonic increase of the cumulative portfolio risk illustrates that the project benefit do not lead to absolute preference in the selection process. Main features and characteristics of selected projects are summarised and presented in Table 1.

Table 1. Main characteristics of selected projects

<table>
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<th>Project number</th>
<th>Expense, LTL</th>
<th>Benefit index</th>
<th>Lean and Six Sigma category</th>
<th>Institution group number</th>
<th>$d_{ij}$</th>
<th>Risk ($R_r$)</th>
<th>Evaluation score</th>
<th>Benefit/cost</th>
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For example, in the limited budget case, in our example it’s 2343.41 millions LTL, some projects are dominated by other projects, however, the optimal portfolio selects non-dominated projects instead of dominated ones. It is due to additional constraints in the model. To analyze the risk of the projects selected in the Pareto frontier set, we present the risk comparisons in table 1, where rows are ranked by the expenses of the project for the Pareto frontier set. Intuitively, the risk of project should also monotonically increase. However, this is not the case shown in table 1.

### 4. Conclusions

The paper presents a problem of project portfolio selection based on implementation of Lean and Six Sigma concepts. As a solution to this problem a multi-objective model integrated with Pareto frontier chart to assist decision makers is suggested.
The paper presents the application of a unique decision support system for implementing the Lean and Six Sigma initiatives that utilizes a multi-objective portfolio formation for project portfolio selection problem in Lithuanian transport sector. The major remarks and suggestion are summarized as follows:

The multi-objective model facilitates the selection of efficient projects into optimal portfolio in line with the set of objectives pursued by the organization as well as in line with the variety of constraints and limitations of projects implementation.

The model provides with the possibility to effectively implement Lean and Six Sigma concepts forming the optimal projects portfolio from the big quantity of projects.

The cumulative risk of Pareto portfolio is not monotonically increasing with the increase of the cost or the decrease of the potential benefit (the increase of the benefit index). The explanation is that the diversity and institutional group limit constraints exclude these simple monotonic properties.

The multi-objective model based project portfolio selection produce Lean and Six Sigma project portfolios that out-perform any other projects chosen through non-portfolio type methods.

The main feature of this model is flexibility:

− it can help decision makers to identify the optimal project portfolio flexibly for Lean and Six Sigma implementation;
− proposed decision support system based on the multi-objective can be flexibly applied to other portfolio selection problems.

Implementing Lean and Six Sigma initiatives based on this multi-objective model for project portfolio selection ensures the optimal choice of projects chosen to the set of implementation in order to allocate the budget of the unit analyzed for its development as good as possible.

The suggested methodology is tested only in a case study of Lithuanian transport sector, which is the limitation of the paper. The robustness of the methodology can be tested by conducting several case studies in other Lithuanian industries. In addition, the results could be compared with other existing methodologies for project selection such as project prioritisation matrix or the failure mode and effect analysis.

The paper accentuates the importance of the project selection process for Lean and Six Sigma deployment, which can have a tremendous effect on the business profitability of an organization.

References


