Acta Mechanica Slovaca **23 (2): 20 - 24,** Jun **2019**
https://doi.org/10.21496/ams.2019.002

Acta Mechanica Slovaca
ISSN 1335-2393
www.actamechanica.sk

Analysis of Mathematical Programming Applications in Supply Chain Management of Manufacturing Enterprises

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Abstract: This paper focuses on a current topic of supply chain management and operations research which serves as a tool manufacturing enterprises to cope with pressure put on them by continuously changing market conditions and global economy itself. Paper presents results of research conducted on sample file of Slovak manufacturing enterprises. The main aim of this paper is to explore the extent of utilization of mathematical programming as optimization methods in production practice in Slovakia to analyse possible relationship between enterprise's size and used optimizing method. Representativeness of the sample file was confirmed by application of Pearson´s chi-squared test ($\chi 2$ - test) due to criterion of enterprise's size. The results of this research have an implication for business practice and may serve managers in their decision-making process. In managerial practice enterprises have to deal with many different problems concerning their supply chains. The majority of them can be resolved using mathematical programming.

Keywords: *mathematical programming; supply chain management; manufacturing enterprises*

1. Introduction

In the 21st century manufacturing enterprises face a severe competition which puts that much pressure not only on their quality requirements, but also on their whole supply chains. It is the main aim of every enterprise's supply chain management to ensure the best possible outcome and gain the competitive advantage which enables enterprise to establish a desirable market position. However, it is not a single set of managerial decisions which make it possible. A strive for excellence is a continuous process which does not only involve establishing a good market position, but it also focuses on implementing measures necessary to maintain it. One of the effective ways enterprises can achieve excellence is through implementing specific measures in order to achieve flexibility and cost minimization throughout their supply chains. One of the basic tools is mathematical programming.

The theoretical aspects of supply chain management are broadly covered at various Universities all around the world and that includes application of various optimizing tools such as mathematical programming. These methods of mathematical programming are extensively taught at the universities; still there is a question if and how such methods are applied in the businesses and more importantly how successful they are. Thus, we consider the closer look at the Slovak reality to be extremely valuable. Another uniqueness of this topic lies in the fact that no such study has been conducted for the last 10 years in Slovakia.

Application of mathematical programming has recently been the topic of research studies of various authors (Xu et al., 2016; Armutlu, 2008; Tibi and Arman,

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Received: 2019.03.22
Revised: 2019.04.16
Accepted: 2019.05.17
Available online: 2019.03.15

2007; Závadský and Hiadlovský, 2014; Gong, 2008; Malhotra et al., 2014; Liao et al., 2016). One of the characteristics of optimizing tasks is the large amount of solutions matching the basic task conditions. The selection of a particular solution as the best to a problem depends on the overall objective that is implied in the statement of the problem. A solution which satisfies both the conditions of the problem and the give objective is considered to be the optimal one (Al-Yakoob and Sherali, 2007; Sodhi and Tang, 2012; Bruglieri et al., 2016; Thaoi, 2010; Závadský and Závadská, 2014; Vlachos et al., 2016; Das, 2011).

Various authors (Weber, 2009; Ben-Tal and Nemirovski, 2000; Avis and Umemoto, 2003; Chadha and Chadha, 2007; Floudas and Lin, 2005; Thuan and Luc, 2000; Grover and Malhotra, 2003) evaluated the advantages and disadvantages of the mathematical programming utilization. They all consider the possibility of applying these methods for the long-term supply chain management to be the most significant advantage. Other advantages include the relative accuracy of results achieved through these methods specifically designed to meet the needs of certain enterprises. The use of mathematical programming in production management assumes the creation of the objective function which describes the problem as closely as possible, which enables to model the conditions in production enterprise as realistically as possible. One of the main disadvantages of mathematical programming utilization is the fact that sometimes the objective function may not be the best option to model the processes and the situation may arise when enterprise would have to resort to other methods of the operations research. Despite of this fact, the advantages of mathematical programming utilization in enterprises are far greater and more significant. The application of these methods can help enterprises solve many different problems.

2. Experimental Section

The main aim of this paper is to explore the extent of utilization of mathematical programming as optimization methods in production practice in Slovakia to analyse possible relationship between enterprise's size and used optimizing method. In order to fulfil our goal, we use data provided by Slovak production enterprises via survey which was conducted in a period between June 2017 and October 2017.

Our research sample file was created as a representative sample of the base file. This file consists of Slovak enterprises classified by the SK NACE classification as manufacturing enterprises. Moreover, we took into account other criteria, mainly the size of enterprise. We focused our research on medium-sized and large-sized enterprises, since we assume the higher extent of linear programming applications in these enterprises. The decisive criterion was set according to the European Standard No. 2003/361/EC.

Research was carried out on a file consisting of 1300 Slovak production enterprises. The enterprises were selected randomly and chosen respondents were addressed by email. The questionnaire was fulfilled by 236 Slovak enterprises which represents 18.15 % return. In key enterprises we used method of structured interviews with enterprise's representatives. Overall research sample consists of 248 Slovak enterprises.

Our questionnaire consisted of 16 questions divided into 3 categories. The first set of questions was focused on exploring various aspects of applications of optimizing methods in supply chain management. This section of questionnaire was fulfilled by all enterprises. The second part of questionnaire involved questions designed in order to gain data about mathematical programming utilization in supply chain management. This section was fulfilled only by enterprises which currently use these methods or had used them sometime in the past. Lastly we also added the socio-economic questions created in order to gain data about respondents. We asked enterprises to provide information about their size (the number of their employees), sector of economy and region where they operate.

Our sample file consists of 38.31 % large-sized enterprises with number of employees over 251. More importantly 61.69 % of enterprises in our sample file have between 51 to 250 employees (Table 1). With the use of SPSS Statistics and information about data base set we can verify the representativeness of the sample according to the size of the manufacturing enterprise. It was discovered that our sample file is representative according to selected criterion.

Tab. 1: *Structure of sample file based on the size of enterprise.*

Number of employees	Number of enterprises	Percentage
51 - 250	153	61.69%
over 251	95	38.31%
Total	248	100.00%

Furthermore, we explored relations between applied enterprise's size and used optimizing method. Correlation coefficient was used to evaluate these relations and to discover significant dependences between factors. Particular coefficients were calculated according to formula 2 (Maloney, Byard, 2013).

$$r = r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (1)$$

where:

x_i, y_i – are defined as a value of i-element belonging to dataset $\{x_1,...,x_n\}$,

$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ – the sample mean and analogously for $\bar{y}$.

3. Results and Discussion

In the first part of the questionnaire we have obtained information about optimization of enterprises' supply chain in general, regardless of the used method. We have found out that only 54.83 % of selected manufacturing enterprises use optimization methods in their supply chains regularly, e.g. more than once a year. Results based on the size of enterprises are provided in Table 2.

The use of the optimization methods is not divided equally among the positive and negative answers in the group of medium-sized enterprises. The tendency is slightly towards the negative since only 35.95 % of enterprises applies optimizing methods in supply chain management more than once a year. In the group of large enterprises, we can mostly identify positive answers. 85.26 % of these enterprises use optimization methods regularly. Only 14 enterprises with more than 251 employees do not use any of the optimization methods more frequently than once a year. These findings indicate that the use of optimization methods in industrial production practice is proportionally dependent on the size of the enterprise. Consequently, the relationship between enterprise's size and used optimizing method was further explored. Correlation coefficient calculated between these factors proved that there is a significant direct dependence between these enterprises' sized and utilization of optimizing tools (0.487).

If the respondent does not use optimization methods to regularly manage their supply chain, we set out to find the reasons of this decision. The most frequent answer was that enterprise does not consider the optimization necessary. In many cases it was the fact that enterprises need to strictly uphold their production processes to customer requirements. Any changes including optimization of supply chain is not possible in this situation. Another reason was the satisfaction of the enterprise with achieved results and therefore no need to change or optimize anything. Several answers were connected to financial aspect, since many enterprises still consider optimization very expensive. This is the fact that we consider as one of the major reasons for non-using optimization methods in supply chain management.

If an enterprise applies optimizing methods, we further explored various aspects of optimization. Firstly, we focused on what types of techniques these enterprises use and if they use mathematical programming. Ten most commonly used measures are displayed in Table 3 and Table 4. The most commonly used measure is flexible promotion. Over 58.28 % of all enterprises apply this tool in their supply chain management. The second most commonly used measure is continuous improvement, applying the concept of learning organization (50 % of all enterprises).

Table 4 also provides information about the number of supplier of these enterprises. We can observe

Tab. 2: *Application of optimizing methods structured by the size of enterprises.*

Application of optimizing methods	Size of enterprise				Total
	Medium-sized enterprises		Large-sized enterprises		
Yes	55	35.95%	81	85.26%	136
No	98	64.05%	14	14.74%	112
Total	153	100.00%	95	100.00%	248

Tab. 3: *Most commonly used methods structured by the number of supplier.*

No. of suppliers Measures	1 – 20	21 – 50	51 – 75	76 - 100	101 – 200	201 – 500	over 501
flexible promotion	81	36	14	16	16	10	10
selection of suppliers based on predefined criteria	43	14	8	32	12	3	9
creation of stocks of finished products for special orders	18	26	9	15	4	3	3
possibilities for redeployment of human and material resources between process and / or facilities	45	14	5	6	8	3	1
implementation of quality system standards (ISO, TQM, etc.)	30	27	13	10	9	8	4
insurance against the risk of adverse events	54	16	10	8	9	3	4
customer orientation as a main strategic concept of enterprise	31	32	31	4	7	6	7
continuous improvement, learning organization	71	19	27	10	12	10	8
frequent adjustments in pricing policies	24	17	6	0	7	4	5
implementation of risk analyses	23	17	9	2	5	2	2

Tab. 4: *Most commonly used methods structured by the number of customers.*

No. of suppliers Measures	1 – 5	6 – 10	11 – 20	21 – 50	51 – 75	76 – 100	101 – 200	201 – 500	over 501
flexible promotion	10	35	13	13	20	30	11	25	26
selection of suppliers based on predefined criteria	11	15	8	11	10	21	6	32	7
creation of stocks of finished products for special orders	7	14	5	6	5	27	6	4	4
possibilities for redeployment of human and material resources between process and / or facilities	7	9	9	11	11	9	5	4	17
implementation of quality system standards (ISO, TQM, etc.)	8	11	10	6	5	29	4	13	15
insurance against the risk of adverse events	7	12	7	9	15	8	8	18	20
customer orientation as a main strategic concept of enterprise	9	14	5	8	13	24	10	16	19
continuous improvement, learning organization	10	32	7	14	20	13	12	18	31
frequent adjustments in pricing policies	10	4	6	4	4	25	4	3	3
implementation of risk analyses	3	6	2	6	7	12	5	9	10

downward trend in these numbers. Therefore, we can state that majority of enterprises in our sample file have less than 20 suppliers (Veselovská, 2015). These results indicate that despite the importance of mathematical programming utilization in practice of production enterprise since they do not apply it to manage their supply chain. None of the enterprises in our sample file stated the use of this particular method.

4. Conclusions

The main aim of this research was to explore the extent of utilization of mathematical programming as optimization methods in production practice in Slovakia and to analyse possible relationship between enterprise's size and used optimizing method. Achieved results provide a current image of Slovak business reality in manufacturing industry. There had not been similar studies covering the Slovak reality in the last decade. Previous results do not consider a wide use of computers as support systems for optimization therefore any comparison with our achieved results would not provide significant conclusions. Moreover, the attitude

towards optimization in supply chain management had been different. These previous research studies focused on optimization of specific tasks not whole supply chains.

Consequently, we consider a closer look at possible mathematical programming applications extremely useful. These provided examples draw an overview of various possible advantages of mathematical application in supply chain management. Furthermore, this study provides a foundation for further research into this topic and may provide a source of information for other authors looking for enrichment of discussion concerning methods used to manage supply chains.

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