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Decision in Implementation of Production Capacity Planning Determinated by Usage of Sensitive Analysis

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Abstract

Purpose of article: Effective planning and management of material flow and production resources, *i.e.* production planning and control is generally regarded as crucial for the success of manufacturing companies. It involves managing all aspects of production, including materials management, planning and scheduling of machines and human resources and coordination of suppliers and key customers. They were followed a more advanced concept MRP II, controls all production resources. Despite production planning using ERP systems, based on MRP II logic. With this tool can company effectively balance all production resources and in the optimal way to schedule production orders according to production capacity. Implementation of capacity planning in the company introduces a number of problems associated with the requirements of quality information and accurate data on which is a production plan created. Decision on the implementation of capacity planning is a challenge associated with high risk and the need to consider the order of several months in advance uncertainty. At points where we do not have full control over decisions, it can be used heuristic methods of decision-making through a decision tree using the known probabilities, and with a partial ignorance of using interval arithmetic.
Methodology/methods: Solving within decision tree with known probabilities obtained from expert in capacity planning.
Scientific aim: Find the upper limit worth of implementation of capacity planning or MRP-II.
Findings: The difference between the implementation the APS and MRP-II based on profits determinate by time.
Conclusions: Enterprise should have after implementation of its own data to the model make decision of what kind of capacity planning is profitable for its purpose.

Keywords: capacity planning, MRP II, decision making, interval arithmetic, sensitive analysis

JEL Classification: O33, O21, D70

Introduction

The planning process involves planning of the following inputs: material, capacity and information regarding the production order. In addition to these direct inputs the production schedule is affected by changes that may be initiated by the customer or by the company itself (*e.g.* material unavailable for the start of production order, lack of capacity). The course of the execution of the job order may be associated with bottlenecks (Goldratt, 1981), which may be the material and capacity constraints.

In the 90s of the 20th century, the concept of MRP II was expanded with additional functions such as production, marketing, finance, purchasing until the emergence of ERP, when Gartner Group of Stamford, Connecticut, USA coined the term. This ushered in a new era of enterprise information systems (Chen, 2001). ERP systems are defined as a system framework for organizing, defining and standardizing business processes necessary for effective planning and management of organizations, so that organizations can use their inside knowledge to pursue an external benefit (Chen, 2001). The area of planning and control of productive resources based on MRP II logic constitutes one of the activities of the ERP system.

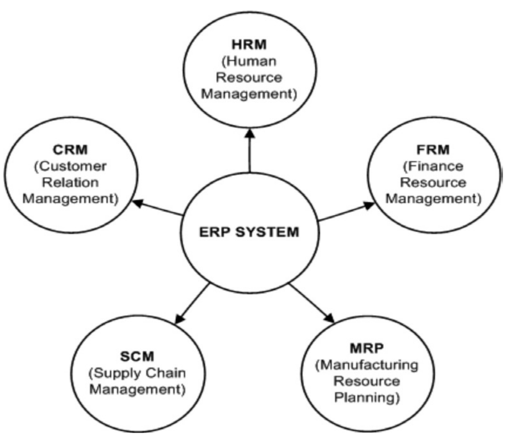

Figure 1. ERP system structure. Source: Chen, 2001, custom processing. Source: own work.

MRP II concept is based on fixed dates of production delivery to shipment. In fact, this term influences many factors, eg. material availability or workload. MRP II also ignores capacity constraints and leaves capacity problems to planners (Taal, Wortmann, 1997). At the end of the 90s it became clear that the ERP system is not an adequate instrument to cover all requirements, whether it was the diversity of the materials and manufacturing capabilities, the ability to meet customer requirements and shortening of lead times (Stadtler, Kilger, 2005). This is dealt with by APS systems of advanced planning and scheduling representing state-of-the-art methods that use information technology to simulate, optimize, streamline production and logistics. APS is able to combine the diversity of production process, plan different scenarios and take into account a number of limitations (David *et al.*, 2006). They apply "what-if" simulations of alternative plans, under which it is possible to evaluate the impact of the changes performed, such as specification of the time for planning of the job-order, changes in the quantity or cancellation of orders, transfer of technological operations using alternative procedures, increase or decrease of the capacity of critical sites (Grimson, Pyke, 2007; Michel, 2007).

The advantage of APS compared to MRP II technologies consists in taking into account all requirements for the production and also the consideration of material and capacity constraints, which means that it considers available capacities over time in the planning and scheduling process. Thereby, the plan becomes more realistic and feasible, production is not loaded with excess inventory and the company is able to realistically propose and then meet deadlines given to the customer (Stadtler, 2005).

All calculations are performed by APS closely linked to the enterprise information system, ie. APS does not retain any information and data of the company, but performs calculations over the data base in the IS and reimports the resulting plan into the information system (Stadtler, Kilger, 2005).

This method of plan calculation of and transfer of data constitutes further benefit of the APS system, which is the speed of planning incorporation (Stadtler, 2005).

Decision about implementation of new system (APS) or improving the current MRP II planning process involve risks, which should be considered, same as for exemple in the entering on capital markets (Meluzín *et al.*, 2012). Output from both of the systems is not comparable. This information could be managed using a decision making trees.

For the determination of implementation of capacity planning is used heuristics Decision theory (Blavatskyy, 2013), where a decision tree (see p. 22) subjected to expert heuristics unlike so. Machine theory (Bringmann, Zimmermann, 2007; Yu, Severin, Lendasse, 2014) where the decision tree generated from the selected data from a predetermined set of statistics (data mining). There are many different algorithms to evaluate the results to determine the return on insolvency see, *e.g.* (Rose, 1976).

Decision–Making Trees

IB decision trees are based on nodes, branches, endpoints, strategy, payoff distribution, certain equivalent, and the rollback method, see *e.g.* (Rose, 1976, Olivas, 2007). An example of a decision tree is given in Figure 2. Nodes are divided into single decision root

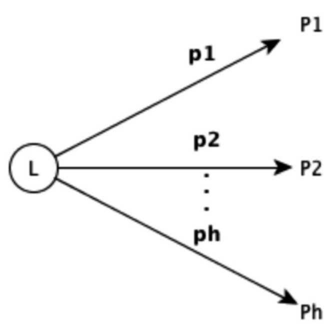

Figure 2. Lottery node. Source: own work.

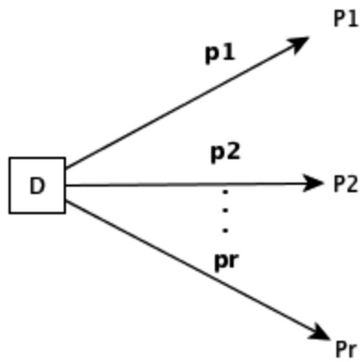

Figure 3. Decision node. Source: own work.

nodes, decision nodes and lotteries/chance nodes see *e.g.* (Magee, 1964). The root node is the top of any decision tree; see the node L Figure 2. Oriented arcs that connect nodes are called branches.

Decision – making node represents a decision made by a decision maker. A choice from r discrete set of choices must be done. A square indicates a decision node in this paper; see the root node, Figure 2. There is a simple algorithm how to evaluate the decision node value – *DNV*, see Figure 3:

$$DNV = \max\ \{P_1, P_2, ...\ P_r\}. \qquad (1)$$

The formula (1) reflects common-sense reasoning of the decision maker – choose the variant which offers the highest profit. Figure 4.

Lottery nodes are plotted as small circles, see nodes no. 2 and 3 Figure 4. Each lottery branch has its probability p, and its profit *P*, see Figure 4. There are many different algorithms how to evaluate LNV (lottery node value), see *e.g.* (Rose, 1976). For example, risk aversions are sources of different modifications LNV modifications, see *e.g.* (Rose, 1976). The following simple formula will be used in this paper

$$LNV = (p_1P_1 + p_2P_2 + \ .\ .\ .\ . + p_nP_n), \qquad (2)$$

where:

$$p_1 + p_2 + ...\ p_n = 1.$$

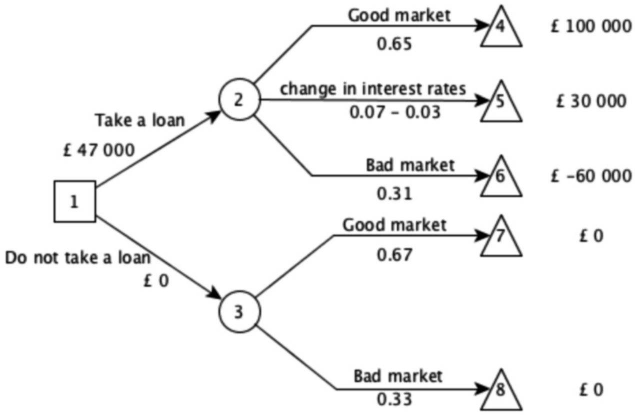

Figure 4. Simple decision tree. Source: own work.

The following IB analysis can be easily based on different modification of formulas (1) and (2).

The decision tree terminals are plotted as triangles, see nodes 4, 5, 6, and 7. Each terminal has its given payoff value.

Figure 4 represents a simple decision tree and it gives all numerical values needed to it using the formulas (1, 2). The decision maker has to choose one out of two lotteries. The corresponding tree evaluation follows:

$$LNV_1 = 0.65 \times 100{,}000 + 0.31 \times \times (-60{,}000) + 0{,}04 \times 30{,}000 = 47{,}000,$$
$$LNV_2 = 0.67 \times 0 + 0.33 \times 0 = 0,$$
$$DNV_1 = \max\,[LNV_1, LN_2] = = [47{,}000;\, 0] = 47{,}000. \quad (3)$$

The decision maker chooses the lottery No. 2, it means he/she chooses the variant – *Take Loan.*

However, IB decisions are often based on trees, which numerical values are not, knows completely. The most sensitive and difficult to evaluate are probabilities of lotteries (Watson, 1994).

1. Case study

Case company is one of Czech leading producer of a precision optics and assembly of complex optical and opt mechanical products. In 2015, management of company established two groups of specialists who analysed the company's production system and had to prepare a set of information for oncoming decision – implement an APS system as a superstructure to a current ERP system or improve existing ERP.

Data collection

Typically, the prime source of data collection in case study research are structured interviews, often backed up by unstructured interviews and interactions. This principle was followed also in the first part of this research. Other sources of data used in this research were gained by an attendance at the management meetings, surveys, and collection of internal reports.

Case study – description of the background

The case company had to face a long term problem with delivering the product to the customer on time. The problem had been fixed by a high level of storage, which was inefficient according to the capital bounded in stock. Production managers were forced to decrease a level of stock and with this decision had started to appear problems with delivering the product from production process on time. After a short analysis it was discovered,

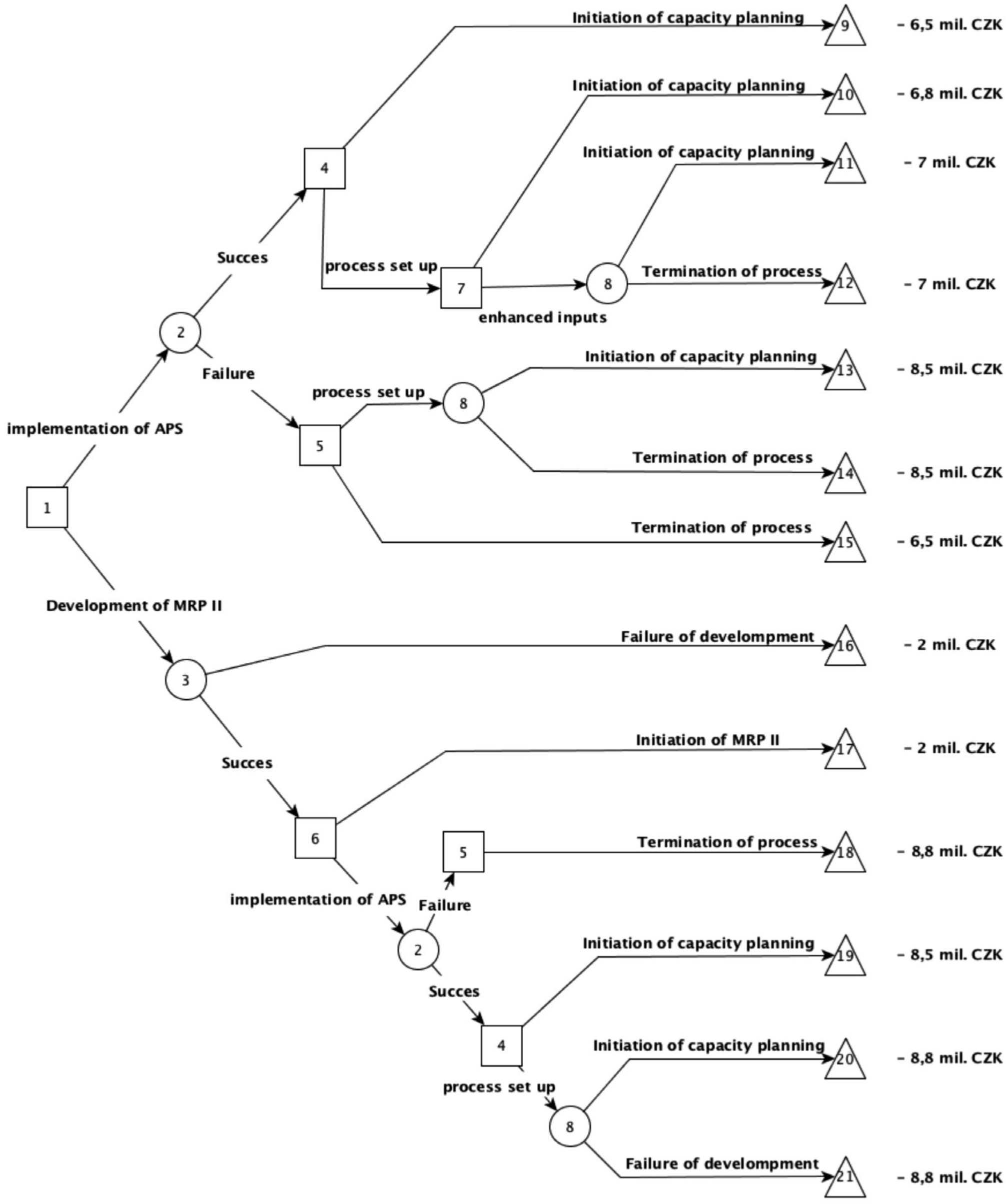

Figure 5. Decision tree of whole process. Source: own work.

that production process is not planned effectively, there are many buffers, constraints, missing material and inaccuracies. The decision was to improve the production planning and scheduling process. Two main opportunities to solve this problem were – implementation of an APS system as a superstructure to an existing ERP system or improving current MRP II logic in the existing ERP system. Both of the variants, in a case of successful implementation bring an estimated increase of the company's turnover through increased value of production orders processed by the same capacities. Both of the variants are connected with costs of the realization and with the risk of unsuccessful implementation.

These risks could be managed by using a decision making tree, which is presented in this article.

To determine the expected increase of a company's turnover was used an expert estimation. The estimation of increased production output is in the case of an MRP II improvement by 10 mil CZK per month (120 mil CZK per year). In a case of APS implementation, which is more detailed in production planning and scheduling and it is able to cover detailed gaps in production, could be the estimated increasing of output by 15 mil CZK per month (180 mil CZK per year). Percentages of probabilities of an unsuccessful implementation were obtained from 5 companies, which had improved the production planning process previously, by structured interview with the production manager.

Decision making tree description

(1) Decision of an APS implementation or an improvement of MRP II.

(2) Uncertainty of a success of an implementation. The success of APS implementation is based on a forwardness of a planning process. APS system is very sensitive on input data and complete structure of data for production planning. During the implementation is being uncovered the real structure and completeness of information. In this case is important for the company to complete the information structure in the short term. From that depends the next success of the implementation.

(3) Decision about a success of APS implementation. The company execute a check planning of all production orders and then decide, if the plan is sufficient and APS planning can be activated (9). The company can decide to delay the start of APS planning and take care about additional completion of data structure. After this phase is executed other check planning of all production orders (7), which shows if the additional adjustments were enough and the system is prepared for using (10) or it involves other inaccuracies, which weren't possible to think ahead (8) which lead to additional adjustments and then activation of APS planning (11) or to the termination of an effort and return to the prime planning system (12).

APS implementation could also end with failure (5) in the case that the company doesn't fill the algorithm of the system with complete structure on data. Then the management has to decide about termination of APS implementation (15) or to continue with the additional project, which objective would be to complete the gaps in information structure (8). On the result of the check planning of production orders would be the system activated (13) or the project terminated (14).

The company can decide to improve the existing MRP II, which is similar time demanding as an APS implementation. The improvements process has similar obstacles like an APS implementation and can lead to successful results (17) or to a failure (16) because company is not able to cover all of requirements with the MRP II logic and then decide to implement APS system (6). After the adjustments described in the previous paragraph can the implementation lead to a successful initiation of capacity planning (20) or to a failure of development (21).

2. Solving by the known probabilities

In the first case there have been use all known probabilities at all chance nodes, which have been obtained on the basis of statistical data and conversion to percentage probability, then applying of the basic calculations of decision tree have been determined total potential profits see *e.g.* (3) (Winston; Albright, 2010).

The following Table 2 shows the profits of the individual variants of the decision and the relevant known probabilities.

In Table 3 can be seen calculated profits for selected routes from a decision tree, where

Table 1. Probability of each variant.

Variant	Probability	Variant	Probability
2–4	0.4	8–14	0.3
2–5	0.6	3–16	0.3
8–11	0.7	3–6	0.7
8–12	0.3	8–20	0.7
8–13	0.7	8–21	0.3

Source: own work.

Table 2. Profit and the specified probabilities.

Variant	Probability	Cost of imp. [mil. CZK]	Possible TYR[1] [mil. CZK]	Possible TR[2] in 26 mth [mil. CZK]
4–9	0.4	6.5	69.4	150.4
7–10	0.4	6.8	69.3	138.6
8–11	0.28	7	48.4	88.8
8–12	0.12	7	–7.0	0.0
8–13	0.42	8.5	72.0	48.0
8–14	0.18	8.5	–8.5	0.0
5–15	0.6	6.5	–6.5	0.0
3–16	0.3	2	–2.0	0.0
6–17	0.7	2	179.2	179.0
5–18	0.42	8.5	–8.5	0.0
4–19	0.28	8.5	48.0	12.0
8–20	0.196	8.8	33.6	4.2
8–21	0.084	8.8	–8.8	0.0

Source: own work.

[1] *Total year revenue.*

[2] *Total revenue.*

Table 3. Average of the profit.

Variant	2–4	2–5	3–16	3–6
Average Profit [mil. CZK]	45.03	19.01	–2	29.38
Possible TR in 26 mth [mil. CZK]	94.40	16.00	0	39.00

Source: own work.

route 1–3 is the averaged result of previous subresults.

Solving by interval arithmetic

After solving a decision tree of capacity planning process using known probabilities obtained from statistics it is obvious to undergo sensitivity analyse the decision-making process and alter the probability of chance nodes. Node no. 2 in APS process and node no. 2 in developing of MRP II. After consultation with the Head of company was the probability in selected nodes altered by the variance of practice.

Let us suppose that the following probabilities are not know exactly. The following

Table 4. Combinations of variants.

	2–4	2–5	2–4 MRP II	2–5 MRP II
a	0.32	0.68		
b	0.58	0.42		
c			0.224	0.476
d			0.406	0.294

Source: own work.

Table 5. Splitting ratio of changed nodes.

Variant 1		Splitting ratio		Splitting ratio
Branch	2–4	0.32	2–4 MRP II	0.224
Branch	2–5	0.68	2–5 MRP II	0.476
Variant 2		**Splitting ratio**		**Splitting ratio**
Branch	2–4	0.58	2–4 MRP II	0.406
Branch	2–5	0.42	2–5 MRP II	0.294
Variant 3		**Splitting ratio**		**Splitting ratio**
Branch	2–4	0.32	2–4 MRP II	0.406
Branch	2–5	0.68	2–5 MRP II	0.294
Variant 4		**Splitting ratio**		**Splitting ratio**
Branch	2–4	0.58	2–4 MRP II	0.224
Branch	2–5	0.42	2–5 MRP II	0.476

Source: own work.

Table 6. Variant 1Profit and the specified probabilities.

Variant	Probability	Cost of imp. [mil. CZK]	Possible TYR [mil. CZK]	Possible TR in 26 mth [mil. CZK]
4–9	0.32	6.5	55.5	120.3
7–10	0.32	6.8	55.4	110.8
8–11	0.224	7.0	38.8	71.0
8–12	0.096	7.0	–7.0	0.0
8–13	0.476	8.5	81.6	54.4
8–14	0.204	8.5	–8.5	0.0
5–15	0.68	6.5	–6.5	0.0
3–16	0.3	2.0	–2.0	0.0
6–17	0.7	2.0	82.6	179.0
5–18	0.476	8.5	–8.5	0.0
4–19	0.224	8.5	38.4	6.4
8–20	0.1568	8.8	26.8	2.2
8–21	0.0672	8.8	–8.8	0.0

Source: own work.

uncertainties musts be taken into consideration (Table 4).

<a,b>

<c,d>

The following combinations are studied:

variant 1 – ac,

variant 2 – bd,

variant 3 – ad,

variant 4 – bc. (4)

The following tables show the profits of all four variants see *e.g.* (Table 5) of the decision and the relevant known probabilities (Tables 6–13).

In Table 6 can be seen calculated profits for selected routes from a decision tree, where route 1–3 is the averaged result of previous subresults of whole capacity planning process. It goes for all other variant's subresults.

3. Conclusion

The results in the following table show the profits of all four variants of the decision. The best possible result is in the case of decision of APS implementation and its successful implementation in Variant 2 and 4, which is represented by method of interval arithmetic's. The worst result is in the case of decision of MRP II development and the failure of the project in all of the variants (Table 14).

The case company compared the results with their expectations about the increasing customer's requirements and decided to implement APS system. Both of the variants (APS implementation and MRP II development) are connected with long – term work on the system and bringing many departments together to set the right data structure and prepare suitable plan to follow the

Table 7. Average of the profit of variant 1.

Variant	2–4	2–5	3–16	3–6
Average Profit [mil. CZK]	35.7	22.2	–2	26.1
Possible TR in 26 mth [mil. CZK]	75.5	18.1	0	37.5

Source: own work.

Table 8. Variant 2 Profit and the specified probabilities.

Variant	Probability	Cost of imp. [mil. CZK]	Possible TYR [mil. CZK]	Possible TR in 26 mth [mil. CZK]
4–9	0.58	6.5	100.6	218.0
7–10	0.58	6.8	100.5	200.9
8–11	0.406	7.0	70.2	128.8
8–12	0.174	7.0	–7.0	0.0
8–13	0.294	8.5	50.4	33.6
8–14	0.126	8.5	–8.5	0.0
5–15	0.42	6.5	–6.5	0.0
3–16	0.3	2.0	–2.0	0.0
6–17	0.7	2.0	82.6	179.0
5–18	0.294	8.5	–8.5	0.0
4–19	0.406	8.5	69.6	11.6
8–20	0.2842	8.8	48.7	4.1
8–21	0.1218	8.8	–8.8	0.0

Source: own work.

Table 9. Average of the profit of variant 2.

Variant	2–4	2–5	3–16	3–6
Average Profit [mil. CZK]	66.1	11.8	–2	36.7
Possible TR in 26 mth [mil. CZK]	136.9	11.2	0	38.9

Source: own work.

Table 10. Variant 3 Profit and the specified probabilities.

Variant	Probability	Cost of imp. [mil. CZK]	Possible TYR [mil. CZK]	Possible TR in 26 mth [mil. CZK]
4–9	0.58	6.5	100.6	218.0
7–10	0.58	6.8	100.5	200.9
8–11	0.406	7.0	70.2	128.8
8–12	0.174	7.0	–7.0	0.0
8–13	0.294	8.5	50.4	33.6
8–14	0.126	8.5	–8.5	0.0
5–15	0.42	6.5	–6.5	0.0
3–16	0.3	2.0	–2.0	0.0
6–17	0.7	2.0	82.6	179.0
5–18	0.294	8.5	–8.5	0.0
4–19	0.406	8.5	69.6	11.6
8–20	0.2842	8.8	48.7	4.1
8–21	0.1218	8.8	–8.8	0.0

Source: own work.

Table 11. Average of the profit of variant 3.

Variant	2–4	2–5	3–16	3–6
Average Profit [mil. CZK]	35.7	22.2	–2	36.7
Possible TR in 26 mth [mil. CZK]	75.5	18.1	0	38.9

Source: own work.

Table 12. Variant 4 Profit and the specified probabilities.

Variant	Probability	Cost of imp. [mil. CZK]	Possible TYR [mil. CZK]	Possible TR in 26 mth [mil. CZK]
4–9	0.58	6.5	100.6	218.0
7–10	0.58	6.8	100.5	200.9
8–11	0.406	7.0	70.2	128.8
8–12	0.174	7.0	–7.0	0.0
8–13	0.294	8.5	50.4	33.6
8–14	0.18	8.5	–8.5	0.0
5–15	0.42	6.5	–6.5	0.0
3–16	0.3	2.0	–2.0	0.0
6–17	0.7	2.0	82.6	179.0
5–18	0.476	8.5	–8.5	0.0
4–19	0.224	8.5	38.4	6.4
8–20	0.1568	8.8	26.8	2.2
8–21	0.0672	8.8	–8.8	0.0

Source: own work.

Table 13. Average of the profit variant 4.

Variant	2–4	2–5	3–16	3–6
Average Profit [mil. CZK]	66.1	11.8	–2	26.1
Possible TR in 26 mth [mil. CZK]	136.9	11.2	0	37.5

Source: own work.

Table 14. Final comparison.

		2–4	2–5	3–16	3–6
	Average TYR [mil. CZK]	45.0	19.0	–2.0	29.4
	Possible TR in 26 mth [mil. CZK]	94.4	16.0	0.0	39.0
Variant 1	Average TYR [mil. CZK]	35.7	22.2	–2.0	26.1
	Possible TR in 26 mth [mil. CZK]	75.5	18.1	0.0	37.5
Variant 2	Average TYR [mil. CZK]	66.1	11.8	–2.0	36.7
	Possible TR in 26 mth [mil. CZK]	136.9	11.2	0.0	38.9
Variant 3	Average TYR [mil. CZK]	35.7	22.2	–2.0	36.7
	Possible TR in 26 mth [mil. CZK]	75.5	18.1	0.0	38.9
Variant 4	Average TYR [mil. CZK]	66.1	11.8	–2.0	26.1
	Possible TR in 26 mth [mil. CZK]	136.9	11.2	0.0	37.5

Source: own work.

Table 15. Final comparison of average profits in 26 months.

	APS implementation	Reimplementation of APS after failure	Failure of MRP II development	MRP II development
Possible profit in 26 mth [mil. CZK]	103.8	14.9	0	38.4

Source: own work.

Table 16. Final comparison of average profits in 26 months with both methods.

	APS implementation	Reimplementation of APS after failure	Failure of MRP II development	MRP II development
Known prob.	94.4	16.0	0	39.0
Intervals	103.8	14.9	0	38.4
	99.1	15.45	0	38.7

Source: own work.

customer needs. In this comparison are the results from decision making tree preferable for the decision of APS implementation, because it offers higher possible turnover in 26 mth. since the decision (Table 15, 16).

The following production planning and scheduling process after the APS implementation in the case company is the possible subject of the research.

The possible other heuristic for determination of implementation of capacity planning could be use of the qualitative modelling (Poláček, Dohnal, 2017). As the process is based again on opinions of the experts/decision makers. There would be a list of defined variables, which are the most important for the process of implementation of capacity planning. By the insight of the experts would be determined the relations among the variables based on first and second derivations of the variables (Vicha, 2008). The result of this heuristic is list of scenarios where is easy for the decision maker to identify actual position of company in process and according to this scenario predict the next step for a successful implementation of capacity planning.

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