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SENSITIVITY ANALYSIS OF SILVER-MEAL ALGORITHM IN THE CASE OF JUST-IN-SEQUENCE SUPPLY RELATED BATCHES

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Abstract: *The economic instability and the significantly increased customer demands have a great impact on the processes of services and production. Not only technology but also logistics can be improved to increase the availability, flexibility, cost-efficiency, and sustainability of these processes. Production companies are focusing on Industry 4.0 technologies to improve their processes in the field of purchasing, production, distribution and recycling. Just-in-sequence solutions represent a new trend, especially in automotive industry. Just-in-sequence solutions and lean tools make it possible to cut costs. Most of the large companies are using ERP (Enterprise Resource Planning) systems, but the solutions of ERP can be improved using add-on solutions, algorithms and applications. Within the frame of this article the authors describe the sensitivity analysis of the Silver-Meal algorithm using to improve the production plan of components calculated by MRP I.*
Keywords: *Just-in-sequence supply, logistics, Silver-Meal heuristics, warehousing.*

Analiza osetljivosti Silver-Meal algoritma u slučaju serija koje se isporučuju samo po redosledu. *Ekonomska nestabilnost i značajno povećani zahtevi kupaca imaju veliki uticaj na procese usluga i proizvodnje. Ne samo tehnologija, već i logistika se mogu poboljšati kako bi se povećala raspoloživost, fleksibilnost, ekonomičnost i održivost ovih procesa. Proizvodne kompanije se fokusiraju na tehnologiju industrije 4.0 kako bi poboljšale svoje procese u oblasti kupovine, proizvodnje, distribucije i reciklaže. Rešenja koja su tačna u suštini predstavljaju novi trend, posebno u automobilskoj industriji. Rešenja po redosledu i Lean-alati omogućuju smanjenje troškova. Većina velikih kompanija koristi ERP (Planiranje resursa preduzeća) sisteme, ali rešenja ERP-a se mogu poboljšati pomoću dodataka, algoritama i aplikacija. U okviru ovog rada autori opisuju analizu osetljivosti Silver-Meal algoritma koristeći poboljšanje plana proizvodnje komponenata izračunatih MRP I-om.*
Ključne reči: *Snabdevanje po redosledu, logistike, Silver-Meal heuristike, skladištenja.*

1. INTRODUCTION

The fourth industrial revolution makes it possible to use state-of-the-art technologies to improve cost-efficiency, productivity, availability, flexibility, and sustainability [1]. This fact is true not only in the field of production but also in the field of services. The increased complexity of products led to the application of new models and methods in the field of production to fulfil extremely diversificated customers' demands. The automotive industry uses more and more new strategies, models, and methods to optimize their processes [2]. One of these strategies is the just-in-sequence supply, which is based on just-in-time philosophy. The just-in-sequence suppliers of automotive industry are facing more and more new challenges focusing on cost efficiency. They are using various ERP solutions including different material requirement planning methods. These MRP modules offers solutions for various cases, but it is possible to develop add-on modules for these well-known methods to improve their performance. Within the frame of this article the authors discuss the sensitivity analysis of Silver-Meal heuristics integrated into an MRP application. The article is based on the problem of a plastic part manufacturer producing high quality plastic parts for luxurious cars just-in-sequence.

2. LITERATURE REVIEW

Material Requirement Planning was a response to the Toyota Production System (TPS), which was developed between 1950 and 1975. It was a result of background research supply British Naval Ballistic Missile System. Economic Order Quantity and other methods was developed to support the design and operation of inventory and production processes for dependent demands. MRP was developed for independent demands. The main questions of MRP are focusing on the questions of what, how many, and when. The problems of material requirement planning has been researched in the past 40 years. Within the frame of this short literature review we would like to focus on some important research results.

There are important research results focusing on the impact of material requirement planning on manufacturing-to-order environment [3]. Material requirement planning methods are based on computer aided technologies and most of the researches focuses on both theoretical and IT problems of their development, analysis, and application [4]. Production environments can be described either with deterministic or with stochastic parameters. Stochastic environment can be modelled with various Fuzzy models, as shown in a research focusing on a rolling horizon approach for material requirement planning [5]. Interesting research results analyse the various approaches of deterministic and Fuzzy constraints [6, 7]. Typical uncertainties are production systems are time-, demand-, resource- or capacity-related [8]. Material requirement planning models are used both in single-level and in multi-level production systems [9]. There are various specifications of material requirement problems, like lot-size dependent lead-time [10], quantity discount constraints [11], deteriorating inventory [12] or finite capacity materials [13]. Material requirement problems depending on the complexity of objective functions and constraints represent NP-hard optimisation problems, their solution is usually based on heuristic and metaheuristic solutions, like the application of a hybrid genetic algorithm and tabu search for finite capacity material requirement planning system in flexible flow shop [14]. Focus research field regarding Silver-Meal application in material requirement planning are the followings:

- single-item dynamic lot sizing problem with returns and remanufacturing [15],
- dynamic lot sizing under incremental quantity discounts [16],
- MRP purchase discount situations [17],
- other modifications in Silver-Meal algorithm [18].

The article is organized as follows. Chapter 2 presents a short literature review, which summarizes the research background of material requirement planning and Silver-Meal heuristics. Chapter 3 is the problem description including the mathematical model of Silver-Meal algorithm and a short scenario to demonstrate the computational process. Chapter 4 presents the computational results of the integration of Silver-Meal heuristics and MRP. Conclusions, managerial impacts, and future research directions are discussed in the remaining part of the article.

3. SILVER-MEAL HEURISTICS IN MRP

The Silver-Meal heuristics is based on the idea that we try to minimise the average per-period cost [19]. It is possible to integrate the below described algorithm into various material requirement planning methods, where it is possible to produce sufficient number of components for more weeks. Depending on the set-up cost of production and the specific warehousing cost we can calculate the production cost of week i depending on the value of produced components available for the next periods as follows:

- the company produces components only for the current week:

$$c_i^i = c_{\sup} \tag{1}$$

- the company produces components both for the current and for the next week:

$$c_i^{i+1} = c_{\sup} + c_{swh} \cdot q_{i+1} \tag{2}$$

- the company produces components both for the current and for the next two weeks:

$$c_i^{i+2} = c_{\sup} + c_{swh} \cdot (q_{i+1} + 2 \cdot q_{i+2}) \tag{3}$$

- the company produces components both for the current and for the next j weeks:

$$c_i^{i+j} = c_{\sup} + c_{swh} \cdot \sum_{\alpha=1}^{j} \alpha \cdot q_{i+\alpha} \tag{4}$$

The optimal average cost can be calculated as the minimum of the production cost divided by the number of weeks of preproduction:

$$\forall j > 0: \quad \overline{c_i} = \min_j \frac{c_{\sup} + c_{swh} \cdot \sum_{\alpha=1}^{j} \alpha \cdot q_{i+\alpha}}{j} \tag{5}$$

Based on the weekly average costs, we can calculate the total optimised production costs for a time span of w weeks as follows:

$$\forall j > 0: c = \sum_{i=1}^{t} \min_j \frac{c_{\sup} + c_{swh} \cdot \sum_{\alpha=1}^{j} \alpha \cdot q_{i+\alpha}}{j} \tag{6}$$

Using the material requirements of a component for six weeks as 117, 122, 42, 127, 48, 130 pieces, a set-up cost of productions 100 EUR and a specific warehousing cost of 2 EUR per week and pieces, we can calculate the optimal production amounts for the six week long time span. For the first week:

$$c_1^1 = c_{\sup} = 100 \tag{7}$$

$$c_1^2 = c_{\sup} + c_{swh} \cdot q_2 = 100 + 2 \cdot 122 = 344 \tag{8}$$

Based on Eq (7-8) we can calculate the average costs:

$$\overline{c_1} = \min(c_1^1, \frac{c_1^2}{2}) = 100 \tag{9}$$

It means that we produce on the first week only the current demand. For the second week:

$$c_2^2 = c_{\sup} = 100 \tag{10}$$

$$c_2^3 = c_{\sup} + c_{swh} \cdot q_3 = 100 + 2 \cdot 42 = 184 \tag{11}$$

$$c_2^4 = c_{\sup} + c_{swh} \cdot q_3 + 2 \cdot c_{swh} \cdot q_4 = 230.6 \tag{12}$$

Based on Eq (10-12) we can calculate the average costs:

$$\overline{c_2} = \min(c_2^2, \frac{c_2^3}{2}, \frac{c_2^4}{3}) = 92 \tag{13}$$

It means that we produce on the second week not only for the current week, but also for the third week. The calculation of the optimal production can be calculated for the fourth week as follows:

$$c_4^4 = c_{\sup} = 100 \tag{14}$$

$$c_4^5 = c_{\sup} + c_{swh} \cdot q_5 = 100 + 2 \cdot 48 = 196 \tag{15}$$

$$c_4^6 = c_{\sup} + c_{swh} \cdot q_5 + 2 \cdot c_{swh} \cdot q_6 = 238.6 \tag{16}$$

Based on Eq (14-16) we can calculate the average costs:

$$\overline{c_4} = \min(c_4^4, \frac{c_4^5}{2}, \frac{c_4^6}{3}) = 98 \tag{17}$$

It means that we produce on the second week not only for the current week, but also for the next week.

Within the frame of the next chapter, the above-mentioned Silver-Meal algorithm will be applied into an MRP calculation to optimise the required production schedule based on the material requirement.

4. COMPUTATIONAL RESULTS

The input parameters of the application are the number of parts and the time span of optimisation. Specifying the number of parts makes it possible to extend the number of components to be taken into consideration. Another input parameter of the application is the set of customers' demands (Fig. 1).

Additional input parameters for the developed application are the start-up costs of production and the specific warehousing cost, while the production time for each part also must be taken into consideration. We can calculate the material requirement and the production plan for components from customers' demand by shifting them with the production time. Fig. 2 shows both the production volumes and the calculated production costs of MRP I. This total cost can be considered as the basic data to be improved by the application of the Silver-Meal correction algorithm. Using the Silver-Meal algorithm, the application can improve the resulted production plan by applying the theoretical model presented earlier. Fig. 3 shows how it is possible to reschedule the production plan generated by MRP I using the Silver-Meal algorithm.

Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Component A	127	155	115	147	123	117	156	138	138	126	105	134	142	155	150	101	133	155	126	141
Component B	121	124	116	103	114	159	103	123	122	129	109	128	115	138	133	109	157	139	130	123
Component C	145	136	150	101	112	104	106	120	107	100	132	140	133	150	104	111	141	127	121	109
Component D	105	146	124	128	130	112	120	105	135	110	156	105	127	116	153	145	116	141	115	105
Component E	118	114	129	115	120	102	129	112	152	135	146	156	120	133	104	138	125	158	106	156
Component F	129	113	160	107	101	121	133	156	132	124	151	150	141	144	160	120	130	125	142	110

Fig. 1. Customers' demands in MRP, as the input parameter of Silver-Meal algorithm

Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total cost
Component A	147	123	117	156	138	138	126	105	134	142	155	150	101	133	155	126	141				**78132**
Component B	116	103	114	159	103	123	122	129	109	128	115	138	133	109	157	139	130	123			**116784**
Component C	112	104	106	120	107	100	132	140	133	150	104	111	141	127	121	109					**120032**
Component D	124	128	130	112	120	105	135	110	156	105	127	116	153	145	116	141	115	105			**58662**
Component E	115	120	102	129	112	152	135	146	156	120	133	104	138	125	158	106	156				**58378**
Component F	107	101	121	133	156	132	124	151	150	141	144	160	120	130	125	142	110				**81634**
Total cost	30081	30081	30081	30081	30081	30081	30081	30081	30081	30081	30081	30081	30081	30081	30081	30081	22579	9747	0	0	**513622**

Fig. 2. The production plan of components calculated from customers' demands shifted by the production time

Produced components	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total amount
Component A	819	0	0	0	0	0	662	0	0	0	0	806	0	0	0	0	0	0	0	0	2287
Component B	840	0	0	0	0	0	0	861	0	0	0	0	0	0	549	0	0	0	0	0	2250
Component C	649	0	0	0	0	0	770	0	0	0	0	0	498	0	0	0	0	0	0	0	1917
Component D	494	0	0	0	470	0	0	0	504	0	0	0	414	0	0	361	0	0	0	0	2243
Component E	865	0	0	0	0	0	0	922	0	0	0	0	0	0	420	0	0	0	0	0	2207
Component F	462	0	0	0	563	0	0	0	715	0	0	0	0	507	0	0	0	0	0	0	2247
Total cost	4129	0	0	0	1033	0	1432	1783	1219	0	0	806	912	507	969	361	0	0	0	0	**13151**

Fig. 3. Optimised production plan based on Silver-Meal algorithm

Based on the improved production plan we can calculate the distribution of total production cost, set-up cost of production and warehousing cost (Fig. 4-6). Based on Fig. 2 and Fig. 4, a comparison can be made between the solution derived from the original MRP I and the solution resulting from the Silver-Meal algorithm. As shown in Fig. 7, there are some weeks with high total costs within the time span of analysis, but significant reduction in total cost can be achieved with the Silver-Meal algorithm.

Total cost	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Component A	5940	1098	864	552	276	0	5668	862	594	310	0	5908	1110	844	534	282	0	24842
Component B	7936	1242	1014	696	490	244	0	7952	1246	990	760	484	218	0	7272	506	246	31296
Component C	9113	1299	981	621	300	0	9416	1494	1095	645	333	0	8573	690	327	0	0	34887
Component D	4739	968	448	0	4659	980	440	0	4651	972	464	0	4303	464	0	4139	420	27647
Component E	4184	630	528	399	287	135	0	4210	620	500	367	263	125	0	3696	156	0	16100
Component F	6222	1016	532	0	6430	1100	604	0	7062	1696	1120	480	0	6310	1008	440	0	34020
Total	38134	6253	4367	2268	12442	2459	16128	14518	15268	5113	3044	7135	14329	8308	12837	5523	666	**168792**

Fig. 4. Total production cost of the optimised production plan

Set-up cost of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Component A	4596						4596					4596					13788
Component B	6488							6488							6488		19464
Component C	7502						7502						7502				22506
Component D	3259				3259				3259				3259			3259	16295
Component E	3434							3434							3434		10302
Component F	4802				4802				4802					4802			19208
Total	30081	0	0	0	8061	0	12098	9922	8061	0	0	4596	10761	4802	9922	3259	**101563**

Fig. 5. Set-up cost of production of the optimised production plan

Warehousing cost	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Component A	1344	1098	864	552	276		1072	862	594	310		1312	1110	844	534	282	0	11054
Component B	1448	1242	1014	696	490	244		1464	1246	990	760	484	218		784	506	246	11832
Component C	1611	1299	981	621	300		1914	1494	1095	645	333		1071	690	327	0	0	12381
Component D	1480	968	448		1400	980	440		1392	972	464		1044	464		880	420	11352
Component E	750	630	528	399	287	135		776	620	500	367	263	125		262	156	0	5798
Component F	1420	1016	532		1628	1100	604		2260	1696	1120	480		1508	1008	440	0	14812
Total	8053	6253	4367	2268	4381	2459	4030	4596	7207	5113	3044	2539	3568	3506	2915	2264	666	**67229**

Fig. 6. Warehousing cost of the optimised production plan

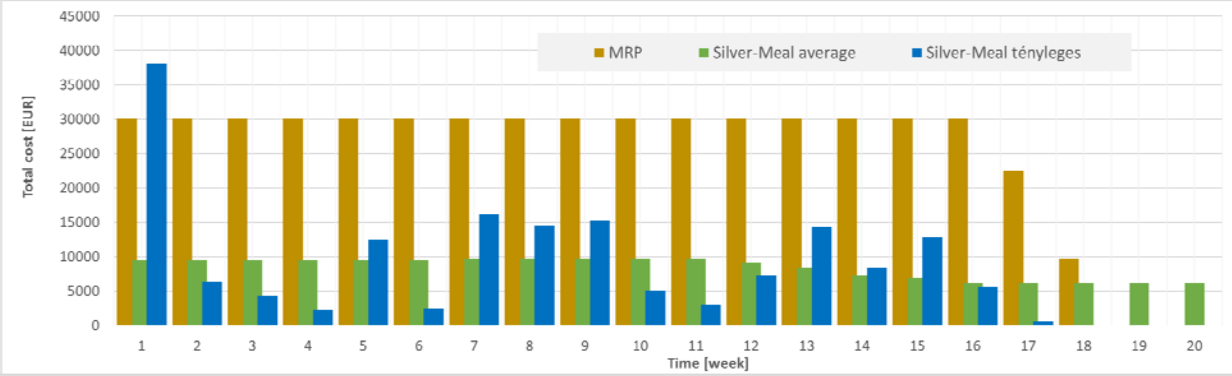

Fig. 7. Total cost distribution of MRP I and Silver-Meal based production costs (specific warehousing cost=1)

Let us examine how often production should be started! The minimum time interval covered by production start-up is 2 weeks, while the maximum such time interval is eight weeks. The mean length of time intervals covered by production starts is 4.71 weeks and the standard deviation is 1.55 weeks. Let us see what happens when we change the ratio of start-up cost to unit storage cost.

If we change the storage cost to ten times that given in the previous example, we get the same solution for MRP, since this model of MRP does not take into account the storage cost, since every weekly demand is generated just in time. In contrast, the Silver-Meal algorithm takes advantage of the precast manufacturing capability to reduce production start-up costs, but at the same time increases storage costs. This is because if we produce less, we must produce a larger quantity, which ensures that sufficient quantity is available for several weeks.

As shown in Fig. 8, although the average total cost is still better than the solution obtained with the original MRP, it is already closer to it. It is always worthwhile to improve the solution obtained with the help of MRP with the Silver-Meal algorithm, as we can achieve improvement even with a relatively high specific storage cost. For sure, the Silver-Meal algorithm will not degrade the total cost of MRP, as even in extreme cases it will result in the original MRP solution itself.

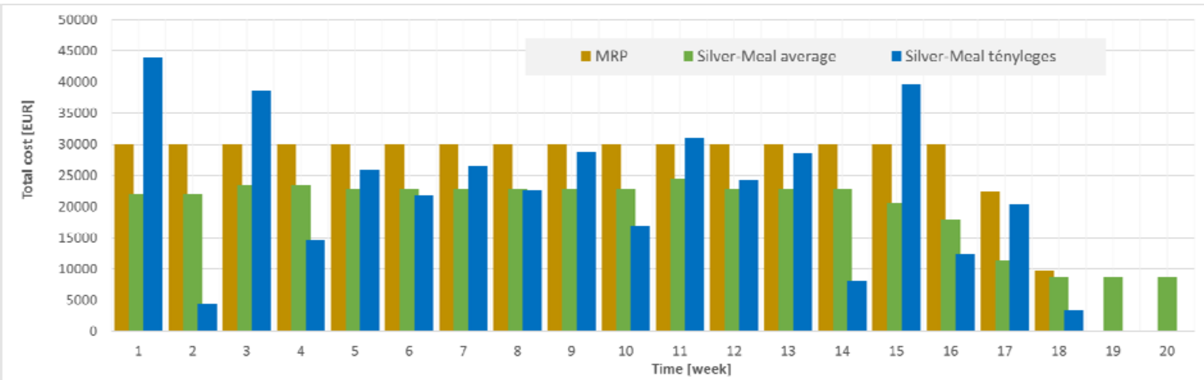

Fig. 8. Total cost distribution of MRP I and Silver-Meal based production costs (specific warehousing cost=10)

At five times the unit specific storage cost, the average number of prefabrication weeks is 1.73 weeks, while the standard deviation is 0.79 weeks. Examining the extent and proportion of specific warehousing costs and start-up costs is important for companies because, on the one hand, start-up costs are very significant for various manufacturing technologies and optimizing the number of changes between different product types has an impact on the production master program. Examining the level of specific warehousing cost and its relationship to start-up cost is important because for products with lower specific warehousing costs, the Silver-Meal algorithm can achieve a significant improvement over the original MRP solution, while for products with higher unit costs, less prefabrication can be expected cost-effectively. Fig. 9 shows the impact of the specific warehousing cost on the total cost, set-up cost of production and warehousing cost.

The figure is a good illustration of the previous statement that the Silver-Meal algorithm can improve the manufacturing plan calculated by MRP even at higher specific storage costs, however, the obtained result is getting closer to the total cost of MRP solution. Fig. 10 shows the mean and standard deviation of the number of weeks of prefabrication. It can be seen from the diagram that as the specific storage cost increases, both the average and the standard deviation of the number of weeks that can be served by the amount of product produced during production decrease. The nature of the diagram is given by the fact that a small change in the specific storage cost does not always cause a change in the improved manufacturing plan calculated by the Silver-Meal algorithm, as an improvement in the total cost can only occur with some parameter change.

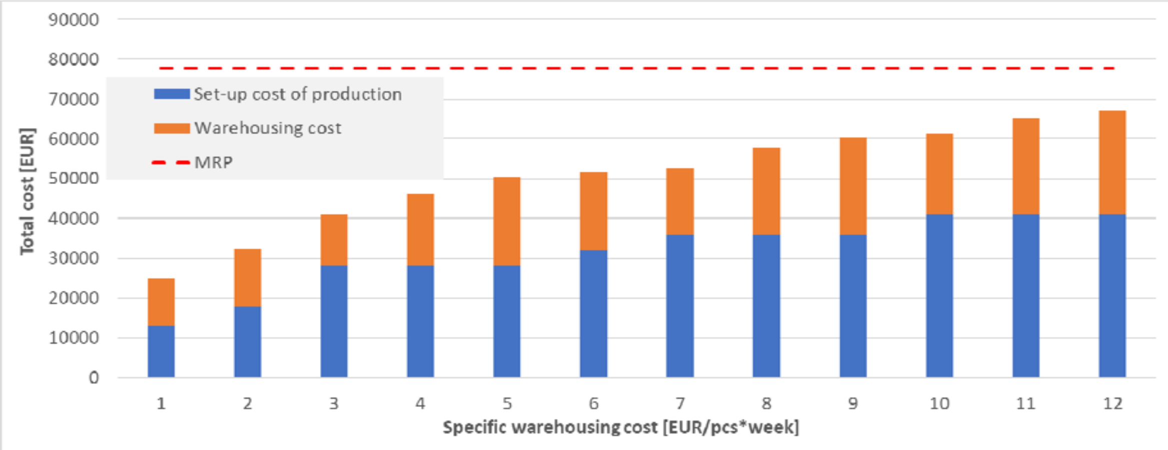

Fig. 9. The change in total cost, start-up cost, and warehousing cost as a function of specific storage cost

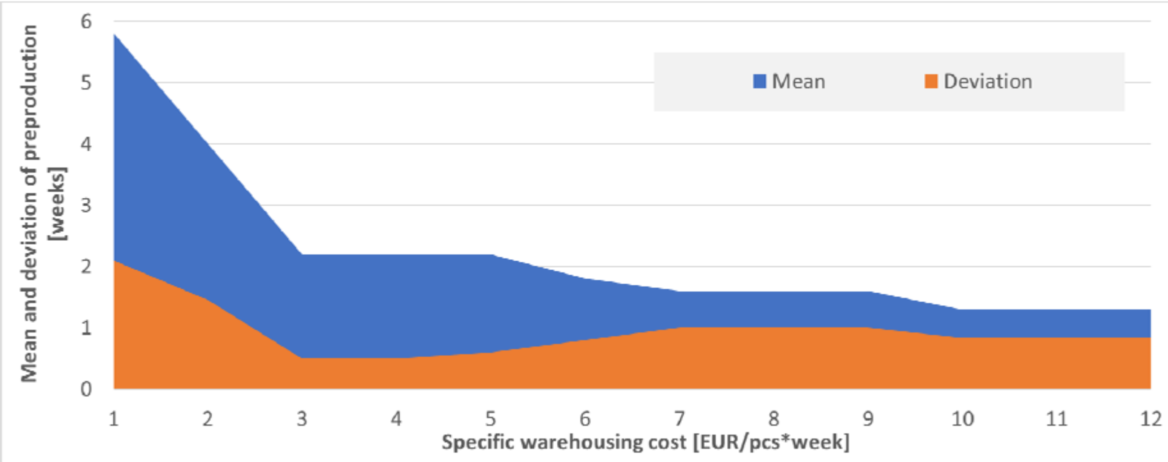

Fig. 10. The impact of specific warehousing cost on the mean and deviation of preproduction weeks

5. SUMMARY AND CONCLUSIONS

The just-in-sequence supply has created new challenges both for production and logistics. Logistics related challenges can be divided into two main parts: in-plant logistics solutions and external logistics solution. As the short literature review showed, the research of material requirement planning methods and applications is an important field of manufacturing and production, especially from logistics and in-plant supply point of view. Within the frame of this article, the authors described the sensitivity analysis of Silver-Meal heuristics integrated into an MRP module. After the mathematical description of the Silver-Meal algorithm a short numerical example demonstrated the process of the calculation. The computational result and the sensitivity analysis validated that Silver-Meal heuristics can improve the performance of MRP, and it makes possible to decrease production cost with the rescheduling of production. The scenario analysis shows the impact of the specific warehousing cost on the total costs, set-up cost of production, warehousing cost, mean and deviation of preproduction weeks. To summarize, the proposed method can be used to improve the efficiency of material requirement planning in the case of independent components.

The added value of the paper is the sensitivity analysis of the Silver-meal algorithm, especially from specific warehousing cost point of view. The scientific contribution of this paper for researchers in this field is the mathematical modelling. The results can be generalized because the model can be applied for various production environment and the Silver-Meal heuristic can be used in other fields of logistics. Managerial decisions can be influenced by the results of this research because the described method makes it possible to analyse the available resources (human, technological and logistic) and make decisions regarding the size and structure of them. As literature sources show, simulation technologies are important tools in the design and improvement of machines and processes [20, 21]. As a future research direction, we would like to apply simulation to analyse the impact of the algorithm in a robust production system. Other future research direction is the analysis of application possibilities in various manufacturing environment [22], like flexible manufacturing systems, additive and hybrid manufacturing environment, or in the case of virtual enterprises.

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