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OPTIMIZATION OF PRODUCTION DEPTH

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Abstract: To meet the increasing challenges of today's global marketplace, production and service companies need sophisticated analytical methods to define the most important factors of profit. The diversity of the needs of marketplaces and customers leaded to the increase of complexity of products. The economical production or manufacturing of complex products is a core problem of profitability of companies. Companies with complex product structures try to increase the transparency of their production processes, which leaded to the decrease of production depth. The optimization of production depth is not only a technological problem, but it also concerns the systems and processes of logistics, for example, from the point of view of make or buy problems or outsourcing questions. Within the frame of this paper authors are focusing on the optimization of production depth from the point of view outsourcing of different components of the product. We introduce a harmony search based heuristic optimization algorithm, which makes it possible to find the optimal production depth in the case of cross related product structures.
Keywords: harmony search, make-or-buy decision, optimization, optimization, outsourcing.

1. Introduction

In today's economy, the logistics costs influence the profit of production enterprises. The product complexity challenges different areas of value making process from the marketing through research, development and production to the purchasing. One of the most important cost factors of research and development is based on the increased costs of material and labour, management of supply chain members, inventory and capital equipment [1]. These costs can be avoided or reduced by the aid of outsourcing of cost intensive non-core processes. The complexity of the products leaded to the increase of the number of required components. Companies with limited technological, human and logistic resources are not able to produce all required components, and they try to outsource some of them. The outsourcing of production of some components is a quite difficult question because of the high number of influencing factors: inventory, throughput time, independence of the company from other manufacturers, available product and technological know-how of the contract manufacturers, available resources and stock, achievability of quality specifications, costs. These influencing factors are the constraints of a make or buy decision. Make or buy decision is a very important part of just in time production. By the aid of a correct make or buy decision, it is possible to increase the return of investment by the aid of reducing the inventory and the required resources. These days the optimization of production depths is involved into lean processes of companies.

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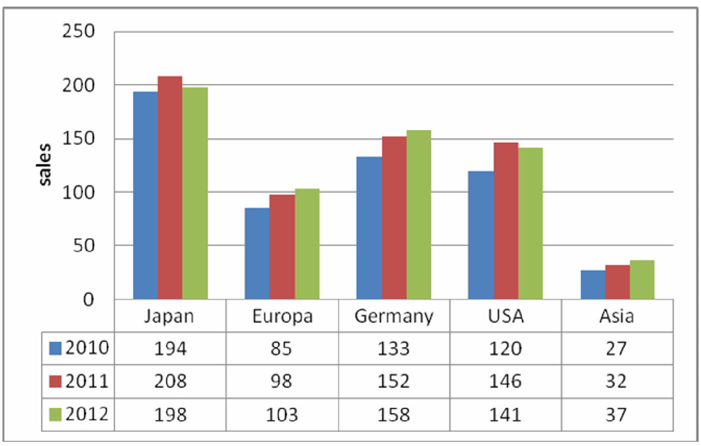
2. Literature overview

The today's economic situation is strongly forcing companies to look for tools for the development of productivity reserves. Many companies, especially in the field of automotive and mechatronics industry, are enforced to a reduction in their value chain by outsourcing [9]. The outsourcing of value making or value adding processes and the "make or buy" decision of manufacturing and assembly have a great impact on the profitability of the production. The literature uses several words for outsourcing: spin off, decrease production depth. The production depth is a very good indicator of vertical integration of companies and shows the added value [2]. The production depth is the proportion of the internal production and the total production value.

$$d = \frac{p_i \cdot 100}{p_t}$$

The production depth of 0% means that the company does not have own production or assembly, so it is a handling company. The production depth of 100% means that the company has a value making chain, which makes it possible to produce their products independent from other suppliers. The production depth is also called as real net output ratio. The average depth of production is strongly decreased: the German automotive industry has got a production depth about 50% in the late 80s. The E-class Mercedes cars has got a production depth of 38% and this value of Porsche Leipzig is about 10% (Porsche 911 and Boxter 20%, Cayenne 10%). The production depth influences the structure of the supplier industry, which is definitely increasing. Figure 1. and Table 1 show some important data according to the suppliers of the automotive industry.



	Japan	Europa	Germany	USA	Asia
2010	194	85	133	120	27
2011	208	98	152	146	32
2012	198	103	158	141	37

Figure 1. Sales of the 100 biggest suppliers in the automotive industry - Asia without Japan and Europe without Germany [3]

The optimization of production depth can be based on the purchasing behaviour of the production system [6]. There are different studies, which are focusing on special areas of the economy. The health services represent a special area, where instead of production depth we can speak about service depth [7]. One of the main streams of literature in the field of design of production depth and vertical integration addressed methods and tools to identify the relevant factors and their interactions [8]. On the basis of the results of these studies, it is possible to develop strategies for the companies, which can help to secure the future success potential.

Table 1

The 10 biggest automotive suppliers in 2012 [4]

Rank	Company	Products	Sales in milliard EURO
1	Continental	tire, safety, break, door system	32,7
2	Bosch	safety	31,1
3	Denso	safety, air condition, electric drive	30,9
4	Bridgestone / Firestone	tire and insulation system	26,8
5	Magna	body, electrical drive	23,3
6	Aisin	pump, suspension, safety	22,5
7	Hyundai Mobis	Hyundai Kia components	21,8
8	Michelin	tire	21,5
9	Johnson Controls	electronic, door, interior, seat	20,6
10	Faurecia	exhaust system, interior, bumper	17,4

One of the basic works in the field of make or buy decision was presented more than 20 years ago [10]. The efficiency of make or buy decision depends on management strategies [11], which are often based only on experience. One of the main stream of make or buy research is based on the design of just in time production systems [12, 13]. Much literature has been published, and some of them have included a comprehensive survey [14, 15].

There are different types of production depth conceptions: spin off, insourcing, outsourcing and reengineering. From the point of view competence spin off and in sourcing are stronger. From the point of view of risk in sourcing and reengineering are critical [5]. Spin off and in sourcing require more know-how, than outsourcing and reengineering do.

The literatures of production depth are strongly related to researches in the field of the optimisation of make or buy systems and the optimal design of the bill of materials. One of the main streams of the BOM optimization is related with the development of the representation of them. The BOM is the technique document on showing the structure of the products. There are different representation models of BOMs. General parameters of BOM models are the followings [16]:

– Parent component: The component, where the given component or material are built in.
– Supplier: The name of the supplier of the given component.
– Cost: Total cost including price, and logistics.
– Quantity: The amount of components to be built into the upper level.

The modeling of BOMs has a wide literature. The industrial companies are participants of BOM based supply chain and their risks assessment can be evaluated on the base of BOM design and optimization [17, 18]. These research directions are strongly parallel with the researches in the field of available-to-promise systems [19]. There is a special field of BOM optimization, where stochastic effects are stronger than in the case of production:

maintenance. There are interesting research works focusing on the BOM optimization (and transformation) in the field of maintenance, repair and overhaul systems [20]. Modeling of BOM and the related make-or-buy problems require an up-to-date data model, because of the huge amount of information [21, 22].

Within the frame of the next chapters authors describe a BOM modeling method, by the aid of which, it is possible to describe cross-references among different products. The description of cross-references is an important part of the modeling because the optimization algorithm of the separated Bill of materials of products will not give the global best solution; therefore, it is necessary to take into consideration one component in every parent component.

3. Modelling of production depth optimisation problem

The modelling of production depth optimisation problem was implemented within the frame of Matlab and an application was written, by the aid of which, it is possible to support make or buy decisions used harmony search algorithm. The applied harmony search algorithm is based on the performance of musicians. Musicians try to find the best pitches to make nice harmonies. Engineers try to find the best parameters for their systems, machines or processes to create an optimized result. We use the harmony search process of jazz musicians to find the best parameters for our logistic systems, in this case for the production depth optimization problem. The make-or-buy decision variables represent the pitches and one supply solution represents one harmony. The aim of the algorithm is to find the best harmony (and the best supply variation) for the logistic problem. The optimization process has four important steps: problem description and initialize the algorithm parameters (number of solution vectors in the harmony memory matrix, harmony memory consideration rate, pitch adjustment rate, termination criteria); initialize the harmony memory matrix; selection and modification of new harmonies based on harmony memory matrix; updating the harmonies of the harmony memory matrix; repeat the algorithm until termination criteria is satisfied.

The first step of the modelling process was to convert the assembly trees into matrix and create a matrix consisting the cost of outsourced and insourced productions of parts.

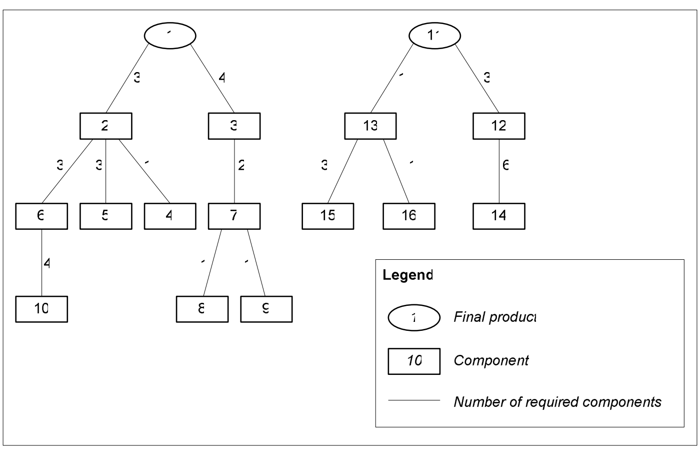


Figure 2. Four-level assembly tree with 2 products and 14 components

Figure 3 shows the matrix representation of the assembly tree. However in this case the matrix is a sparse matrix, but in the case of complex assembly trees the matrix is less thin. The (1,1) matrix element describes the required amount of product 1 derived from the master production schedule. The (11,11) matrix describes the required amount of product 2. Other entries of the matrix diagonal are zero.

		Parts (from)															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Major components (into)	1	1000	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	1	3	3	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	50	1	3	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3. Matrix representation of two four-level assembly trees (example)

It is possible to define the costs of outsourced and insourced production of components. These make-or-buy costs can be defined either as fix costs or depending on the size of the set of in- or outsourced components.

Components	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cost of making	5000	1400	1100	500	670	350	510	360	240	140	6000	1400	1100	200	800	800
Cost of buying	100000	4300	1700	400	800	320	310	370	220	170	100000	1300	2200	750	1300	1200

Figure 4. Costs of insourced and outsourced production of components (example)

The second step of the optimisation process is the creation of the connection matrix and the total parts need matrix.

```
connections =

     1     0     0     0
     2     1     0     0
     3     1     0     0
     4     2     1     0
     5     2     1     0
     6     2     1     0
     7     3     1     0
```

```
required parts =

     1     1     1     1
     1     3     1     1
     1     4     1     1
     1     1     3     1
     1     3     3     1
     1     3     3     1
     1     2     4     1
```

```
 8     7     3     1               1     1     2     4
 9     7     3     1               1     1     2     4
10     6     2     1               1     4     3     3
11     0     0     0               1     1     1     1
12    11     0     0               1     1     1     1
13    11     0     0               1     3     1     1
14    12    11     0               1     6     1     1
15    13    11     0               1     3     3     1
16    13    11     0               1     1     3     1
```

```
TPN = (1, 1000), (2, 3000), (3, 4000), (4, 3000), (5, 9000), (6, 9000),
(7, 8000), (9, 8000), (10, 36000), (11, 50), (12, 50), (13, 150), (14,
300), (15, 450), (16, 150)
```

The total cost for an assembly tree is calculated by the aid of the following formulas:

$$Cba_n = Cb_n * N_n * (1 - X_n) * X_p$$

$$Cma_n = Cm_n * N_n * X_n * X_p$$

$$C = \sum_{n}^{1} (Cba_n + Cma_n)$$

$$C \rightarrow min.$$

where

- Cba_n is the total costs of outsourced production of the n^th^ component in the case of solution represented by one vector of the harmony memory matrix,
- Cma_n is the total costs of insourced production of the n^th^ component in the case of solution represented by one vector of the harmony memory matrix,
- Cb_n is the specific costs of outsourced production of the n^th^ component,
- Cm_n is the specific costs of insourced production of the n^th^ component,
- N_n is the number of the components required to make a higher level of the assembly tree,
- X_n is the variable of the actual component; this variable can take two values: 0, if we buy, the component and 1, if we make the component,
- X_p is the predecessor variable of the actual component; this variable can take two values: 0, if we buy, the higher level component which contains the actual component and 1, if we make it.
- C is the total production cost of the solution.

To obtain the final result we use Harmony search algorithm and modified the equation solving program to make and choose the best variation. In the final solution the value “0” means we should buy that component, the value “1” means we should make it.

```
solution = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
           1 1 1 0 1 0 0 0 0  0  1  0  1  0  1  1

total cost = 31390
```

Figure 5 shows how the program optimizes the variables to get the final result. The optimizing process consists of 500 steps which can be taken within only 2 second.

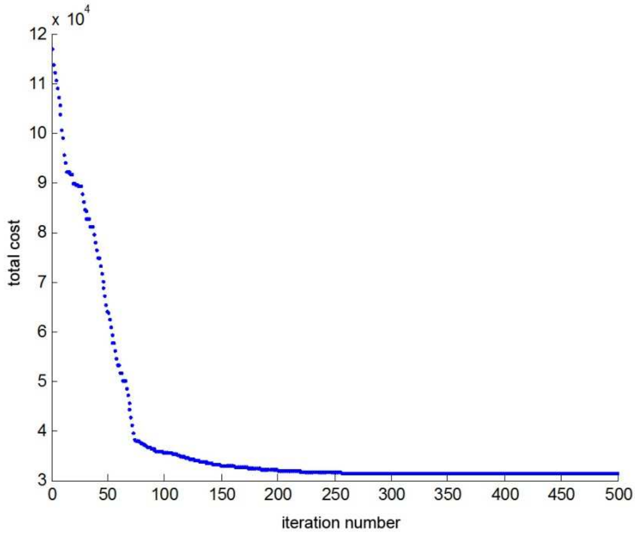


Figure 5. Convergence of the average harmony value of the harmony memory matrix (scenario)

It is possible to analyse the effect of the parameters of the harmony search algorithm (harmony memory consideration rate, pitch adjustment rate, band width) on the convergence. Figure 6 and 7 show the difference of the convergence function of the average harmony value and the best harmony value in the case of different harmony search parameters. These figures illustrate, that the analysis and evaluation of algorithm parameters is very important from the point of view of required iteration number and convergence.

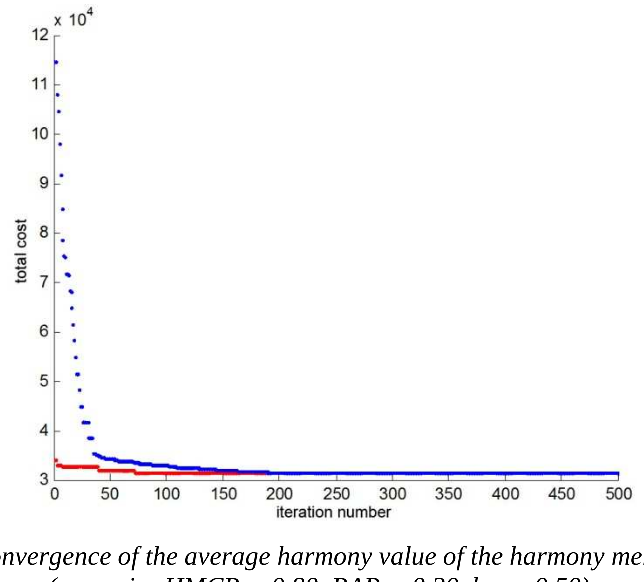


Figure 6. Convergence of the average harmony value of the harmony memory matrix (scenario: HMCR = 0,80, PAR = 0,20, bw = 0,50)

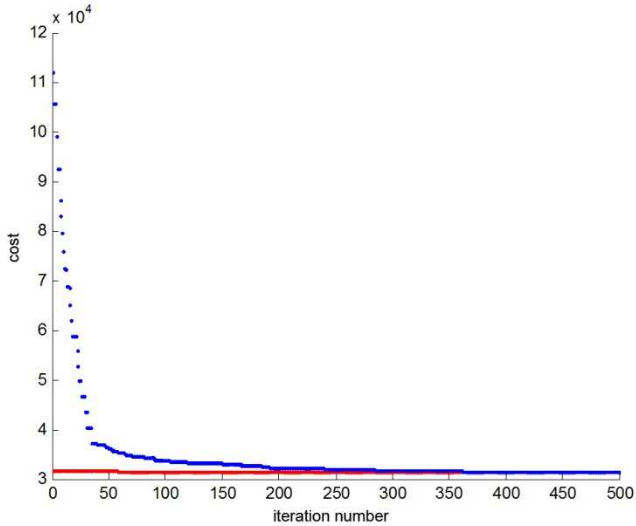


Figure 7. Convergence of the average harmony value of the harmony memory matrix (scenario: HMCR = 0,20, PAR = 0,80, bw = 0,10)

The parameters influence the first phase of the optimisation process, therefore Figure 8. and 9. describe these phases in logarithmic scale. The future research directions are the following: development of the more robust algorithm to be able to find the optimal production depth in the case of huge number of products; deeper analysis of the algorithm parameters to speed up the convergence of the harmony search.

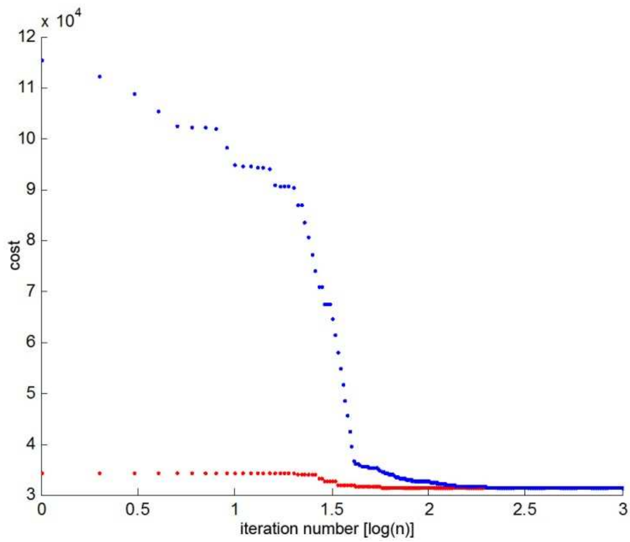


Figure 8. Convergence of the average harmony value of the harmony memory matrix in logarithmic scale (scenario: HMCR = 0,80, PAR = 0,20, bw = 0,50)

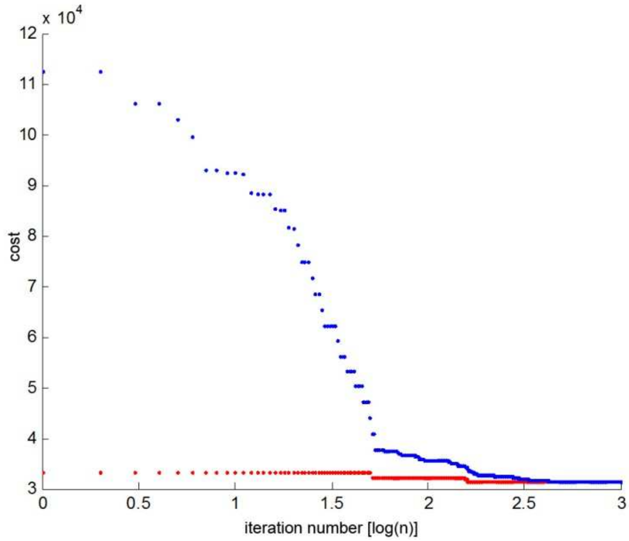


Figure 9. Convergence of the average harmony value of the harmony memory matrix in logarithmic scale (scenario: HMCR = 0,80, PAR = 0,20, bw = 0,50)

4. Summary

The aim of this research work was to develop such a heuristic optimisation method which can be efficiently used in the everyday practice, to optimise the production depth primarily in automotive and mechatronic assembly companies. The optimisation problems of production depth can derivate from the problem of the optimal design of bill of material. The study proposes a model of production depth optimisation by the aid of BOMs and gives a mathematical description including not only the model specification, but also the evaluation and optimisation parameters including cost based objective function and constraints. The paper describes a harmony search based optimisation algorithm. The results of this study can be used to improve the whole logistics process of companies from the purchasing through production logistics to distribution. The paper concludes with suggestions of further research directions, namely the dynamic optimisation of production depth.

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