Modeling and realization of manufacturing logistics network

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Notation

- \( b_i \) - utility for by \( M_i \);
- \( b_n \) - utility by \( M_n \);
- \( c_d \) - less defects philosophy;
- \( c_m \) - manufacturing cost of the \( n \) th product;
- \( c_p \) - increased production philosophy;
- \( c_r \) - manufacturing resources cost;
- \( c_w \) - reduced waste philosophy;
- \( d_n \) - functionality of the \( n \) th product;
- \( f_n \) - form of the \( n \) th product;
- \( G_i \) - state of logistics network formed by \( M_i \);
- \( G_n \) - state of logistics network formed by \( M_n \);
- \( LT \) - lead time;
- \( m_n \) - mass of the \( n \) th product;
- \( M_n \) - the \( n \) th manufacturer;
- \( n \) - a customer;
- \( N \) - a set of network members;
- \( N_m \) - a set of manufacturers;
- \( P \) - product specification matrix required by a customer;
- \( P_n \) - product title;
- \( q \) - batch size;
- \( RT \) - run time.
- \( s_a \) - production availability;
- \( s_i \) - payment realization;
- \( s_s \) - shipping times
- \( s_t \) - information transfer;
- \( ST \) - set up time;
- \( t_c \) - cycle times;
- \( t_l \) - reduced lead times;
- \( t_m \) - manufacturing time of the \( n \) th product;
- \( t_o \) - reduced overall inventory;
- \( t_s \) - machinery set up time;
- \( t_w \) - waiting times;
- \( t_w \) - reduced work-in-process;
- \( x_a \) - agreement case instituted by \( M_i \);
- \( x_m \) - agreement case instituted by \( M_m \);
- \( y_d \) - disagreement case instituted by \( M_i \);
- \( y_m \) - disagreement case instituted by \( M_m \);
- \( z_t \) - delivery time of the \( n \) th product;
- \( \alpha \) - a customer utility.

1. Introduction

In most industrial nations, the struggle to survive has become an integral part of each company’s way of life. It was found that manufacturing output is the main factor that can increase the competitiveness of separate companies [1]. The manufacturing output depends on the success of products that are sharing in various marketplaces. New product development and production time and costs are available to decrease when simultaneous engineering is to be used [2]. With the distribution of different jobs among partners organizations in one or various countries can apply the product simultaneous design and engineering and production process seeking minimization of manufacturing time, cost and delivery time. This approach can often create the appreciative conditions for the implementation of lean production [3] methods. Sharing information among the available partners, people, suppliers and customers is very important in this context. The modeling procedure is a common technique to create and to check the most appropriate web-based network for the above-mentioned tasks. The model can work in virtual environment and can test developed software and parametrical functions for product and process design, and manufacturing resources planning. The review [4-6] carried out showed the shortage of appropriate models and techniques. This issue is evident due to constantly increasing competition and changing market requirements. Therefore, this paper reflects the strive of today’s manufacturer survival under global competition circumstances.

2. Problem description

The problem we would like to consider can be formulated as follows. Customers using the developed model can provide their orders to potential manufacturers (Fig.1).

Consider a manufacturing logistics network consisting of a customer and several manufacturers. A network forms inbound logistics supply chain that consists of products, information and resources being exchanged among supply chain members [4]. This particular case is a relevant subject in practice in Lithuania where customers from other countries especially the ones from European Union are looking for manufacturers in Lithuania or other countries from Eastern block to form a supply chain.

The customer contacts a potential manufacturer and puts an order with certain specifications on products to be manufactured. Meanwhile the manufacturer considers a possibility of accepting an order. In practice, certain prod-
uct specifications required by customer are at variance with the ones of manufacturer. In such a case the manufacturer weighs potential costs that arise from striving to satisfy customer’s needs and utility if the members reach a consensus. Both sides of network the customers and manufacturers can create the process plan and calculate the manufacturing resources using our early research [7, 8]. Additive costs arise when manufacturers develop profitable solutions on their own initiative in order to satisfy customer needs (see numerical application section).

3. Logistics network modeling

Let the network members denote \( N = \{1, \ldots, n\} \) and let a set of manufacturers \( N_m \subset N \) be \( N_m = \{1, \ldots, n-1\} \); where \( n \) is a core customer.

A customer \( n \) selects potential manufacturers \( M_1 \) and \( M_2 \) and defines product characteristics in Matrix \( P \) (Table 1). Manufacturers revise the obtained data and unfortunately, both manufacturers are not able to satisfy some parameters. The first manufacturer \( M_1 \) for the following products satisfies the first four parameters except for the manufacturing time and cost

\[
\begin{align*}
& t_1(M_1) > t_n & (1) \\
& c_n(M_1) > c_n & (2)
\end{align*}
\]

It means that the first manufacturer is not able to produce \( n \) products upon the required time. Furthermore, the manufacturing cost of \( n \) products is higher than the customer is ready to pay.

Manufacturer \( M_2 \) can not satisfy delivery time \( z_n \) of products

\[
z_n(M_2) > z_n & (3)
\]

Due to certain constrains the second manufacturer is not able to deliver \( n \) group of products upon the required schedule. These parameters are higher than necessary, which means that production delivery time does not match the schedule.

Table 1

<table>
<thead>
<tr>
<th>Product</th>
<th>Mass ( m_i, ) kg</th>
<th>Form</th>
<th>Functionality</th>
<th>Manufacturing time ( t_i, ) h</th>
<th>Manufacturing cost ( c_i, ) €</th>
<th>Delivery time ( z_i, ) h</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1 )</td>
<td>( m_1 )</td>
<td>( f_1 )</td>
<td>( d_1 )</td>
<td>( t_1 )</td>
<td>( c_1 )</td>
<td>( z_1 )</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>( m_2 )</td>
<td>( f_2 )</td>
<td>( d_2 )</td>
<td>( t_2 )</td>
<td>( c_2 )</td>
<td>( z_2 )</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>( m_3 )</td>
<td>( f_3 )</td>
<td>( d_3 )</td>
<td>( t_3 )</td>
<td>( c_3 )</td>
<td>( z_3 )</td>
</tr>
<tr>
<td>( \ldots )</td>
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<td>( \ldots )</td>
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</tr>
<tr>
<td>( P_n )</td>
<td>( m_n )</td>
<td>( f_n )</td>
<td>( d_n )</td>
<td>( t_n )</td>
<td>( c_n )</td>
<td>( z_n )</td>
</tr>
</tbody>
</table>

Furthermore, if manufacturers satisfy customer’s requirements, all members of manufacturing logistics network will benefit and agreement between the parties will take place (Fig. 2).

Fig. 2 Extensive form of manufacturing logistics network model

An extensive form of manufacturing logistics network model illustrates cases of manufacturing cooperation among chain members and their potential utilities. A customer defines product characteristics (given by matrix \( P \)) and selects two manufacturers that in case of satisfying customer’s conditions get utility. Two cases are possible: agreement \( G=x \) and disagreement \( G=y \) among network members.

4. Lean manufacturing approach application in modeling logistics network

Under the existing circumstances of high level competition, manufacturers should strive and increase quality of their production. In order to satisfy customer’s requirements (matrix \( P \)), the first manufacturer has to decrease manufacturing time of the first product \( P_1 \) and manufacturing cost of the second product \( P_2 \).

Based on lean production approach, manufacturing time \( t \) is a function of reduced lead times \( t_l \) machinery set up time \( t_s \) and waiting times \( t_w \), reduced overall inventory \( t_r \), reduced work-in-process \( t_w \) and cycle times \( t_c \).

\[
t = f(t_l, t_r, t_s, t_w, t_c) \Rightarrow \min
\]
Manufacturing time $t$ may be reduced by diminishing it simultaneously \cite{3}. For instance, it is possible to start with reduced lead times and eventually it may appear that it was enough to decrease lead times and no other additional solutions are needed. Although it may appear that the reduced lead times are not a satisfactory argument while reaching customer’s desired level. In such a case the manufacturer must invest more and maybe to reassess inventory management. The following algorithm (Fig. 3) was created applying lean approach and realized using modeling software package Meta Software v4.3 \cite{9}. It shows a step-by-step manufacturing process of production time minimization:

If the first manufacturer satisfies first condition (1), and $t_m(M_i) = t_m$, the following parameter of manufacturing cost must be considered. Note that manufacturing time is also a function of manufacturing cost $c = f(t)$ which shows a direct dependency of reduced manufacturing time to automatically decreased manufacturing cost. Hence, it may appear that if the first manufacturer diminishes manufacturing time using lean production approach, manufacturing cost may be decreased as well without unnecessary investments. However, manufacturing time $t$ is not the only parameter influencing manufacturing cost, that is also a function of increased production $c_p$, manufacturing resources cost $c_r$, less defects $c_d$, and reduced waste $c_w$.

\begin{equation}
    c = f(t, c_p, c_r, c_d, c_w) \Rightarrow \min
\end{equation}

Improving each member of manufacturing cost function, eventually the goal may be established and $c_i(M_i) = c_m$. If two conditions are satisfied, an agreement is reached and manufacturing logistics network is formed.

In the second case a manufacturer $M_2$ must decrease production delivery time $z$, which is a function of production availability $s_a$, payment realization $s_i$, information transfer $s_t$ and shipping time $s_s$.

\begin{equation}
    z = f(s_a, s_t, s_i, s_s) \Rightarrow \min
\end{equation}

Similarly, using step-by-step algorithm (Fig. 3) methodology manufacturer $M_2$ seeks that conditions established by a customer would be met and the following condition would hold true and $z_m(M_2) = z_m$.

Finally the bargaining may obtain several forms of agreement and disagreement on terms of customer with both manufacturers. The utility may be shared among logistics network members. There is also another, the so-called “no winners” case when no one benefits from this situation (Table 2).

Table 2 Logistics network members’ utility

<table>
<thead>
<tr>
<th>Manufacturer $M_2$</th>
<th>Agreement $G_i=x_i$</th>
<th>Disagreement $G_i=y_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer $M_1$</td>
<td>Agreement $G_i=x_i$</td>
<td>$(b_i, b_w, \alpha)$</td>
</tr>
<tr>
<td></td>
<td>Disagreement $G_i=y_i$</td>
<td>$(0, b_w, \alpha)$</td>
</tr>
</tbody>
</table>

where $\alpha$ is a customer utility.
is assumed to be in coalition with a customer. Under such conditions only two network members get bilateral utility: for $M_1$: if $G_i=x_i$ and $G_n=0$ then utility is $b_i00\alpha$; for $M_2$: if $G_i=0$ and $G_n=x_n$ then utility is $0b_n\alpha$.

The last and unsuccessful case is when manufacturers do not satisfy customer’s requirements and manufacturing logistics network is not formed. No one gets any utility. If $G_i=0$ and $G_n=0$ then there is no utility.

5. Numerical application

This section applies the results on previously derived mathematical expressions. Modeled manufacturing logistics network will be realized in this section using software for manufacturing resources estimation [8]. A logistics network consists of a customer and two manufacturers. Manufacturers are denoted by numbers 1 and 2 and the consumer by index 3. $N = \{1,2,3\} \ N_m = \{1,2\}$.

A customer orders three types of products produced from steel. Three types of flanges must be manufactured in quantities of 60 pieces. In the above matrix (Table 3) the customer sets requirements for manufacturers. The first manufacturer is from Country A and cannot satisfy the manufacturing time (Fig. 4) and cost parameters given by the customer.

$$t_i(M_1)=1.62h, \quad t_i(M_2)=1.58h, \quad t_i(M_3)=1.66h.$$ $c_i(M_1)=24.5\ \varepsilon, \quad c_i(M_2)=23\ \varepsilon, \quad c_i(M_3)=26\ \varepsilon$

In such case manufacturing time of flanges must be decreased using lean manufacturing approach and applying algorithm of production time minimization. Following the algorithm and taking into account equation (6), lead time $LT$ is the first parameter which is time interval between the initiation and completion of the production process [6]. $LT$ is estimated from set up times $ST$, batch size $q$ and run times $RT$ using the following formula:

$$LT = ST + q * RT$$

Table 3

<table>
<thead>
<tr>
<th>Customer's demand</th>
<th>Manufacturer's data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 Difference between customer’s demanded and manufacturer’s defined manufacturing time of flanges

This step encompasses the following step of algorithm that primarily strives for reduced machinery set up times $ST$. It is necessary to stress that in this particular case the difference between manufacturing times required by the customer and manufacturer $M_i$ is comparatively small. For flange 200 the difference is 19.2 min, for flange 100 is 20 minutes and for flange 250 is 19.2 min too. Firstly, let us revise production operations and time required to accomplish them. Three operations cutting, turning and drilling are necessary to produce flanges. Timing of the operations for flange 100 is established as follows: cutting 4-5 min, turning 20 min and drilling 20 min as well. Preparation and machine set up time of each operation is as follows: 20 min, 20 min and 10 min respectively. This operation time measure is also valid for flanges 200 and 250 however due to bigger dimensions it is necessary to take into account additional minutes for each operation. Following the algorithm, machinery set up and preparation times may be obviously reduced by 20 min. Preparation for the first manufacturing operation (cutting) takes up 20 min, that may be reduced up to 10 min. The same 10 min are taken away from preparation time for the second turning operation. This may be accomplished by increasing skilled machine operator’s working efficiency and effectiveness [4]. The worker must be educated and promoted. Investments are not high and moreover, those costs are recoverable [4]. Applying production time minimization algorithm manufacturing time of flange was reduced by 20 min (set up 1 for cutting operation and set up 2 for turning operation), meanwhile the difference was 20 min as well (Fig. 5). Finally, the goal was reached using only two first steps of algorithm and there is no need to follow it further, because the condition (equation 1) is satisfied.

Fig. 5 Decreased manufacturing time of flanges

Manufacturing cost minimization condition may be satisfied solving equation (7), where the first variable is manufacturing time. In above presented computations, manufacturing time is decreased by 20 min per flange

Table 3

<table>
<thead>
<tr>
<th>Product</th>
<th>Mass $m$, kg</th>
<th>Form, $f$</th>
<th>Functionality, $d$</th>
<th>Manufacturing time, $t_i$, h</th>
<th>Manufacturing cost, $c_i$, $\varepsilon$</th>
<th>Delivery time, $z$, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flange 200</td>
<td>5</td>
<td>200</td>
<td>1</td>
<td>1.3</td>
<td>23.5</td>
<td>30</td>
</tr>
<tr>
<td>Flange 100</td>
<td>4</td>
<td>100</td>
<td>1</td>
<td>1.25</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>Flange 250</td>
<td>5.5</td>
<td>250</td>
<td>1</td>
<td>1.33</td>
<td>25</td>
<td>30</td>
</tr>
</tbody>
</table>
which in monetary terms may be expressed as 1.2 €. As the difference between customer’s and manufacturer’s manufacturing cost is 1 €, so there is no need to decrease it further (Fig. 6). The utility appears to be bilateral between the customer and manufacturer $G_i = x_i$, then the utility is $b_i = 5130 \text{ €}$ [8] meanwhile the consumer obtains ordered production.

![Customer’s demand Reduced manufacturing cost](image)

Fig. 6 Manufacturing cost reduction

The second manufacturer selected is from Country B where manufacturing time and cost of flanges are acceptable, but delivery time is higher

$$z_i(M_1) = 40h \quad z_2(M_2) = 40h \quad z_3(M_3) = 40h$$

The manufacturer must decrease delivery time of flanges at least by ten hours. The second manufacturer must develop a cost effective solution referring to the equation (8). If using simultaneous engineering method the solution appears to be cost effective, eventually the manufacturer agrees to form a manufacturing logistics network.

![Customer’s demand Increased production availability](image)

Fig. 7 Decreased delivery time of flanges

Production availability $z_a$ could be increased if the manufacturer knew about customer’s order in advance. The manufacturer may use forecasting techniques and establish production number in advance [4]. This technique does not require a lot of investments and likewise has a matter of lack of accuracy. Although if a manufacturer increases its safety stocks at least by 30 flanges of each different product, the manufacturing time decreases by 13 hours [8] of the first type of flanges and total delivery time becomes $z_i(M_w) = 27h$ only (Fig. 7).

The same happens with the second and the third type of flanges and delivery time decreases till $z_2(M_2) = 27h$ as well.

This technique appears to be cost effective and efficient and therefore in this particular case no other investments are necessary. The utility appears to be bilateral between a consumer where $\alpha$ is equal to the obtained flanges and for manufacturer $G_i = x_i$ then the utility is $b_i = 5130 \text{ €}$ [8].

Finally, the manufacturer from Country B agrees to accept customer’s order and forms a manufacturing logistics network.

6. Conclusions

1. The developed model of generic manufacturing logistics network encompasses the information about products and their manufacturing resources that can help to win orders for producer.

2. Based on lean manufacturing approach created algorithms help to develop optimal production plan including logistics with minimal costs and delivery time.

3. Algorithms realized using our own Computer aided process Panning software are based on consecutive reduction of manufacturing resources and appropriate objective functions make them possible to reduce production time and costs sequencing various plants, processes and facilities.

4. The created manufacturing logistics network model has been tested on three different one type mechanical products; testing results showed its correctness and means for further model improvements extending types of products and processes.

References

L. Anužienė, A. Bargelis

GAMYBINĖS LOGISTIKOS TINKLO MODELIO KŪRIMAS IR REALIZAVIMAS

R e z i u m ė


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MODELLING AND REALIZATION OF MANUFACTURING LOGISTICS NETWORK

S u m m a r y

The paper presents a model of manufacturing logistics network forming relationships among different manufacturers and customers seeking for minimal manufacturing resources. The created model is applicable for potential customers in finding producers providing the least manufacturing resources and the shortest distribution times. Based on lean manufacturing approach created algorithms were modeled using modeling software for the purpose of designing optimal processes with least manufacturing resources and delivery times for the product under investigation. Whenever the obtained results satisfy a customer, they are incorporated into manufacturing logistics network where its members share multilateral information. Correctness of the model has been tested by three different products from spin class.

Л. Анужене, А. Баргялис

МОДЕЛИРОВАНИЕ И РЕАЛИЗАЦИЯ ПРОИЗВОДСТВЕННОЙ ЛОГИСТИЧЕСКОЙ СЕТИ

Р е з ь м е

В статье представлена модель сети производственной логистики для формирования связей различных производителей и потребителей при поиске минимальных производственных затрат. Разработанная модель сети помогает найти производителей с наименьшими затратами и минимальными терминами доставки продуктов для потенциальных заказчиков. В пакете моделирования разработанные алгоритмы применяют методы «экономного» производства проектируют рациональные процессы исследованного продукта с наименьшими затратами и терминами доставки. Когда полученные результаты удовлетворяют требованиям заказчика, тогда они включаются в сеть производственной логистики и ее члены делятся многосторонней информацией. Правильность работы модели проверяна тремя различными продуктами класса тел вращения.

Received April 13, 2005