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Modeling and realization of manufacturing logistics network

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Notation

b_i - utility for by M_1;
b_n - utility by M_2;
c_d - less defects philosophy;
c_n - 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_1;
G_n - state of logistics network formed by M_2;
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_n - manufacturing time of the *n th* product;
t_r - reduced overall inventory;
t_s - machinery set up time;
t_t - waiting times;
t_w- reduced work-in-process;
x_i - agreement case instituted by M_1;
x_n - agreement case instituted by M_2;
y_i - disagreement case instituted by M_1;
y_n - disagreement case instituted by M_2;
z_n - delivery time of the *n th* product;
α - 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

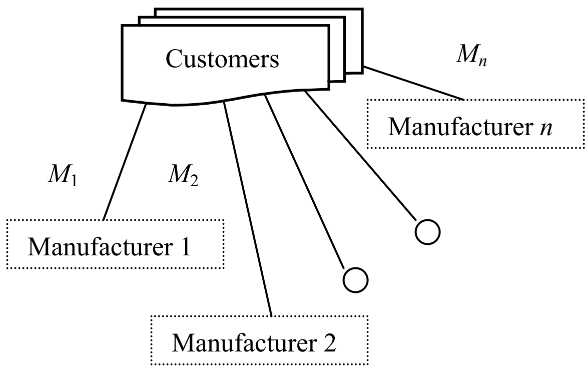

Fig. 1 Manufacturing logistics network among customers and manufacturers

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 product 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 $N = \{1,...,n\}$ and let a set of manufacturers $N_m \subset N$ be $N_m = \{1,...,n-1\}$; 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

$$t_n\left(M_1\right) > t_n \quad (1)$$

$$c_n\left(M_1\right) > c_n \quad (2)$$

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

$$z_n\left(M_2\right) > z_n \quad (3)$$

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

Customers' defined matrix M for production requirements

$P =$

Product	Mass m, kg	Form f	Functionality d	Manufacturing time t, h	Manufacturing cost c, €	Delivery time z, h
P_1	m_1	f_1	d_1	t_1	c_1	z_1
P_2	m_2	f_2	d_2	t_2	c_2	z_2
P_3	m_3	f_3	d_3	t_3	c_3	z_3
...	...	...	...	...	...	...
P_n	m_n	f_n	d_n	t_n	c_n	z_n

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).

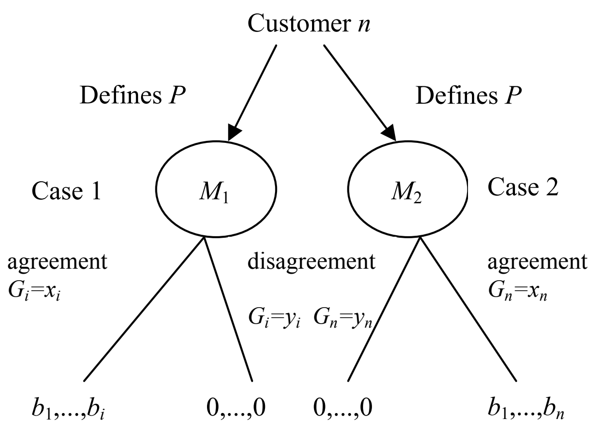

Fig. 2 Extensive form of manufacturing logistics network model

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.

$$G_i = \{x_i, y_i\} \quad (4)$$

$$G_n = \{x_n, y_n\} \quad (5)$$

If a manufacturer M_1 agrees to produce products (case G_i=x_i) both network members will benefit and in this case the first manufacturer will get utility x_i=b_i. If M_1 is not able to satisfy consumer's requirements (case G_i=y_i), the cooperation will result in no utility y_i =0.

If the second manufacturer M_2 agrees to cooperate (case G_n=x_n) both network members will come up with utility x_n=b_n. Otherwise the companies will end up with disagreement case G_n=y_n.

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_t, reduced overall inventory t_r, reduced work-in-process t_w and cycle times t_c.

$$t = f\left(t_l, t_s, t_t, t_r, t_w, t_c\right) \Rightarrow min \quad (6)$$

Manufacturing time t may be reduced by diminishing it simultaneously [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 [9]. It shows a step-by-step manufacturing process of production time minimization:

If the first manufacturer satisfies first condition (1), and $t_n(M_1) = t_n$, 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.

$$c = f(t, c_p, c_r, c_d, c_w) \Rightarrow min \quad (7)$$

Improving each member of manufacturing cost function, eventually the goal may be established and $c_n(M_1) = c_n$. 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.

$$z = f(s_a, s_i, s_t, s_s) \Rightarrow min \quad (8)$$

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 $z_n(M_2) = z_n$.

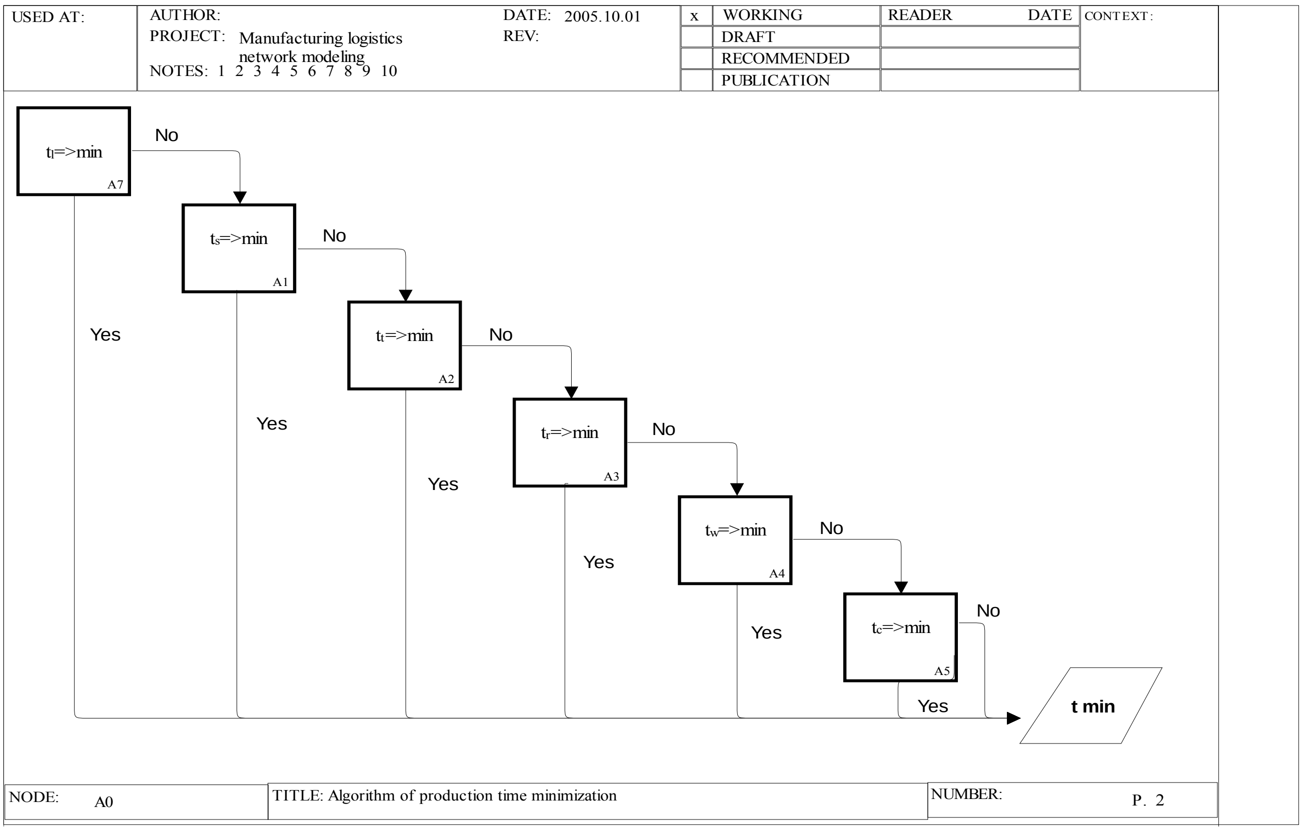

Fig. 3 Algorithm of production time minimization applying lean manufacturing approach

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).

If a network is formed, all members benefit from coalition formation and the obtained utility is mutual if $G_i=x_i$ and $G_n=x_n$ then b_i, b_n, α.

There is a case when only one manufacturer satisfies customer's requirements, then only one manufacturer

Table 2

Logistics network members' utility

Manufacturer M_1

Manufacturer M_2	M_1 / M_2	Agreement $G_i=x_i$	Disagreement $G_i=y_i$
	Agreement $G_n=x_n$	(b_i, b_n, α)	$(b_i, 0, \alpha)$
	Disagreement $G_n=y_n$	$(0, b_n, \alpha)$	$(0,0,0)$

where α 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 $b_i, 0, \alpha$;
for M_2: if G_i=0 and G_n=x_n then utility is $0, b_n, \alpha$.

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.

$$t_1(M_1) = 1.62h, \quad t_2(M_1) = 1.58h, \quad t_3(M_1) = 1.66h.$$
$$c_1(M_1) = 24.5\,€, \quad c_2(M_1) = 23\,€, \quad c_3(M_1) = 26\,€$$

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:
where $LT = ST + q * RT$.

Table 3

Customers' defined matrix P for production requirements

$P =$

Product	Mass m, kg	Form f,	Functionality d	Manufacturing time t, h	Manufacturing cost c, €	Delivery time z, h
Flange 200	5	200	1	1.3	23.5	30
Flange 100	4	100	1	1.25	22	30
Flange 250	5.5	250	1	1.33	25	30

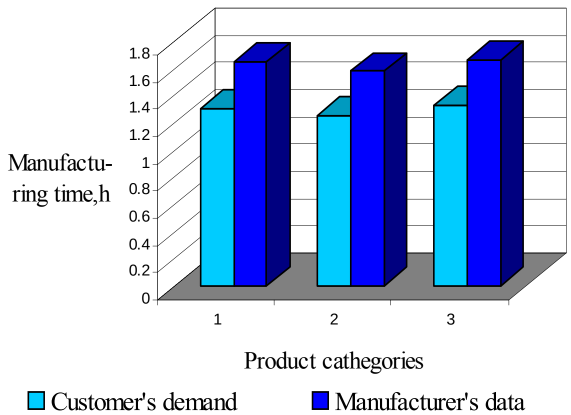

Fig. 4 Difference between customer's demanded and manufacturere's defined manufacturing time of flanges

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_1 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.

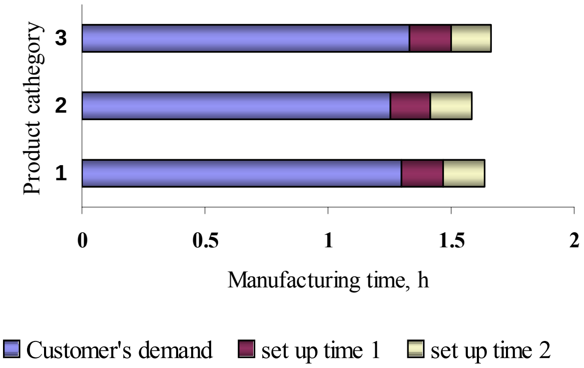

Fig. 5 Decreased manufacturing time of flanges

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 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 € [8] meanwhile the consumer obtains ordered production.

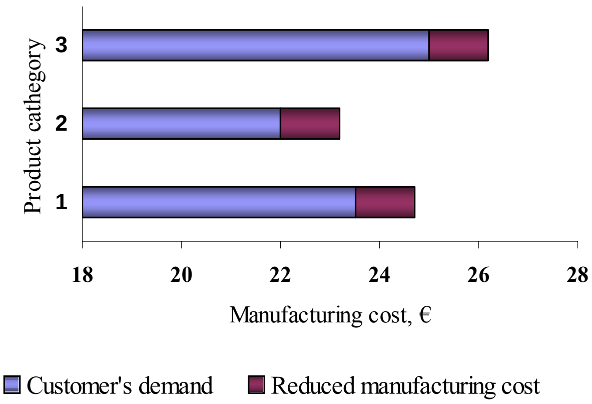

Fig. 6 Manufacturing cost reduction

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

$$z_1(M_2) = 40h \quad z_2(M_2) = 40h \quad z_3(M_2) = 40h$$

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.

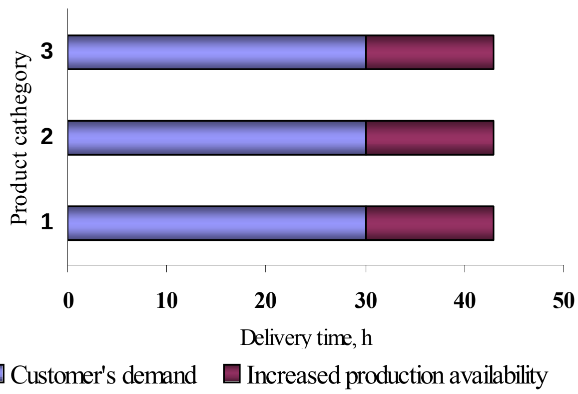

Fig. 7 Decreased delivery time of flanges

Production availability s_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 $z_1(M_2)$= 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 $z_3(M_2)$= 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 α is equal to the obtained flanges and for manufacturer $G_n=x_n$ then the utility is b_n=5130 € [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.

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GAMYBINĖS LOGISTIKOS TINKLO MODELIO KŪRIMAS IR REALIZAVIMAS

R e z i u m ė

Straipsnyje pateikiamas gamybinės logistikos tinklo modelis, formuojantis ryšius tarp įvairių gamintojų ir vartotojų ieškant mažiausių gamybinių sąnaudų. Sukurtas tinklo modelis padeda rasti mažiausių sąnaudų ir trumpiausių pristatymo terminų gamintojus potencialiems gaminių užsakovams. Naudojant taupios produkcijos metodus, modeliavimo pakete sukurti algoritmai projektuoja optimalius tiriamo gaminio gamybos procesus mažiausiomis sąnaudomis ir pristatymo terminais. Kai gauti rezultatai tenkina vartotojo reikalavimus, jie įtraukiami į gamybinės logistikos tinklą ir jo nariai dalijasi daugiašalia informacija. Modelio veiklos teisingumas patikrintas trimis skirtingais sukinių klasės gaminiais.

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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 ю м е

В статье представлена модель сети производственной логистики для формирования связей различных производителей и потребителей при поиске минимальных производстенных 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 иследованного продукта с наименьшими затратами и терминами доставки. Когда полученные результаты узовлятворяют требованиям заказчика, тогда они включаются в сеть производственной логистики и ее члены делятся многостворонней информацией. Правильность работы модели проверяна тремя различными продуктами класса тел вращения.

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