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A Linear Programming Model of Integrating Flexibility Measures into Production Processes with Cost Minimization

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Abstract

This paper focuses on a current topic of production management and operations research which serves as a tool for small and medium enterprises to cope with pressure put on the by continuously changing market conditions and global economy itself. Paper presents a linear programming model developed in order to achieve flexibility of production processes in operations management and also to minimize costs throughout the whole production process. Created model is general in its nature and therefore it can be applied on any kind of production process with just a few modifications. Therefore it is suitable for production company with any type of process orientation. Model stresses the importance of cost minimization, which is also its main objective. Resource procurement costs, fixed and variable production costs, inventory costs and transportation costs are included. Several possibilities of flexibility measures implementation are considered. These measure focus on employee flexibility, machinery flexibility and resource flexibility. Proposed model also take into account market conditions.

Keywords: Cost minimization; Production process; Flexibility; and Linear Programming

1. Introduction

Nowadays production companies face a severe competition which puts that much pressure not only on their quality requirements, but also on their supply chains.

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It is the goal of company's operations management to ensure the best possible outcome and gain the competitive advantage which enables company to establish a desirable market position. However it is not a single set of managerial decisions which make it possible. A strive for excellence is a continuous process which does not only involve establishing a good market position, but it also focuses on implementing measures necessary to maintain it. Cost minimization is one of the original goals of all companies, which is nowadays viewed more as an essential part of companies' financial management. One of the newer ways companies can achieve excellence is through implementing specific measures in order to achieve flexibility of their processes. One of the basic tools is linear programming.

The main objective of this paper is to present the linear programming model of flexible production processes which main goal is to achieve cost minimization throughout the whole process. The paper is divided into five main parts. In the beginning we provide a brief literature review of topics which were a motivation for this study. We focus on linear programming as an effective tool used in modeling. Secondly we also include a brief overview of integrating flexibility measures into operations management and its importance nowadays. The next part of the paper describes the proposed model in detail. We also include the model assessment and discussion about its possible practical applications and some ideas for further research.

The main contributions of this paper can be summarized as follows:

- Introducing a novel operations management planning model by integrating resource procurement, goods transformation, resources restrictions, market conditions, time restrictions and quality requirements into a multi-plant, multi-product and multi-period production network.
- Integrating flexibility measures into production processes with the stress on cost minimization throughout the process.

2. Motivation for the Study

Nowadays the global economic crisis deteriorates the business environment and makes it more difficult for companies to manage. Therefore companies must learn to adapt and make an effort to secure an effective and promising development in these constantly changing conditions.

Therefore managers pay more attention to improving and optimizing possibilities, which would help their company not only to survive but also to best fulfill their goals. Integration of flexible measures and application of linear programming are just two of these possibilities.

1.1 Linear Programming

Linear programming was developed in early 50s simultaneously by Russian mathematicians Kantovič and Gavurin and American mathematician Dantzing. The most breakthrough discovery was Dantzing's creation of the Simplex method. Therefore he is referred to as "the father of linear programming". This method has been developed and evolved ever since mostly due to new technological inventions and wide-spread use of computers and other IT tools. Throughout almost 70 years of its usage as a method of optimization in companies linear programming has been applied in order to model many different types of company's processes. This operations research method enables the transformation of real economic operations and processes into mathematical models.

Sarker, Newton(2008), Buresh-Openheim, Davis, Impagliazzo (2011) and Baker (2011) evaluated the advantages and disadvantages of the linear programming utilization. They both consider the possibility of applying these methods for the long-term production planning to be the most significant advantage. Other advantages include the relative accuracy of these methods for the needs of certain companies. The use of linear programming assumes the creation of the linear objective function which describes the problem as closely as possible. The variables also enable their modeling as closely to the conditions in the company as possible. One of the main disadvantages of linear programming utilization is the fact that sometimes he linear function may not be the best option to model the processes and the situation may arise when company would have to resort to other non-linear methods of the operations research.

Despite of this fact, the advantages of linear programming utilization in companies are far greater and more significant. The application of these methods can help companies solve many different problems.

Linear programming is a powerful mathematical technique that can be used to solve various problems in managerial practice. Operations research is a management discipline which deals with optimizing problems in companies (Rader, 2010). Therefore the purpose of linear programming utilization in managerial practice is to solve linear optimizing problems. Many authors describe various possible utilizations of these methods in management. Some of the most common uses of linear programming are:

- max-cut tasks (Avis, Umemoto, 2003; Lodi, Monaci, 2003);
- allocation problems such as life cycle assessment (Azapagic, Clift, 1998); adaptability in agroforestry (Bertomeu, Bertomeu, Gimenez, 2006);staff training (Fagoyingo, Ajibode, 2010);
- mixing problems (Banks, 1979; Eiselt, Sandblom, 2010);
- routing optimization and transportation problems (Bertsekas, 2003; Gass, 2010; Bley, 2011);
- scheduling: employees' work shifts (Baker, 2011);time minimizing problems (Floudas, Lin, 2005);draw control (Guest et al., 2012);
- financial management (Zemánková, Komorníková, 2008; Weber, 2009);

Avis, Umemoto (2003) describe how Linear Programming can be used in solving the cutting problems. In these cases the objective is to create an optimal cutting pattern which provides the best use of raw materials and minimizes waste produced as a byproduct. The problem of determining a cutting pattern also involves maximizing the sum of the profits of the cut items (Lodi, Monaci, 2003). The problem of cutting a given set of small rectangles (items) from large identical rectangular pieces of stock material has been regarded as a prototypical problem of how Linear Programming can be used in practice. The objective function of such tasks is to minimize the amount of raw material used.

Arguably the largest group of problems which can be solved with the use of Linear Programming is the allocation problems. Azapagic and Clift (1998) have successfully used Linear Programming in product life cycle assessment.

It can be used to solve the problem of allocation in multiple-output systems in both the inventory and impact assessment phases. In addition Linear Programming can also provide the calculations of the environmental impacts and burdens.

In the improvement assessment phase, it provides a systematic approach to identifying possibilities for system improvements by optimizing the system on different environmental objective functions. Ultimately, if the environmental impacts are aggregated to a single environmental impact function, Linear Programming optimization can identify the overall environmental optimum of the system.

Bertomeu, Bertomeu and Gimenez (2006) provide yet another example of how Linear Programming can became an essential tool for solving problems in practice. They proposed an alternative solution to some of the problems of agroforestry industry. These authors developed a simple Linear Programming model which enables small farmers to optimize the allocation of land and resources to different activities. The application of this model can not only help the farmers meet the criteria set by the law, but also to increase the financial incomes from their activities. The most important feature of this model is the fact that it enables the variability in different crop production, which is necessary due to the nature of this industry since small farmers' decisions are highly influenced by the prices on the market. Consequently it effects the land use allocation. Therefore the adaptability is also one of the key requirements for such Linear Programming model.

In order to provide more evidence that Linear Programming can be used in all aspects of companies' operations management, Fagoyinbo and Ajibode (2010) demonstrate its use in personnel management. They focused on creating a mathematical model which would represent the allocation of resources for staff training. In practice this problem actually consists of two separate problems which are highly dependent on each other. Firstly the company has to find the optimal amount of resources to allocate for staff training and secondly it has to deal with the problem of scheduling such training. A Linear Programming model with duality can be used to provide a company with the optimal solution.

The calculations for the preparation of mixtures can also be solved using the Linear Programming. It enables companies to prepare a certain type of mixture using a determinated ingredients and recipe (Eiselt, Sandblom, 2010).

Linear Programming can also help to estimate the standard error of the chemical data, which is introduced as weights into the set of linear equations.

This way, it is possible to assign the limits to the solutions which are obtained and to apply them in the mixing model. Satisfactory solutions to mixing problems can be obtained by minimizing the sum of absolute values of the individual substances. In consequence, the entire analysis can be handled as a linear programming problem with a considerable savings in time. On the other hand Banks (1979) warns that if the composition of a mixture involves different types of material, Linear Programming may not be enough to provide the best possible results. Therefore he recommends the use of two-stage optimizing process which would require the use of Linear Programming with combination of other methods.

Many authors also describe how Linear Programming can be used to solve problems in different aspects of routing optimization. Bley (2011) demonstrates the utilization of this method in finding the shortest path. In this case, the main goal is to find the routing lengths of each unique demand and to minimize the congestion over all links in the resulting routing. Bertsekas (2003) and Gass (2010) illustrate the use of Linear Programming in other transportation problems.

Guest et al. (2012) provide a special example of how Linear Programming is being used in managerial practice. They describe how a certain company built an entire operating system of their plant based on these methods. This involves daily optimization of scheduling processes, control processes, time and cost minimizations etc. They also describe some of the advantages that come with the Linear Programming utilization, which involve flexibility, simplicity, generality, both log and short term planning, incorporation of safety restrictions into business tasks, short-term period of achieving desirable solutions etc.

Moreover we cannot limit the possibilities of Linear Programming utilization only to the options described above. The limitations of its utilization are just in terms of needs of individual companies. Therefore we can state that Linear Programming can be used to provide solutions to a variety of different problems which companies encounter. Rajan et al. (2010) provide evidence to this theory. They describe another possibility of how Linear Programming can improve companies' processes, specifically the decision-making process. To strengthen their argument, they offer an example of Linear Programming utilization in supply chain management.

1.2 Integrating Flexibility into Operations Management

Vanichchinchai, Igel (2011) and Baghalian et al. (2013) state that nowadays the competition between companies is not as significant as the competitions between their supply chains. Therefore integrating flexibility measure is getting more important than ever. According to Peidro et al. (2010) companies have to face many uncertainties as a result of changes in their inner and outer environment. Adaptation to these changes is crucial for company's survival.

Gong (2008) defines flexibility at the internal production level as the ability of the manufacturing system to cope with changes such as product, process, load, and machine breakdown. A more comprehensive definition might be the ability of the enterprise to respond to variations more quickly, with lower costs, and less effect on system effectiveness. In this paper, flexibility is considered as the ability of the manufacturing system to cope with internal and external variation with high competitive competency and high economic profitability in form of cost minimization.

It is an established fact that the inclusion of effective flexibility measures can make a business more responsive—resolving most production process uncertainty issues. Businesses must include flexibility planning at the strategic level, based on overall business perspectives, if they intend to be successful within this type of complex, predominantly global business environment (Das, 2011). Overall integrating flexibility measures into company's production processes can provide an opportunity for increasing its economical effectiveness and securing company's market position.

3. Linear Programming Model of Flexible Production Processes

Based on the theoretical background and summarized knowledge we can present the linear programming integrated model of production process. This model is based on linear programming and therefore it consists of objective function and related restrictions. The objective of this model is to minimize costs and to achieve flexibility in production processes.
Linear programming model is formulated as follows:

A_{nt}	availability of plant n at time t, its ability to produce, <0;1>
AR_{ri}	amount of resource r available
BR_{irt}	purchase quantity of resource r at time t
c	costs
CQ_{ir}	accepted level of quality parameter
CR_{irt}	purchase price of resource r at time t
$D_{i,t-1}$	unsatisfied demand from previous time period
D_{it}	demand of product i in time period t
E_{rt}	amount of resource available on the market
FPC_{nt}	fixed costs necessary for plant n to run in time t
G_i	goal / planned amount of product i produced
h	other resources
i	product
k_{mt}	number of production runs on machine m at time t
K_r	total amount of resource available to company
L	set of teams of employees available to the company for production of product i
M	set of machines available to the company for production of product i
MKT_{nt}	max. time of resource available
MOT_{nt}	overtime capacity of resource available if necessary, reserve
MZK_{it}	max. inventory capacity for product i in time period t
MZK_{rt}	max. inventory capacity for resource r in time period t
n	plant
Q_{ir}	quality parameter
r	resource
S_{it}	supply of product i already on the market
ST_m	machine set up time - time to start it, program it…
t	time
t_{il}	time team l needs to finish one unit of product i
t_{im}	time quota of product i processed on machine m
T_L	total labor working hours of team of employees
T_m	total number of machine working hours
u	transport method
UC_{inut}	transport costs
UK_{it}	total transport capacity in time t
UX_{it}	set of produced products assigned to transportation
VK_{nt}	production capacity of plant n at time t for product i
v_{nt}	1-0 function, 1 if plant n is opened in time period t, 0 otherwise
VPC_{inrt}	variable production costs
VT_{int}	average production time of product i
X_i	quantity of product i produced
X_{il}	amount of product i produced by team l
X_{im}	number of products i produced on machine m
z	inventory
ZC_{it}	inventory costs of holding one unit of product i during time t
ZC_{rt}	inventory costs of holding one unit of resource r during time period t
ZX_{it}	amount of inventory of product i in time period t
Z_{rt}	amount of inventory of resource r in time period t
δ_m	probability that machine m runs normally

$$\text{Minimize } z = \sum_i^I \sum_n^N \sum_r^R \sum_t^T (VPC_{inrt} \times X_{inrt} + CR_{nrt} \times BR_{nrt}) +$$
$$+ \sum_i^I \sum_n^N \sum_t^T (ZC_{int} \times Z_{int}) + \sum_r^R \sum_n^N \sum_t^T (ZC_{rnt} \times Z_{rnt}) +$$
$$+ \sum_i^I \sum_n^N \sum_u^U \sum_t^T (UC_{inut} \times UX_{inut}) + \sum_n^N \sum_t^T (FPC_{nt} \times v_{nt}) \ \forall\, i, n, r, u, t \quad (1)$$

Subject to

$$\sum_i^I (X_i \times AR_{ri}) \leq K_r \forall r \quad (2)$$
$$R \in \{L; M; H\}; R \in Z; R \geq 0 \quad (3)$$
$$K_r = Z_r + E_r \forall r \quad (4)$$
$$\sum_n^N (v_{nt} \times A_{nt} \times VK_{nt}) - \sum_n^N X_{int} \geq 0 \ \forall t \quad (5)$$
$$\sum_i^I (X_{il} \times t_{il}) \leq T_L \ \forall l \quad (6)$$
$$X_{it} = G_{it} \ \forall\, i, t \quad (7)$$
$$\sum_i^I (X_{im} \times t_{im} \div \delta_m + ST_m) \leq T_m \ \forall m \quad (8)$$
$$\sum_i^I \left(Z_{it} + ZX_{i,t-1}\right) \leq MZK_{it} \ \ \forall t \quad (9)$$
$$\sum_r^R \left(Z_{rt} + Z_{r,t-1}\right) \leq MZK_{rt} \forall t \quad (10)$$
$$ZX_{int} = ZX_{in,t-1} + X_{int} + UX_{int} \ \ \forall i, n, t \quad (11)$$
$$\sum_n^N X_{int} \geq \left(D_{it} + D_{i,t-1} - S_{it}\right) \forall i, t \quad (12)$$
$$\sum_n^N (X_{inr} \times VT_{inr}) \leq MKT_{nr} + MOT_{nr} \ \ \forall i, r \quad (13)$$
$$T_m \geq (k_m \times t_{im}) \ \forall m, i \quad (14)$$
$$Q_{ir} \times R_i \geq CQ_{ir} \times R_i \ , \forall r \quad (15)$$
$$\sum_i^I \sum_n^N UX_{it} \leq UK_{it} \ \ \forall u, t \quad (16)$$
$$X_i \geq 0; \ X_i \in Z \quad (17)$$

Equation (1) represents the objective function of the linear programming model. Its main goal is to minimize most the costs any production company has to deal with. The first part considers the variable production costs for current level of produced product including the resource procurement costs. The second and the third parts consider the inventory costs for both resources and final products. Transportation costs are also included. The final part of function represents the fixed production costs for each of the operable plants.

The first condition in the model (2) considers the availability of resources. The left part of inequality represents the amount of resources necessary to produce certain amount of product. This amount cannot be greater than total amount of resource available to company. In this model the term resource does not only include raw material, but it also includes machinery, labor factor and other (3).

For the needs of practical applications of model resource can only be nonnegative integer numbers. The third condition (4) specifies total amount of resource available to company. It consists of inventory of resource and of the amount of resource available on the market. These conditions have to be met for all resources used by production company.

Equation (5) controls the production capacity of company's plants. It ensures maintaining sustainable levels of production which are in accordance with the limits of capacity restrictions of plant. This condition needs to be met for every production facility. It considers also the fact whether the plant is opened and capable to operate normally in a given time period.

Next condition (6) considers the time restrictions for labor force. In this model we work with an assumption that each product is not produced by a single employee, but by a team of them. Therefore the equations describes the labor time of work teams. The amount of product produced by a single work team is multiplied by time it takes this team to produce one product. This total labor time of one team cannot be higher than the total labor working hours of particular team of employees. This condition has to be adhered for every labor team of employees and during the production of all types of products.

Equation (7) establishes the fulfillment of production plan. In an ideal case total amount of product produced as an outcome of a certain production process during the considered time period should be equal to the amount of produced product described in plan. This condition should be considered in terms of production of all types of products and for all time periods set in the plan.

The next condition (8) represents the time restrictions of machines involved in the production process. This inequality considers the time quota of product processed on a machine and the amount of product produced on this machine. It also includes the possibility that the machine does not operate correctly or without failure. Time restrictions also involve the set up and start up time of each machine. All these time requirements during the production process have to be lower than total number of machine working hours during a certain time period. This condition has to be met for every machine involved in the production process regardless of its location.

Equations (9) and (10) describe the capacity restrictions on inventory of resources and final products. The amount of inventory of a certain product cannot be higher than the maximal capacity of storage. This involves all products which are produced and stored by the company. Similarly this condition applies to the inventory of resources, especially raw material company needs as an input of its production process. Both of these restrictions take into account also the inventory from previous time period which has not yet been consumed or shipped out. In a case company uses one the production systems with no inventory policy (such as JIT for example), condition (10) is irrelevant. Equation (11) focuses on specifying the inventory of certain product in company's storage places.

Equation (12) considers the limitations set on the company by conditions on the market, in particular the demand of each product. The amount of produced product should be larger than the level of current demand and level of the unsatisfied demand from previous time period, but minus the supply of given product already on the market.

The next condition (13) establishes limitations for time capacity of resources. The average production time of one product multiplied by the amount of product produces has to be lower than maximal time of resource available including overtime capacity of resource available to the company if necessary. This limitation has to be met for all resources and during the production of all products.

Inequality (14) controls the operating time of machines. Number of production runs on machine during the time period multiplied by the time quota of one product processed on machine has to be lower than total number of machine working hours during the same time period. This condition has to be met for all machines involved in production process in all production plants. This condition also considers the fact that each product could have different production time.

Equation (15) represents the general quality restrictions for the structure of produced product. A certain percentage of quality parameter of resource has to obtained in the final product. Its level is set In the Bill of Material and also in production plan of company. This condition also works as foundation for determining the correct amount of resource needed to produce each product.

Transportation capacity is controlled by Equation (16). The amount of products designated for transport at the current time cannot be greater than capacity of all transportation vehicles. This condition has to be met for all produced products at all facilities.

Lastly for the needs of practical applications of described model the amount of product produced by company as an output of its production process has to be expressed as a nonnegative integer number (17).

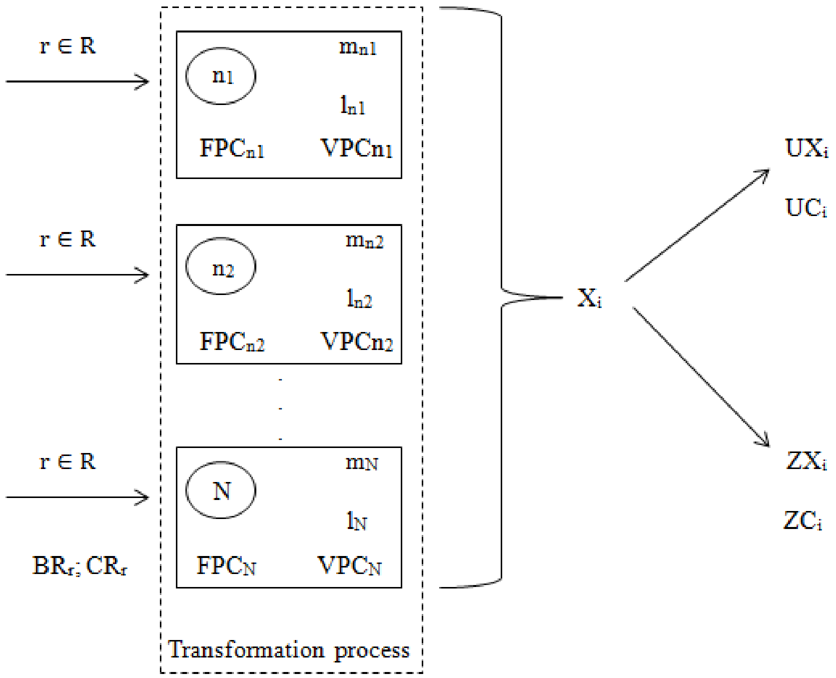

Diagram 1. The Schematic illustration of proposed model

In order to help with better understanding the proposed model a diagram can be created (Diagram 1).

4. Model Assessment

Proposed model described above considers following facts:

- Company produces multiple types of products, which are not homogeneous in their nature and structure;
- Production process takes place during multiple time periods;
- Transportation of resources and products;
- Company uses multiple types of inputs – raw material, labor, machinery etc. which enter the production process;
- Machinery – its production capacity, the duration of production runs and production process as whole including the set up times of machines;
- Company has multiple production plants; each with its own fixed production costs, possibilities to operate properly and different production capacity;
- Market – the supply and demand of each product and the unsatisfied demand from previous time period;
- Market of production factors – different prices and availabilities of each factor;
- Company's production plan, which in the ideal case should be adhered;
- Inventory – storage capacity for both final products and raw materials, costs of holding a certain amount of inventory of all products and resources.

Described model is general in its nature, which makes it possible to apply on any type of production process. Its main objective is to minimize production company's costs and to make production process more flexible. This model is based on linear programming. The generality of model also brigs many possibilities how to modify it and make it more suitable for a particular company and its production process. These modifications also provide ideas for future research of the subject. The few of the most significant possibilities of modification are as follows:

- Time approach – a more dynamic model can also consider the variations from average production time and enable to divide the production process into various stages;
- Some parameters cannot be described by a certain number. Therefore a fuzzy approach should be considered, since it enables certain parameters to be expressed as interval. This approach can be more accurate especially in terms of variables which are difficult to express or their values can only be determinate from data originated in previous time periods;

- Model does con consider the distribution plan in detail. Therefore one of the possible modifications can involve optimization of company's distribution plans and/or route optimization. Linear programming would be an effective tool in this case;
- Closer look into fixed production costs and their optimization. Some of the factors which influence their level can be evaluated;
- Resource allocation and optimization;
- Model does not consider the unfinished products in company, their storage, transportation and so on;
- One of the other unexplored areas are employees. Model does not consider specialization of employees. All teams of them are universal and there are no restrictions for substitutions.

5. Conclusions

This paper presents a linear programming model of integrating flexibility into production processes with cost minimization as its main objective. We chose linear programming as a modeling tool because of its generality. It is a well-known fact that the majority of problems in practice of production companies can be expressed as linear programming tasks. Our goal was to develop a model of production process which would be flexible in its nature and would also be able to ensure achievement of its main objective. Integrating flexibility measures into operations management is one of the new trends. Flexibility is especially important nowadays since the market conditions are changing rapidly and the whole economy is becoming very uncertain. Adaptability is becoming one of the key survival tools of the majority of companies. Flexibility can be one of effective measures developed in order to deal with both inner and outer uncertainties.

The proposed linear programming model of production process is quite general in its nature which makes it possible to apply it on any production process. It can be modified to make it more suitable. Few examples of possible modifications were also described in this paper. These examples also provide ideas for further research.

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