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Determination of bottlenecks in the production of wooden constructions

Every production process has issues to deal with. One of these problems is the issue of bottlenecks. It is possible to reveal them through the use of optimising models that are inseparable parts of every production process these days. This article discusses the revelation of these problems during the production process. As an example we have used the production of wooden constructions. It is possible to use mathematical models, which were produced and applied in MATHEMATICS 5 program, for the revelation of bottlenecks as well as for subsequent production planning with a view to avoiding their formation.

Keywords: manipulation with material, optimisation, wooden constructions, bottlenecks, mathematical methods

Introduction

For production control it is important to know how to design the most optimal solutions which are not money-consuming and at the same time make it possible to yield the highest possible profit. To ignore quality would mean to lose customers. Therefore quality should be a main priority. In order to make profit and maintain a high quality of products, it is necessary to design the production process with the lowest risks possible, both technically and technologically. To achieve this goal, it is possible to use a program that re-evaluates the already existing process and identifies its bottlenecks, thus allowing us to find possible solutions to the problems pointed out. The most suitable programs for that purpose are simulative optimisation programs.

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The solution to the problem of production process optimisation

A subsequent methodical order was designed to solve the issue of production process optimisation:

- analysis and appellation of basic optimisation conditions (technological, economical, time, qualitative and quantitative),
- the influence of each criterion on the progress of the optimisation process of material flow,
- mathematical model of optimisation,
- selection and evaluation of the most suitable solution.

In the first place it was necessary to define what was essential in order to optimise the process. The second step was to decide how to do it. We asked ourselves these questions and acted in accordance with the answers we arrived at.

First of all, from summary tables for the production of the desired number of constructions we created a matrix for the determination of the minimal machine load (the lowest possible number of machines used). We developed a work plan for each machine to find out what were the options of production of each component by number of machines defined by us. We based our work on a matrix that defined the components, machines and time of each machine needed for the production of construction components (we used different marking which we selected by defining linear programming).

Note: the mark $C_{m,n}$ means that matrix C has m-rows and n-columns.

Subsequently we created matrix B that described the number of components in every type of construction, as well as the price of constructions and the production time of one construction.

The solution for the production of wooden constructions GRINGO – IMAGO – PEDRO

Analysis of the production process of GIP constructions (GRINGO – IMAGO – PEDRO)

For analysis of the production process it was necessary to focus on the time data of production machines for each construction, which meant designing a matrix of each machine time required for production of constructions.

We knew/designed matrix C (table 1), which we also called the matrix of time consumed by each machine for the production of components. Columns from H1 to H31 present individual components and rows from S1 to S9 present machines; while the fields in the matrix are filled with values of production times of machine by each component. Matrix B (Tab.2) is a matrix of consumption of each component which includes the quantity of pieces of each component from H1 to H31 in each type of construction from D1 to D11 required to build a given construction.

$$C_{9,31} = (c_{ik}),\ c_{ik} \tag{1}$$

- the consumption of time of i-machine for the production of k-component

Table 1. Matrix C
Tabela 1. Macierz C

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24	H25	H26	H27	H28	H29	H30	H31	bi
S1	140	140	140	140	140	140	140	140	140	140	200	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	200	200	140	140	140	28800
S2	605	605	605	605	605	605	618	618	1226	618	613	605	605	605	605	605	615	605	615	605	605	605	605	605	605	605	613	613	613	605	605	28800
S3	240	240	240	290	290	290	180	180	155	180	0	340	440	415	340	155	155	230	205	280	330	530	180	205	230	505	0	0	180	0	0	28800
S4	188	188	188	280	290	290	154	154	0	154	154	178	178	154	142	0	142	0	0	0	0	0	0	0	0	0	154	0	142	192	192	28800
S5	0	0	0	0	0	0	0	0	133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28800
S6	0	0	0	0	0	0	0	0	720	0	0	0	0	0	0	840	0	0	0	0	0	0	0	0	0	0	0	0	720	0	0	28800
S7	0	0	0	0	0	0	0	0	0	720	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	720	720	0	0	0	28800
S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	145	145	145	145	145	145	145	145	145	0	0	0	0	0	28800
S9	36	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	36s	28800

$$B_{31,11} = (b_{kj}),\ b_{kj} \tag{2}$$

- the consumption of k-component for j-construction

Table 2. Matrix B
Tabela 2. Macierz B

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
H1	0	3	4	12	18	24	0	0	0	0	0
H2	1	1	4	12	18	24	0	0	0	0	0
H3	0	1	4	12	16	24	0	0	0	0	0
H4	0	0	1	8	12	16	0	0	0	0	0
H5	1	2	2	12	18	24	0	0	0	0	0
H6	0	0	3	12	18	24	0	0	0	0	0
H7	1	4	4	12	16	24	0	0	0	0	0
H8	0	2	4	12	16	24	0	0	0	0	0
H9	1	2	4	12	16	24	0	0	0	0	0
H10	4	4	4	12	20	24	0	0	0	0	0
H11	2	2	2	4	12	8	0	0	0	0	0
H12	0	0	0	0	0	0	1	6	0	0	0
H13	0	0	0	0	0	0	1	7	0	0	0
H14	0	0	0	0	0	0	2	4	0	0	0
H15	0	0	0	0	0	0	1	4	0	0	0
H16	0	0	0	0	0	0	3	6	0	0	0
H17	0	0	0	0	0	0	4	8	0	0	0
H18	0	0	0	0	0	0	2	4	0	0	0
H19	0	0	0	0	0	0	0	4	0	0	0
H20	0	0	0	0	0	0	2	4	0	0	0
H21	0	0	0	0	0	0	0	4	0	0	0
H22	0	0	0	0	0	0	0	6	0	0	0
H23	0	0	0	0	0	0	4	6	0	0	0
H24	0	0	0	0	0	0	1	4	0	0	0
H25	0	0	0	0	0	0	0	2	0	0	0
H26	0	0	0	0	0	0	0	1	0	0	0
H27	0	0	0	0	0	0	2	4	0	0	0
H28	0	0	0	0	0	0	20	50	0	0	0
H29	0	0	0	0	0	0	0	1	0	0	0
H30	0	0	0	0	0	0	0	0	0	0	168
H31	0	0	0	0	0	0	0	0	2	4	12

A matrix of time consumed by each machine to complete constructions was named $A_{9,11} = (a_{ij})$, where a_{ij} is time consumption of i-machine for completion of j-construction. From the above, it follows that it was necessary to find the components that defined matrix A (Tab. 3).

In the following step we searched for components a_{ij}.

$a_{ij} = c_{i1}.b_{1j} + c_{i2}.b_{2j} + ... + c_{i31}.b_{31j}$, so

$$A_{9,11} = C_{9,31} \times B_{31,11} \quad (3)$$

Table 3. Matrix A
Tabela 3. Macierz A

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
S1	1520	3060	5160	17040	25920	34080	7340	20740	6160	12320	25200
S2	6750	14093	24436	80552	119608	161104	26231	76185	26620	53240	108900
S3	1585	3890	7400	26260	38240	52520	4980	20715	0	0	0
S4	1556	3368	6142	22128	33432	44256	1682	5392	8448	16896	34560
S5	133	266	532	1596	2128	3192	0	0	0	0	0
S6	720	1440	2880	8640	11520	17280	2520	5760	0	0	0
S7	4320	4320	4320	11520	23040	23040	15840	38880	0	0	0
S8	0	0	0	0	0	0	1305	5075	0	0	0
S9	360	756	1296	4320	6480	8640	1548	4500	1584	3168	6840

Subsequently the mathematical model for analysis of the production process of constructions looked as follows [Fellnerová, Zimka 2000]:

$$\max z(x) = m.x \quad (4)$$

at the conditions

$$A.x \leq b, \quad x_j \geq 0 \quad (5)$$

where input data was:
m – vector of construction prices,
b – vector of dispositional times for each machine,
A – the matrix of time consumption of machines for construction completion.

The output was: x – vector of the production program
x_j – number of D_j.

The following programs were used for analysis: PRVYRGIP and VGIPOB.

1. Linear Programming PRVYRGIP (fig. 1) (this program optimises the production process; while its output is the number of constructions produced per month and the profit that can be made from sale of those constructions).
   In this program the input data is:

$$[\{-m\}A,\{b,-1\}\{l_1, l_2, ...l_n\}] \quad (6)$$

where $l_j \leq x_j$.

This optimisation program is used if there are no conditions set for constructions or if the user wants to have one construction made in a definite number of pieces and there are no conditions set for other constructions.

2. Linear Programming VGIPOB (fig. 2) (this program optimises the production process by restricting some of construction types).
   In this program the input data is:

$$[\{-m\}A,\{b,-1\}\{\{l_1,u_1\},\ \{l_2,u_2\}......\{\ l_n,\ u_n\}\}] \tag{7}$$

where $l_j \leq x_j \leq u_j$.

It is possible to use this program in the case when one type of construction has been cumulating in the warehouse, so the company does not need to produce it for some time. In this program the user defines the construction that is stored in the warehouse and the program recommends which constructions and at what cost should be produced. Also in this case the price and the number of each construction recommended by the production optimisation program are the input data.

In the first case the whole production program is changed ;– ,while in the second the production of some types of constructions is restricted and the production of other types is increased.

The results of the first program, i.e. PRVYRGIP, are presented in the following picture, showing the main position of the program that is the basis for optimisation as well as the most optimal solution:

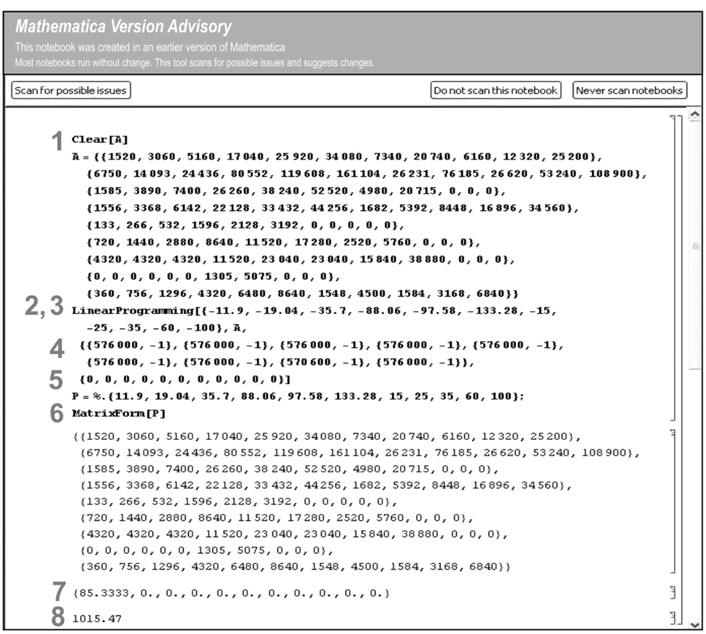

Fig. 1. Production program PRVYRGIP
***Rys. 1.* Program produkcji PRVYRGIP**

Key (*Legenda*):

1 – The matrix of time consumed by machines for completion of constructions,
Macierz czasu zużywanego przez maszyny na ukończenie konstrukcji,

2 – Linear programming,
Programowanie liniowe,

3 – Vector of construction prices,
Wektor cen konstrukcji,

4 – Vector of dispositional times of each machine,
Wektor czasów dyspozycyjnych każdej maszyny,

5 – Vector of restricting conditions of the production program,
Wektor warunków ograniczających program produkcji,

6 – Matrix P,
Macierz P,

7 – Vector of the optimal production program,
Wektor optymalnego prorgamu produkcji,

8 – Profit per month,
Miesięczny zysk.

The results of the second program, i.e. VGIPOB, are presented in the following picture which depicts the main position of the program that is the basis for optimisation and also the most optimal solution:

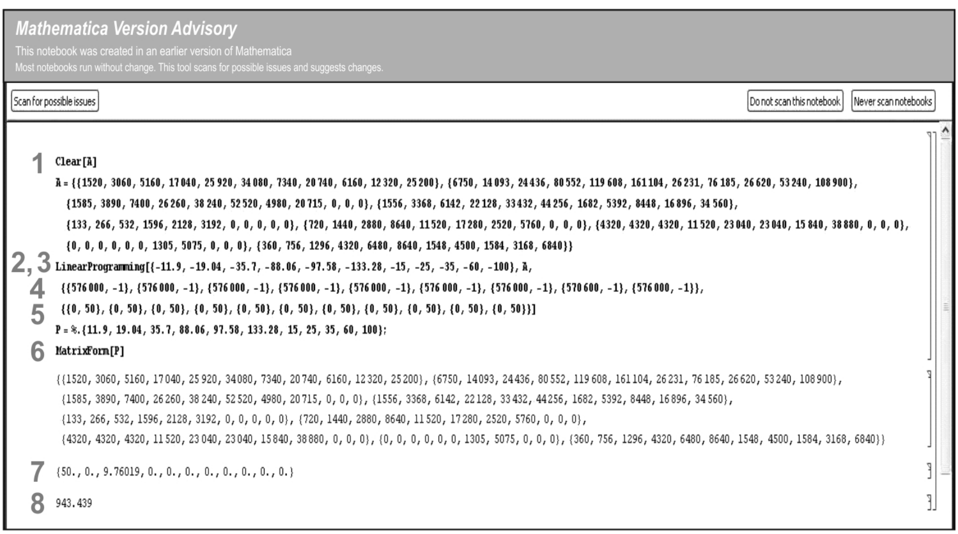

Fig. 2. Production program VGIPOB
Rys. 2. Program produkcji VGIPOB

Key (*Legenda*):

1 – The matrix of time consumed by machines for completion of constructions,
Macierz czasu zużywanego przez maszyny na ukończenie konstrukcji,

2 – Linear programming,
Programowanie liniowe,

3 – Vector of construction prices,
Wektor cen konstrukcji,

4 – Vector of dispositional times of each machine,
Wektor czasów dyspozycyjnych każdej maszyny,

5 – Vector of restricting conditions of the production program,
Wektor warunków ograniczających program produkcji,

6 – Matrix P,
Macierz P,

7 – Vector of the optimal production program,
Wektor optymalnego prorgamu produkcji,

8 – Profit per month,
Miesięczny zysk.

Should the chosen production program be impossible to implement, the program returns a mistake in the linear programming.

In the end we can see that the production program has a bearing not only on the profit from product sale, but also on the composition and consumption of the production resources. As previously mentioned, in the case considered here, the program also affected the time disposal of each machine.

In order to examine the fatigability of each machine, time limits we added to PRVYRGIP program the command: Q = A.Out[v], where *v* means the number of output from the computer which determines a relevant production optimisation program (fig. 3).

The following results were achieved for the most optimal production program:

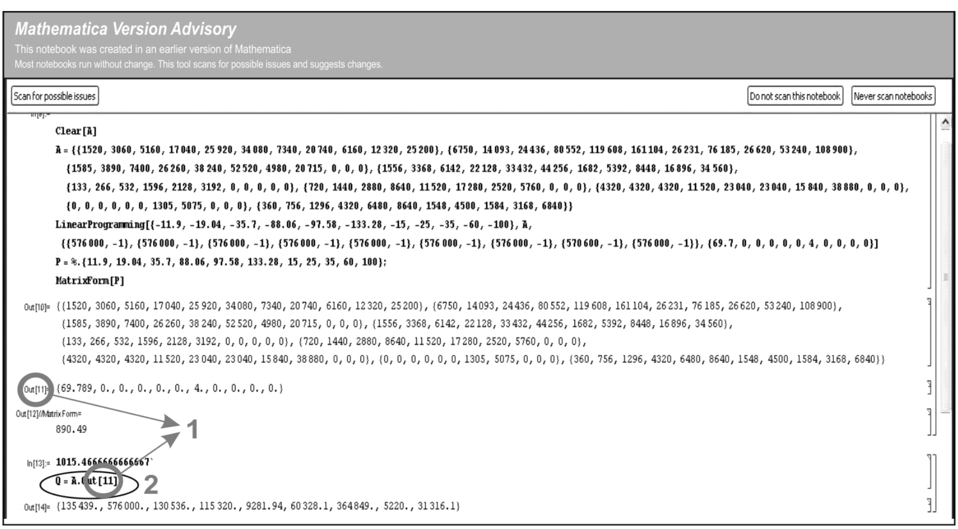

Fig. 3 Production program 1
Rys. 3 Program produkcji 1

Key (*Legenda*):

1 – Command added: Q = A.Out[v],
Polecenie dodane: Q = A.Out[v],

2 – Out[v] (in this case 11),
Out[v] (w tym przypadku 11).

Conclusions

The mathematical optimisation programs created confirmed that it is possible to reveal bottlenecks by planning, as well as to avoid them. Constructions and their production were good examples of model situations of production planning. MATHEMATICS 5 program proved to have been a good tool, thanks to which it was possible to use mathematical optimisation programs. The programs of linear programming, i.e. PRVYRGIP and VGIPOB, helped us reveal bottlenecks and plan production in a way to avoid them. Therefore, while designing material flows, all technologists, not only those from the wood processing industry, should base their designs on mathematical models. Already in the stage of idea creation it is necessary to think about the production process and potential difficulties. Product quality is created already in the design stage and refined in production. It is very important to create mathematical models of such difficult systems, so as to be able to optimise the production process in the best way possible and at the same time maintain the highest quality possible and set the lowest price. The mathematical model we created and used, is suitable not only for the production of toys or constructions, but also for the any type of production in the wood processing industry, provided that more than one product is manufactured.

References

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OKREŚLENIE WĄSKICH GARDEŁ W PRODUKCJI KONSTRUKCJI DREWNIANYCH

Streszczenie

W każdym procesie produkcyjnym pojawiają się problemy, z którymi trzeba sobie poradzić. Jednym z tych problemów jest zagadnienie wąskich gardeł. Ich identyfikacja jest możliwa dzięki wykorzystaniu modeli optymalizacyjnych, będących obecnie nieodłącznymi elementami każdego procesu produkcyjnego. W niniejszym artykule omówiono identyfikację tych problemów już w trakcie procesu produkcyjnego. Za przykład posłużyła produkcja konstrukcji drewnianych. W celu identyfikacji wąskich gardeł, jak również planowania produkcji, w taki sposób aby ich uniknąć, możliwe jest wykorzystanie modeli matematycznych, które autorzy opracowali i zastosowali w środowisku programu MATHEMATICS 5.

Słowa kluczowe: manipulacja materiałem, optymalizacja, konstrukcje drewniane, wąskie gardła, metody matematyczne