

MATERIAL FLOW OPTIMIZATION THROUGH MODELLING AND SIMULATION IN THE SOFTWARE TOOL TX PLANT SIMULATION

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Abstract: The article is oriented on the optimization of material flow through modelling and simulation in the software tool Tx Plant Simulation. The company in which optimization was realized is engaged in production of plastic and aluminum windows and doors. The aim of optimization was to propose production disposition which would provide the production productivity increase, since company expands its activity portfolio also to foreign markets. Part of the proposal is evaluation and return on investment of the proposed production disposition, specifically, the calculation of economic efficiency of investments through indicators: net present value, index present value, discounted payback period, discounted economic value added DEVA. The estimated values of these characteristics are further used for the economic evaluation of investment costs and benefits of these proposals.

1 Introduction

The company which is the subject of the case study is a company engaged in the production and sale of plastic windows and doors. It focuses mainly on the Slovak market, but in recent years it began to work also with foreign countries. The main objective of the company is to deliver quality products at a reasonable price and in time. The products are made of quality materials and compliance with technological processes, allowing them to ensure high quality products with minimal complaints.

The company has one production hall, which produces plastic and aluminum windows and doors. The offices are in the hall. Warehouses are directly in the production hall. Great attention is paid to assembly work, since improper installation of the most common causes the reduction of product quality and comfort of use.

The company has one production factory (Fig.1), which produces plastic, and aluminum windows and doors. The offices are in the hall. Warehouses are directly by the production hall, but also inside of it (Fig.2). Materials storage works on electronic customer's orders, which are processed by software. This software is not

connected with production. After that, process engineer create the technological procedure. Storekeeper orders the material which is necessary for processing the contract.

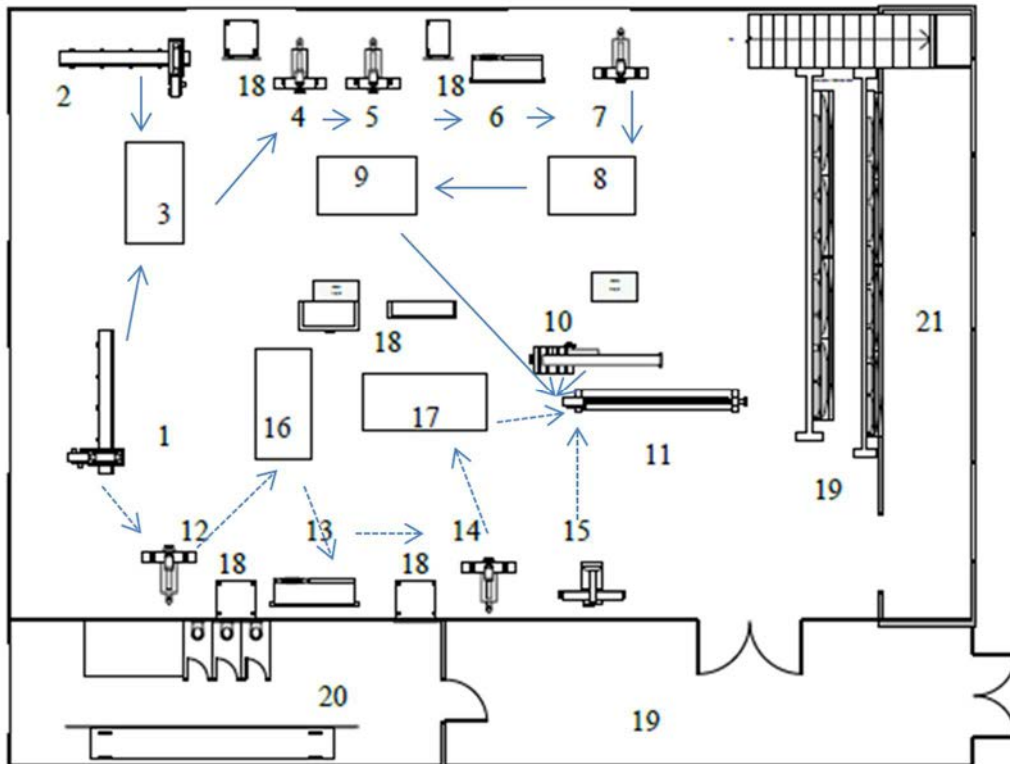
Company disposes with production hall, where plastic and aluminum windows and doors are produced. Parts of the production hall are also warehouses and offices (Fig. 1). is a plan view of the hall. There are shown the different workplaces, warehouses, locker rooms, and offices.

A flow chart elaborated in Tab. 1 shows the sequence of technological operations of the manufacturing process for the production of plastic windows. It is important for the analysis of material flow to monitor:

- individual transactions in the context of production activities in terms of type and time,
- handling activities and methods of transportation, storage,
- control quality and quantity,
- organizational provisions for the particular motion, waiting, idle time, etc.

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Legend: 1. CNC saws, 2. belt hacksaw, 3. work desk with drill, 4. cutter, 5. drill, 6. welder double-barreled, 7. cutter, 8. work desk with neatening cutter, 9. work desk with drill, 10. saw on glazing bars, 11. roller track, 12. saw on metal, 13. cutter, 14. the single-press, 15. saw on glazing bars, 16. workbench with neatening cutter, 17. workbench with drill, 18. tool cabinets, 19. warehouses, 20. dressing rooms, 21. Offices, 12. saw on metal

Figure 1 Ground plan of the production hall of the company



Figure 2 Production hall and warehouses of the company

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Table 1 Flow chart of window production

Num.	Type activity of	Symbol of operations							Time [min]
		operation	transport	control	X un/loading	storage	packing	waiting	
1.	Sawing of plastic profiles								15
2.	Cutting of reinforcement								15
3.	Completion								25
4.	Milling								10
5.	Drilling								7
6.	Welding								22
7.	Machining of corners								15
8.	Bonding of gaskets								30
9.	Montage of fitting								45
10.	Cutting of glazing beads								15
11.	Glazing								30
12.	Final testing								12
13.	storage and transportation								-

Simulation time: 8:00:00.0000

Cumulated Statistics of the Parts which the Drain Deleted

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
vystup	hlinikove_okno	28:16.8821	22	3	99.59%	0.41%	0.00%	99.01%	
vystup	plastove_okno	31:05.8623	19	2	99.62%	0.38%	0.00%	90.04%	

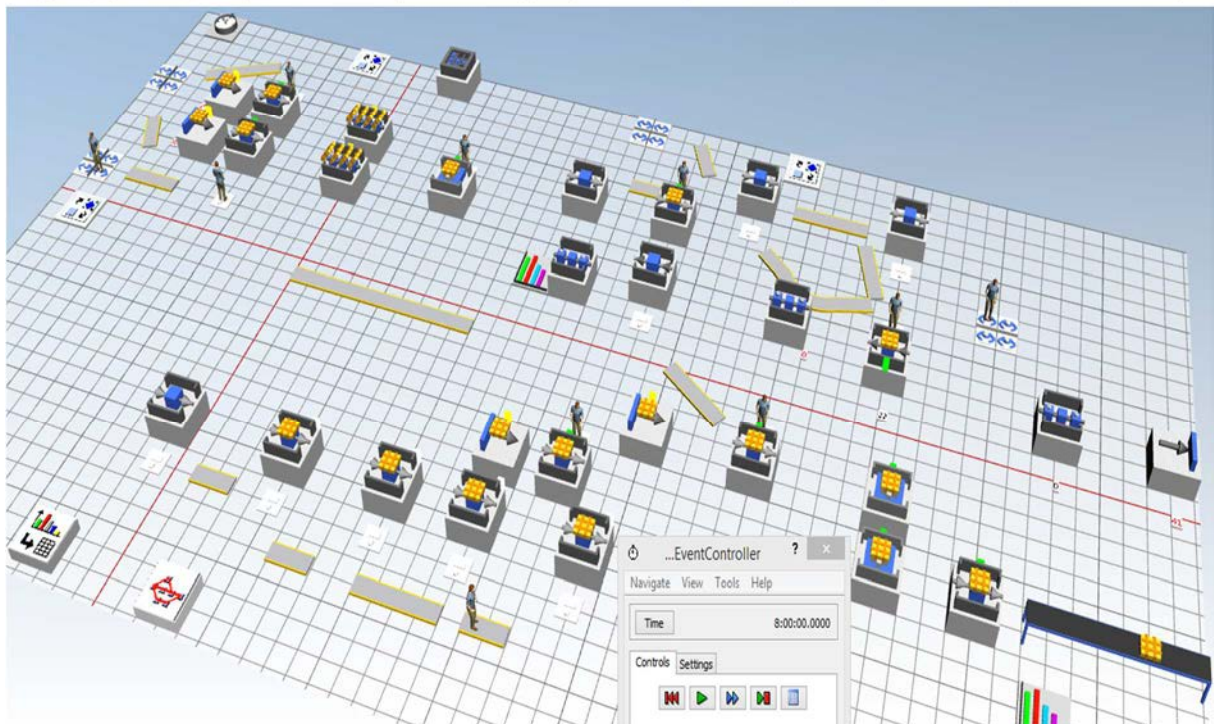


Figure 3 Production hall of the company modelled in Tx Plant Simulation in 3D

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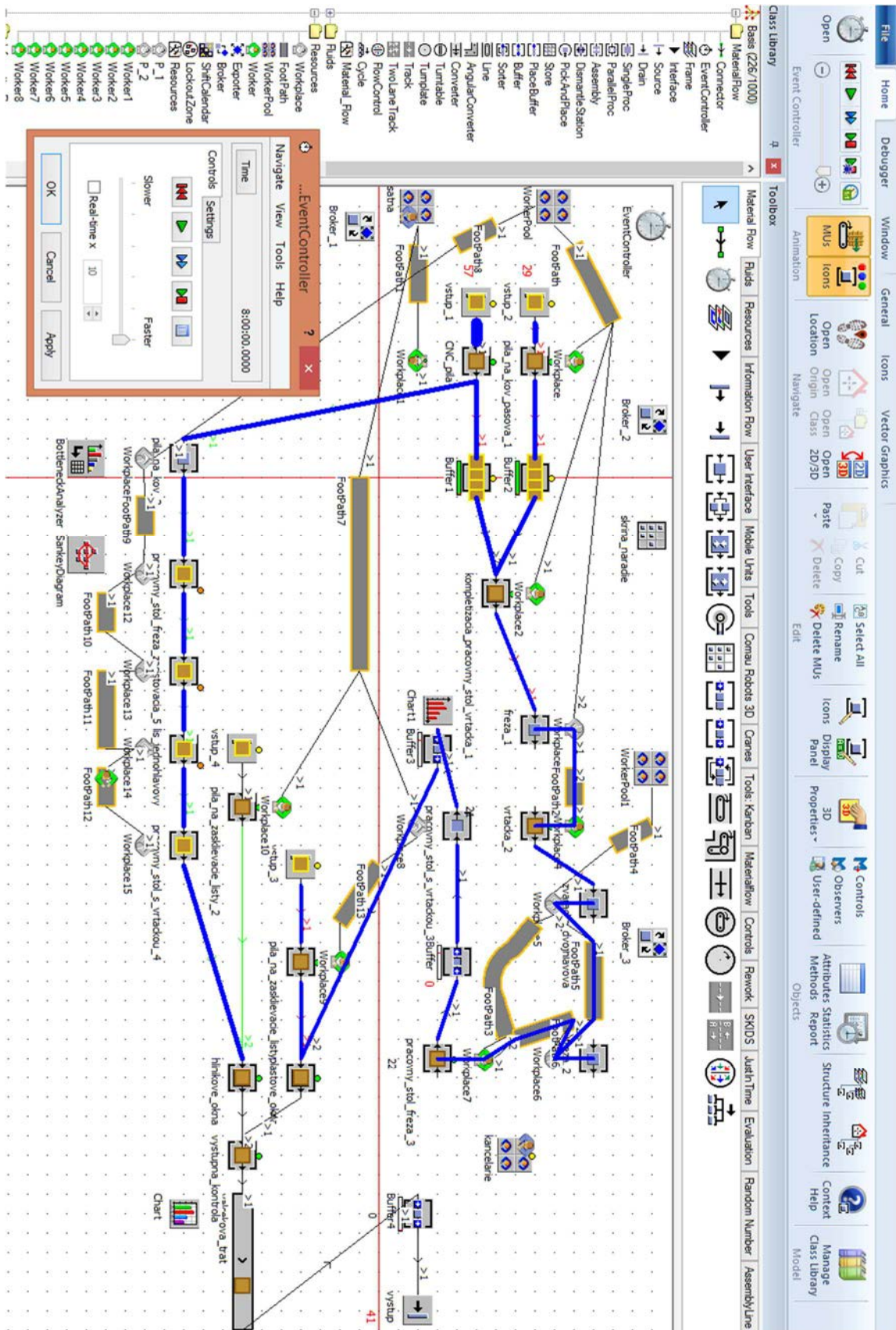


Figure 4 Production hall of the company modelled in Tx Plant Simulation

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Table 2 Time portions of the workers in Tx Plant Simulation

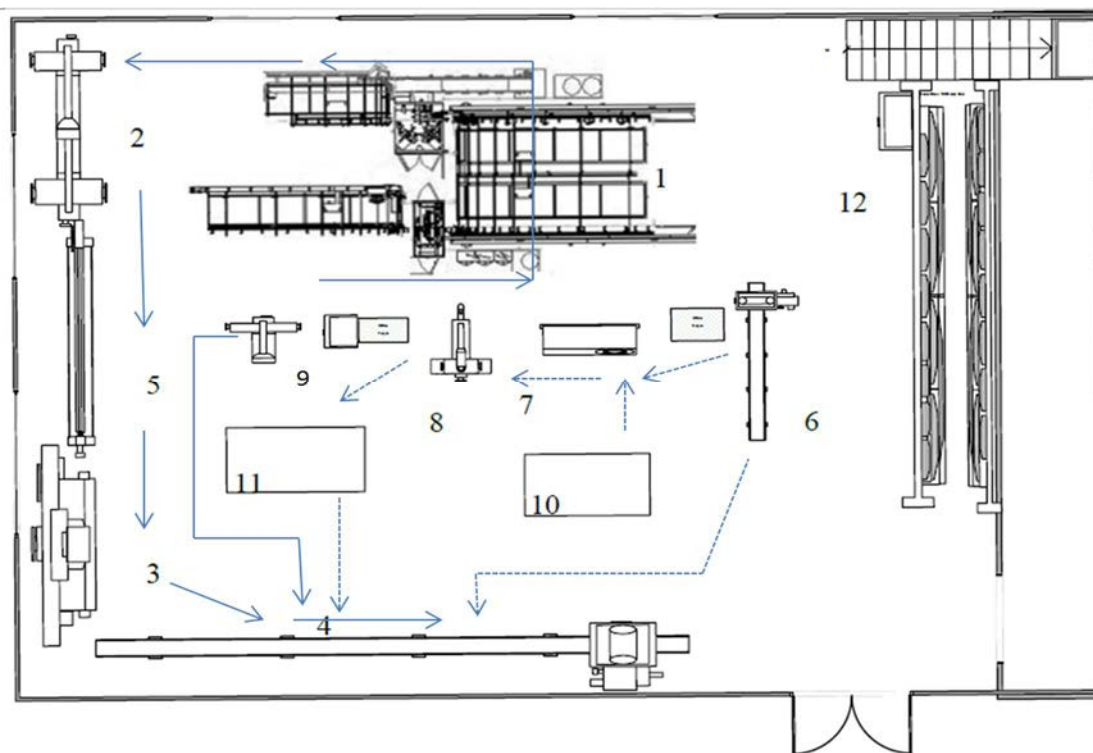
	Working	Setting-up	Repairing	Transporting	En-route to job	Waiting for Importers	Waiting for MUs Failed		
Worker8	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	
Worker	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	
Worker1	59.57%	0.00%	0.00%	0.00%	0.01%	40.42%	0.00%	0.00%	
Worker2	82.90%	0.00%	0.00%	0.00%	0.01%	17.09%	0.00%	0.00%	
Worker4	97.07%	0.00%	0.00%	0.00%	0.01%	2.92%	0.00%	0.00%	
Worker3	47.06%	0.00%	0.00%	0.10%	0.10%	52.74%	0.00%	0.00%	
Worker6	90.18%	0.00%	0.00%	0.33%	0.30%	9.20%	0.00%	0.00%	
Worker8	5.02%	0.00%	0.00%	0.00%	0.02%	94.96%	0.00%	0.00%	
Worker5	50.42%	0.00%	0.00%	0.00%	1.09%	48.50%	0.00%	0.00%	
Worker7	89.15%	0.00%	0.00%	0.00%	0.33%	10.52%	0.00%	0.00%	

The result of the analysis of material flow of plastic windows in the company is concerned to the fact, that if a company wants to increase its productivity from about 30 windows per day to at least 80 windows per day, it will be necessary to optimize production disposition and propose a new production line, Fig.3 and Fig. 4 and Tab. 2. To increase productivity, factory needed to rationalize the

material flow through the simulation program Tx Plant Simulation.

Aim was to:

- eliminate unnecessary handling,
- increase production productivity,
- ensure proper working conditions and safety at work,
- optimize in-process handling and storage.



Legend: 1. STBAZ PVC 300 X-Slicers and machining center, 2. SE-VSM-CS-Vertical quadriceps welder, 3. FBS-2M-H - Semi screwdriver to screw the fitting components to the wing 4. Fixus D-Control and glazing unit, 5. ELAN OS- retaining wall, 6. Hacksaw, 7. cutter, 8. the single-press, 9. Saw on glazing bars, 10. Workbench with unique debarring cutter, 11. Work desk with a drill, 12. Tool cabinets

Figure 5 Production hall with the proposed production line

The proposed production line needs four employees to operate the machinery. It's lead to a reduction in the number of employees from the eight staff allocated to the production of plastic windows to 4. Fig. 5 shows the flow of materials between workplaces. Material flow of plastic

windows is marked in red, material flow of aluminum products is marked in dashed line.

Optimization of the production process was elaborated with help of software support TX Plant Simulation, Fig. 6 and Fig. 7. It is a view of placement some particular workplaces, needs of workers' and views of material flow

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in the form of Sankey diagram, which reflects the intensity of flow between the different workplaces.

With the investment in this range company will shorten the production process, reduce scrap, improve the quality of their products, and increase productivity. It will

be able to expand into foreign markets, such as Poland, Czech Republic. Also reduce the number of production workers from 8 to 4, which will have the effect of reducing labour costs. The result is an increase of income.

Simulation time: 8:00:00.0000

Cumulated Statistics of the Parts which the Drain Deleted

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
vystup	hlinikove_okna	12:24.7130	47	6	98.97%	0.81%	0.22%	88.62%	
vystup	plastove_okna	13:57.8330	37	97.32%	0.72%	1.97%	78.77%		

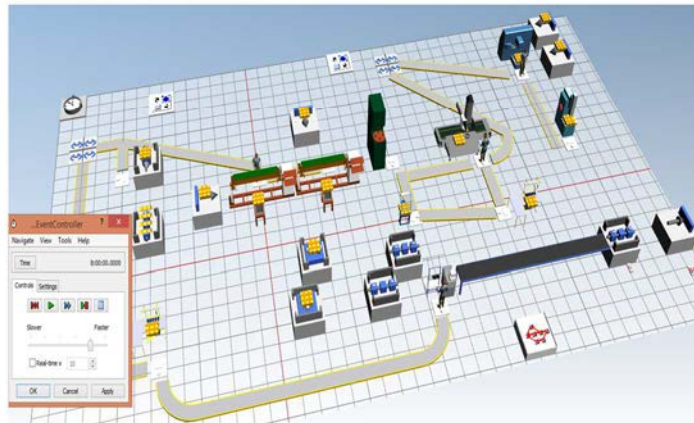


Figure 6 Production hall with the proposed production line in 3D

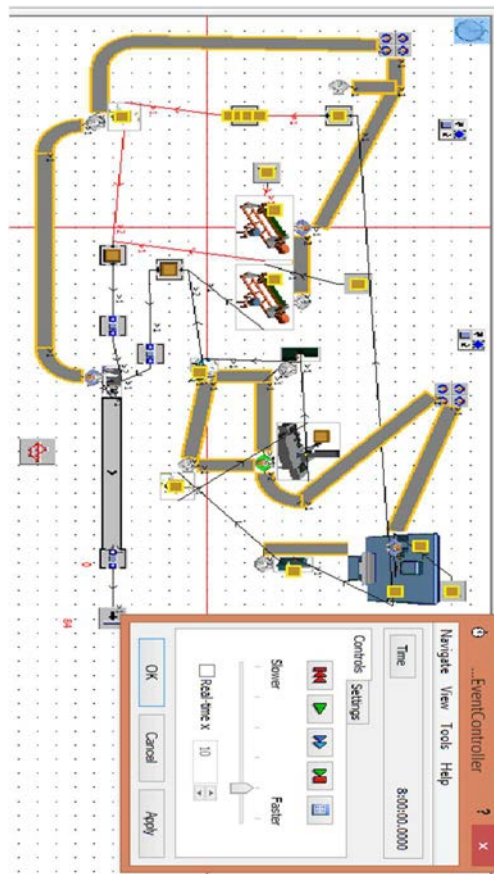


Figure 7 Production hall with the proposed production line

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Resource statistics as listed in Tab. 3, Tab.4 gives an overview of capacity utilization as well as downtimes of individual machines and equipment for the production of plastic and aluminum windows. It is a statistical summary

of production during the course of an eight-hour work shift. Summary statistics indicate the number of pieces that have been produced and the time of production, transportation and storage expressed as a percentage.

Table 3 Time portions of the workers in Tx Plant Simulation after optimization

	Working	Setting-up	Repairing	Transporting	En-route to job	Waiting for Importers	Waiting for MUs	Failed
Worker4	12.36%	0.00%	0.00%	0.00%	1.40%	86.24%	0.00%	0.00%
Worker1	29.58%	0.00%	0.00%	0.00%	1.23%	69.19%	0.00%	0.00%
Worker6	98.50%	0.00%	0.00%	0.00%	1.20%	0.30%	0.00%	0.00%
Worker2	27.71%	0.00%	0.00%	0.00%	2.14%	70.15%	0.00%	0.00%

Table 4 Resource statistic in Tx Plant Simulation after optimization

Cumulated Statistics of the Parts which the Drain Deleted

Object	Working	Set-up	Waiting	Stopped	Failed	Paused	Mean Life Time	Mean Exit Time	Total Throughput	Throughput per Hour	Throughput per Day
vystup	84.76%	0.00%	15.24%	0.00%	0.00%	0.00%	13:05.7301	5:32.6095	84	10.5	252

Part Types which the Drains Deleted

Object	All Types	hlinikove_okna	plastove_okna
vystup	84	47	37

Detailed Statistics of the Part Types Which the Drain Deleted

vystup	Production						Transport						Storage							
	Working	Set-up	Waiting	Stopped	Failed	Paused	Sum	Working	Set-up	Waiting	Stopped	Failed	Paused	Sum	Working	Set-up	Waiting	Stopped	Failed	Paused
hlinikove_okna	88.62%	0.00%	10.35%	0.00%	0.00%	0.00%	98.97%	0.81%	0.00%	0.00%	0.00%	0.00%	0.81%	0.00%	0.00%	0.22%	0.00%	0.00%	0.00%	0.22%
plastove_okna	78.77%	0.00%	18.54%	0.00%	0.00%	0.00%	97.32%	0.72%	0.00%	0.00%	0.00%	0.00%	0.72%	0.00%	0.00%	1.97%	0.00%	0.00%	0.00%	1.97%

vystup	Life Time					Exit Time					Throughput	
	Mean Value	Standard Deviation	Minimum	Maximum	Sum	Mean Value	Standard Deviation	Minimum	Maximum	Total Per Hour	Per Day	
hlinikove_okna	12:24.7130	27.2623	12:19.1737	15:22.5978	10:00.1432	9.4462	9:31.7228	10:28.2772	47	5.875	141	
plastove_okna	13:57.8330	2:45.1775	13:14.3832	29:52.7912	12:08.3832	56.1849	10:02.7682	14:13.9983	37	4.625	111	

Portions of the States

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
vstup_2	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
narezove_obračacie_centrum	3.40%	0.00%	10.36%	86.24%	0.00%	0.00%	0.00%	0.00%	0.00%	
stvorhlava_zvaracka	11.25%	0.00%	2.74%	86.01%	0.00%	0.00%	0.00%	0.00%	0.00%	
vstup_1	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
poloautomaticky_skrutovac	10.21%	0.00%	2.42%	87.37%	0.00%	0.00%	0.00%	0.00%	0.00%	
vystupna_kontrolna	17.50%	0.00%	82.50%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
pila_na_kov	8.96%	0.00%	0.90%	90.14%	0.00%	0.00%	0.00%	0.00%	0.00%	
freza	41.67%	0.00%	58.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
jednohlavovy_lis	8.13%	0.00%	91.88%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
pila_na_zasklievacie_listy	10.21%	0.00%	10.64%	79.15%	0.00%	0.00%	0.00%	0.00%	0.00%	
pracovny_stol_zacistovacia_freza	8.54%	0.00%	91.46%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
pracovny_stol_vrtacka	40.17%	0.00%	59.83%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
oporna_stena	0.00%	0.00%	2.30%	97.70%	0.00%	0.00%	0.00%	0.00%	0.00%	
valcekova_trat	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
vystup	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
vstup_3	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
hlinikove_okna	99.12%	0.00%	0.88%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer1	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer2	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Source	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
pila_na_zasklievacie_listy_1	8.13%	0.00%	2.74%	89.13%	0.00%	0.00%	0.00%	0.00%	0.00%	
plastove_okna	79.16%	0.00%	20.84%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Simulation time: 8:00:00.0000

Cumulated Statistics of the Parts which the Drain Deleted

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2 Economic efficiency evaluation of the proposed production disposition,

The price of production line is 320 000 €, costs associated with installation, shipping is 2 000 €. The company can invest 40% from the price, it represents 128 800 €. The remaining 60%, which amounts to 193 200 €, would have asked for a loan from the bank for six years, the other inputs data are in Tab. 5.

Table 5 Inputs data

price of the production line	320 000 €
costs related to installation, transportation	2 000 €
own resources	128 800 €
external resources	193 200 €
time of the loan	6 years
interest rate	6 %
installment	the same height
depreciation group	2
required rate of return	11%

increase in net working capital	o 1 000 €/for 6 years
number of pieces per year	18 000 pieces
price	220 €/ pieces
WACC	11%

The calculation of labour costs:

- for 1 worker:
 - o number of hours of one worker 1687,5 hours.
 - o hourly wage is 3,20 €
 - o annual costs for hourly wage is 5 400 €.
- for 8 workers:
 - o -8 hours for workers is 13 500 hours.
 - o hourly wage is 3,20 €.
 - o annual costs for hourly wage is 43 200 €.

Labour costs would be 21 600 €. In Tab. 6 there is composed of repayments for a period of six years.

Table 6 Repayment Schedule

Year	State of the loan	Installment of the loan	Payment of interest	Annuity
1.	193200,00	27697,66	11592,00	39289,66
2.	165502,34	29359,52	9930,14	39289,66
3.	136142,82	31121,09	8168,57	39289,66
4.	105021,73	32988,36	6301,30	39289,66
5.	72033,37	34967,66	4322,00	39289,66
6.	37065,72	37065,72	2223,94	39289,66
Σ		193200,00	42537,96	235737,96

After the completion of the repayment plan (with the same amount of total payments) payment will get the sum 39 289,66 €. The total loan amount is 235 737,96 €.

Quantifying the expected costs and benefits:

Revenues: 3,960,000 € (unit price x volume)

Cost:

- + direct materials: 2 340 000 € (130 €*18 000 pieces)
- + direct salary: 21 600 € (6750 hrs.*3.20 €)

+ indirect materials: 18 000 € (10 €*18 000 pieces)

+ energy: 25 500 € (0.3 €/kWh*85 000 kWh)

Σ 2 405 100 €, the cost is 133.6 €/window.

Tab.7 contains calculations that are needed to determine the annual cash receipts, net present value, index, and present value discounted payback period.

Table 7 Calculations for net present value, index present value, discounted payback period

Indicator	1	2	3	4	5	6
Revenue	3 960 000	3 960 000	3 960 000	3 960 000	3 960 000	3 960 000
-Costs	2 405 100	2 405 100	2 405 100	2 405 100	2 405 100	2 405 100
-Depreciation	53666,67	53666,67	53666,67	53666,67	53666,67	53666,67
Gross profit	1501233,33	1501233,33	1501233,33	1501233,33	1501233,33	1501233,33
-Income tax (19%)	285234,33	285234,33	285234,33	285234,33	285234,33	285234,33
Net profit	1215999	1215999	1215999	1215999	1215999	1215999
+Depreciation	53666,67	53666,67	53666,67	53666,67	53666,67	53666,67
- Net working capital	1000,00	1000,00	1000,00	1000,00	1000,00	1000,00
Annual cash income	1268665,67	1268665,67	1268665,67	1268665,67	1268665,67	1268665,67
i=0,11	0,9009	0,8116	0,7319	0,6587	0,5935	0,5346
Discounted	1142940,90	1029649,06	928536,40	835670,08	752953,07	678228,67

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payback period						
Cumulated DPP	1142940,90	2172589,96	3101126,36	3936796,43	4689749,51	5367978,17

Annual cash income of 1 268 665,67 €.

The net present value (1):

$$\check{C}SH = \sum PPn * \frac{1}{(1+i)^n} - KV \quad (1)$$

NPV = 5367978,17- 322 000
 NPV = **5045978,17 €**- Investment is acceptable.

Discounted payback period (3):

$$DDN = \sum PPn * \frac{1}{(1+i)^n} = KV \quad (3)$$

$$DDN = 0 + \frac{322000}{1142940,90} = 0,28$$

Index present value (2):

$$ISH = \frac{\sum PPn * \frac{1}{(1+i)^n}}{KV} \quad (2)$$

$$ISH = \frac{5367978,17}{322000} = 16,67$$

IPV = **16,67 €**- 1 €the investment will bring € 16.67.

DPP = **0,28** year.

Annual cash income reaches 1 268 665,67€. Net present value is a positive value of 5 045 978,17€, the investment is acceptable. Index of present value is 16.67€, bringing one euro invested. Payback period is 0.28 years. By help of indicator DEVA/discounting the economic value added is determined whether the market value of the company will grow. The procedure of the calculation for DEVA is in Tab.8.

Table 8 Calculations for DEVA

Indicator	1	2	3	4	5	6
Revenue	3 960 000	3 960 000	3 960 000	3 960 000	3 960 000	3 960 000
-Costs	2 405 100	2 405 100	2 405 100	2 405 100	2 405 100	2 405 100
-Depreciation	53666,67	53666,67	53666,67	53666,67	53666,67	53666,67
Gross profit EBIT	1501233,33	1501233,33	1501233,33	1501233,33	1501233,33	1501233,33
-Income tax (19%)	285234,33	285234,33	285234,33	285234,33	285234,33	285234,33
Net profit NOPAT	1215999	1215999	1215999	1215999	1215999	1215999
C	322000	268333,33	214666,66	160999,99	107333,32	53666,65
C*WACC	35420	29516,6663	23613,3326	17709,9989	11806,6652	5903,3315
EVA	1180579	1186482,33	1192385,66	1198289,00	1204192,33	1210095,67
i=0,11	0,9009	0,8116	0,7319	0,6587	0,5935	0,5346
DEVA	1063583,62	962949,06	872707,07	789312,96	714688,15	646917,14
						Σ 5050158

DEVA is 5 050 158,00 €, which means that DEVA > 0 - the investment is acceptable, the market value of the company will grow.

From the optimization of production line of company, benefits are following:

- increasing the production of 30 windows of at least 80 windows per day, representing an impact of 166,6%;
- reducing the number of employees from 8 to 4, saving staff costs is 21 600 €,
- return on investment in the production of 80 windows per day is 0,28 years,
- one euro invested would give 16,67 €,
- the company's market value will increase,

- speedier customer orders,
- possibility of involvement in demanding projects,
- penetration into foreign markets,
- increasing quality of product.

Conclusions

To increase the productivity in the context of increasing the efficiency of the production process of plastic and aluminum windows and doors, as a whole, there was processed draft of the measures to optimize material flow in software program TX Plant Simulation.

The optimal solution is related to the introduction of a new production line. This software was helpful in the process of design and appreciation by comparison with

MATERIAL FLOW OPTIMIZATION THROUGH MODELLING AND SIMULATION IN THE SOFTWARE TOOL TX PLANT SIMULATION

Peter Trebuňa; Miriam Pekarčíková; Andrea Petříková; Radko Popovič; Marek Kliment

the default state. Chosen production facilities were allocated to the production hall of the company in area of Tx Plant Simulation. The principal value of the simulation is that the proposed solutions allow you to check prior to their implementation and to identify possible errors. Direct intervention into the production process would initiate significant expenses.

Evaluation of investment measures is an important part of a comprehensive process of optimization. This is a quantification of economic indicators which help to assess the proposed solutions and prepare a basis for decision-making in relation to planned changes in the company. The case study focused specifically to quantify labor costs, net present value, index, present value, discounted payback period, and determining whether the investment would increase the market value of the company. Based on the above facts it can be concluded that the proposed measures would certainly contribute to the optimization of material flow and increase the productivity of the enterprise.

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MONTE CARLO SIMULATION FOR ANOVA

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Keywords: One-way ANOVA, simulation, Monte Carlo method

Abstract: The article we will present Monte Carlo simulation for assessing consequences of data non assumption. Analysis of variance (ANOVA) is used to determine whether there are any significant differences between the means of three or more independent (unrelated) groups. Fundamental assumption for ANOVA is that the independent variable is normally distributed and groups with equal variances. Monte Carlo simulation we observed Type I. error rate of analysis of variance.

1 Introduction

Using quantitative mathematical or statistical model looking for the best optimal solution. In practice it is often unrealistic to find an optimal solution, for example, there are used the basic conditions of the methods. It is possible to use simulating models to solve these situations. Simulating real problems is one of the most frequently used approach that facilitates decision-making. The simulation model generally shows a system modeled using mathematical formulations and logical relationships. In the model we distinguish between a random input to control, that is transformed to output model. For the simulation experiment in the beginning you select controlled access and random (stochastic) inputs are randomly generated.

Simulations are among the quantitative tools that can be used for decision support. Simulation of work with a particular model is an experiment with the model. It is a subset of simulation modeling allows broaden the scope of the investigation and of the specific model types. Monte Carlo simulation method is known that uses a large number of randomly generated samples from the probability distribution that is used for computer simulation solutions to various managerial problems from mathematics, physics, financing, design, sales, human resources, psychology and other [1], [2].

In statistical theory, we meet two basic types of methods: parametric and nonparametric. Parametric methods (tests) are characterized in that they comply with certain assumptions. If you fulfill the requirements of the methods, such as processed data come from a normal distribution, statistical methods offer an effective and valid estimates of the probability distribution of statistics [3]. When the theoretical assumptions do not examine data, then the validity of the statistics reliable estimates of the probability distribution is uncertain. In such situations, it is possible to use Monte Carlo simulations [4], [5]. This method favors empirical estimates statistics probability distribution file prior theoretical expectations on these figures. The essence of Monte Carlo method is that it

generates numerous scenarios studied a random file. Using Monte Carlo simulation can demonstrate how to approach the theoretical results. In this paper, the Monte Carlo method applied to a situation where the assumptions are not met statistical methods, namely analysis of variance (ANOVA).

Monte Carlo method comprises the following steps:

- Determine the objective of the simulation.
- Propose appropriate methods of Monte Carlo.
- On the basis of concrete statistics randomly generated data.
- Implement quantitative methods.
- Quantify the necessary statistics.
- Simulation contrary (eg. 100 to 1 000,000 times).
- Analysis of statistics found.
- Assess the results obtained by the methods of Monte Carlo.

2 One-way ANOVA

The One-way ANOVA (analysis of variance) is used to determine whether there are any significant differences between the means of three or more independent (unrelated) groups. The one-way ANOVA compares the means between the groups you are interested in and determines whether any of those means are significantly different from each other [6]. Specifically, it tests the null hypothesis (1):

$$H_0: \mu_1 = \mu_2 = \mu_3 = \dots = \mu_k \quad (1)$$

and then $H_1: \text{non } H_0$

where μ - group mean and k - number of groups. If, however, the one-way ANOVA returns a significant result, we accept the alternative hypothesis (H_1), which is that there are at least two group means that are significantly different from each other. Its aim is to detect whether any differences between the means for these files are statistically significant or only incidental. Analysis of variance was trying to figure out which of quantitative or

qualitative factors significantly influence the monitored variables.

The basic assumptions for the use of analysis of variance include:

- Independence of observations - the individual selections are independent of each other.
- Normality of sampling distribution - the samples come from a core set of normal distribution.
- Homogeneity of variance (homoscedasticity) – equal variances.

Number of factors examined by analysis of variance divided on:

- One-way analysis of variance - if the observed effect of one factor.
- Multi-factorial analysis of variance - for the monitoring of the impact of several factors.

According to distinguish the range of sample:

- Balanced model - if the coverage is the same sample.
- Unbalanced model- if different range of sample.

Random selection of independence is considered logically and ensure the appropriate selection of files. To verify in practice the second and third condition. Whether the results are valid in ANOVA failing these checked by using the Monte Carlo simulation, in which will be monitored type I error by One-way ANOVA (p-value).

2.1 Various alternative for simulation by Monte Carlo methods

Specifically, in this paper it is to test the hypothesis of conformity means of three groups:

$$H_0: \mu_1 = \mu_2 = \mu_3 = 100$$

Compared to the alternative hypothesis that the at least two diameters are equal. The simulation method Monte Carlo we will consider all alternatives that may arise, this means meeting respectively. failure to comply with terms and conditions of normality data homogeneity of each group.

Consider the following alternatives: (Table 1)

- The data come from a normal distribution with means (average) $\mu = 10$.
- The data come from the division that has skewness $\gamma_3=1.15$ and kurtosis $\gamma_4= 2$.
- Where equal variances we suppose $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 = 25$.
- In case of different variances we suppose $\sigma_1^2 = 4, \sigma_2^2 = 25, \sigma_3^2 = 49$.
- Assume that the individual files have the same number of observations, for example, the twenty.

Probability density graphs for all possible alternatives are on the Figure 1. Normal distribution is bell-shaped, which takes a maximum at $x=\mu$. The hill is steepened when variances are smaller.

The assumptions of normality can be tested e.g. Shapiro-Wilk test. The Shapiro–Wilk test utilizes the null hypothesis principle to check whether a sample x_1, \dots, x_n came from a normally distributed population. Result of test is *p-value*, if $p < \alpha$ ($\alpha = 0,05$) and the null hypothesis is rejected on the significance level is 0.05. Test results for the various alternatives are in Table 2. Alternatives C and D does not satisfy the condition of normality.

The equal of variances basic set can be determined by Bartlett's test, it's a universal test that can be used for assessing the homogeneity of variances, but is relatively weak and quite sensitive to the violation of normality files, which can be a problem for files with a small number of observations. If the frequency of all choose the same used to test Cochran test or Hartley test. The most commonly used test for homogeneity of variance test is Leveneov test, which we test the homogeneity of the various alternatives (Table 3). Alternatives B and D does not satisfy the condition of homoscedasticity.

Table.1 Alternatives for One-way ANOVA - Monte Carlo simulation

Alternatives	Normal distribution			Normality	Homogeneity of variance
A	$N_1(10,25)$	$N_2(10,25)$	$N_3(10,25)$	yes	yes
B	$N_1(10, 4)$	$N_2(10,25)$	$N_3(10,49)$	yes	no
C	$N_1(\mu, 25)$	$N_2(\mu, 25)$	$N_3(\mu, 25)$	no	yes
	$\gamma_3 = 1.15 \gamma_4 = 2$				
D	$N_1(\mu, 4)$	$N_2(1 \mu, 25)$	$N_3(\mu, 49)$	no	no
	$\gamma_3 = 1.15 \gamma_4 = 2$				

2.2 Generating random numbers

Data should be generated for the Monte Carlo simulation. To create simulation models can also use MS Excel and its enhancements: Risk Solver, @Risk, Risk Analyzer, Monte Carlo. In Microsoft Excel for generating random numbers, you can use the command *RAND* (), we

get a random number with uniform distribution in the interval (0,1), or you can use the "Random Number Generation" the Data Analysis ToolPak on the Tools menu. We get a random number $X \sim N(\mu, \sigma^2)$ with a given means and standard deviation. The program STATISTICA for generating random numbers, you can

use the "Rnd (x)", which generates a random number of interval (0, x), or the "RndNormal (x)", which calculates.

The number from a normal distribution with a means 0 and standard deviation x. Example of generating random number is in Figure 2.

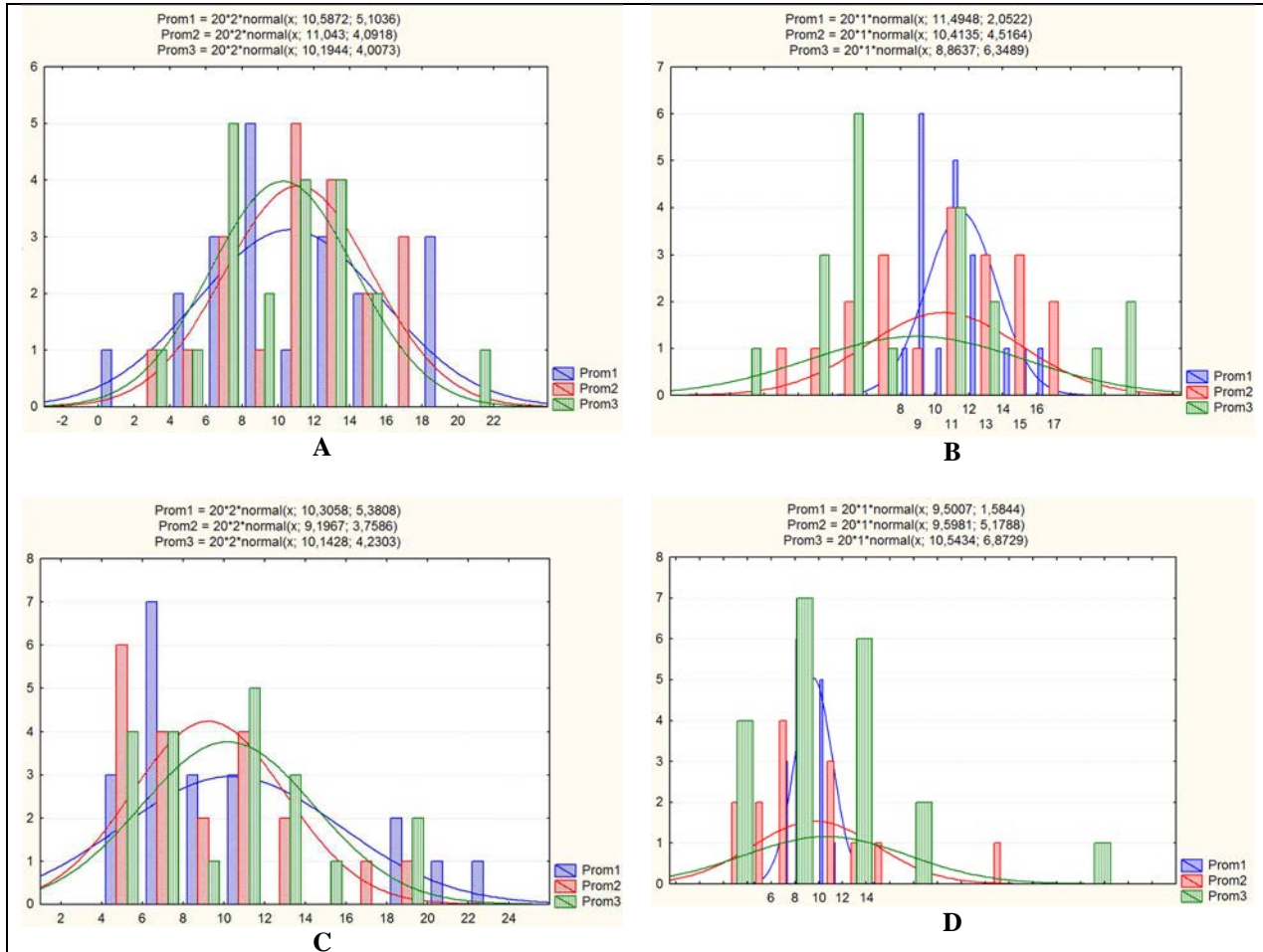


Figure 1 The graph probability density of the alternatives

Table 2 Shapiro-Wilk test

Alternatives	SW-W		p-value	Result (A=0.05)
	(A=0.05)	0.90499997		
A ₁		0.973	0.8174	H ₀ accepted
A ₂		0.9555	0.4587	H ₀ accepted
A ₃		0.9534	0.4224	H ₀ accepted
B ₁		0.9309	0.1604	H ₀ accepted
B ₂		0.9439	0.2834	H ₀ accepted
B ₃		0.9127	0.0717	H ₀ accepted
C ₁		0.8074	0.0011	H ₀ rejected
C ₂		0.8964	0.0354	H ₀ rejected
C ₃		0.9238	0.1172	H ₀ accepted
D ₁		0.9503	0.3722	H ₀ accepted
D ₂		0.8864	0.0231	H ₀ rejected
D ₃		0.8349	0.0030	H ₀ rejected

Table 3 Levenov test - testing homogeneity of variances

Variable	Levene Test of Homogeneity of Variances (Levene)							
	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
A	31.76869	2	15.88435	481.5002	57	8.447372	1,880389	0,161781
B	194.5966	2	97.29828	523.8941	57	9.191124	10.58611	0.000123
C	8.288350	2	4.144175	575.9281	57	10.1040	0.410152	0.665492
D	116.0580	2	58.02901	363.2120	57	6.372414	9.106674	0.000370

Since we need to generate value from $N(\mu, \sigma^2)$ a given means and standard deviation that can be generated directly using the "Random Number Generation" (MS Excel) and enter the parameters or to perform transformations (2):

$$Y = X * \sigma + \mu, \tag{2}$$

where $X \sim N(0, 1)$ and $Y \sim N(\mu, \sigma^2)$, μ is the means value and σ^2 is variance.

In the case of data generation with determined skewness and kurtosis it is appropriate to use Fleishman's power of transformation methods. Fleishman's the squares polynomial transformation (3) has the form:

$$Y = a + b * X + c * X^2 + d * X^3, \tag{3}$$

where Y is the transformed variable with the desired skewness and kurtosis, and $X \sim N(0, 1)$ and a, b, c, d are the coefficients of which are, for some pairs of skewness and kurtosis tabulated, for example, we used the values of Table 4.

ANOVA procedure was implemented for the various alternatives and tracks the probability of passing a null hypothesis. The group had of identical means and changed only valid or invalid assumptions about normality and equal variances ANOVA. This means that the null hypothesis should not be rejected. Results simulations (p-value) are in Table 5 and Table 6.

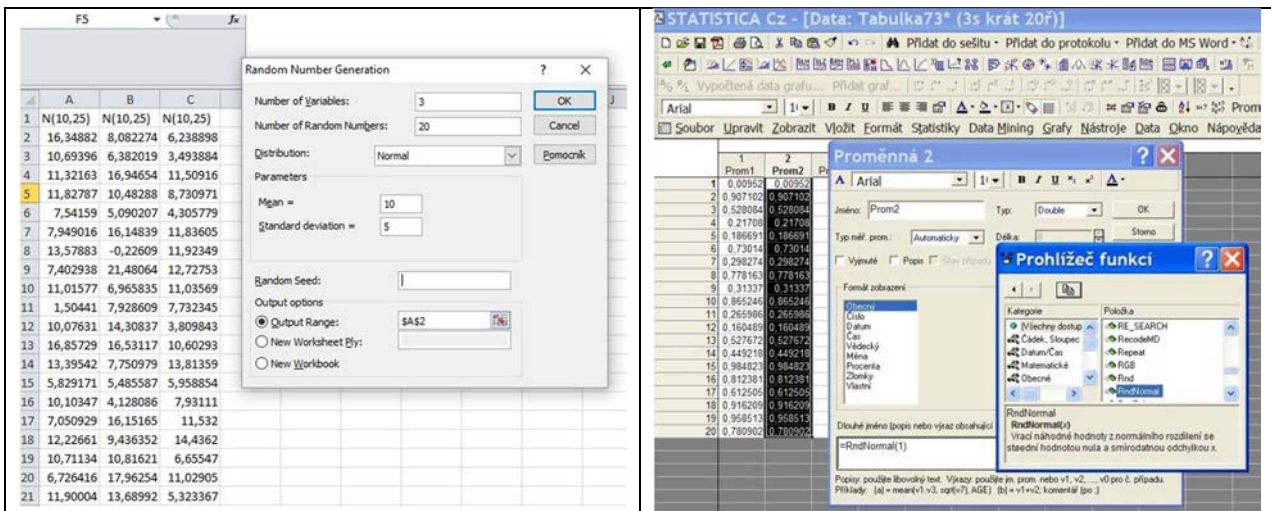


Figure 2 Generating random number

Table 4 Coeficients for Fleishmans transformation

Skewness	Kurtosis	a	b	c	d
1.15	2	-0.1858204	0.9368777	0.1858204	0.0092367

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Table 5 Results ANOVA – p-value

Sim.	A		B		C		D	
	p-value		p-value		p-value		p-value	
1	0.9211	H_0 accepted	0.8347	H_0 accepted	0.6609	H_0 accepted	0.7718	H_0 accepted
2	0.8001	H_0 accepted	0.4882	H_0 accepted	0.3202	H_0 accepted	0.8374	H_0 accepted
3	0.2915	H_0 accepted	0.9821	H_0 accepted	0.9458	H_0 accepted	0.6719	H_0 accepted
4	0.5469	H_0 accepted	0.7435	H_0 accepted	0.0237	H_0 rejected	0.8086	H_0 accepted
5	0.6912	H_0 accepted	0.2623	H_0 accepted	0.8217	H_0 accepted	0.9492	H_0 accepted
6	0.2072	H_0 accepted	0.7946	H_0 accepted	0.8590	H_0 accepted	0.8237	H_0 accepted
7	0.0128	H_0 rejected	0.9091	H_0 accepted	0.8286	H_0 accepted	0.8537	H_0 accepted
8	0.3029	H_0 accepted	0.7089	H_0 accepted	0.0213	H_0 rejected	0.2053	H_0 accepted
9	0.7165	H_0 accepted	0.8639	H_0 accepted	0.1920	H_0 accepted	0.1952	H_0 accepted
10	0.2688	H_0 accepted	0.9614	H_0 accepted	0.8598	H_0 accepted	0.7428	H_0 accepted

 Table 6 Outup of simulation method Monte Carlo for $n=10$

	Normality	Equal Var	H_0 accepted	H_0 rejected	Freq.
A	yes	yes	9	1	10%
B	yes	no	10	0	0%
C	no	yes	8	2	20%
D	no	no	10	0	0%

For each alternative. was found the percentage of rejection of the null hypothesis at a significance level of 5%, Tab.6. In the case of meeting the assumptions of normality were refusals 10% of cases, even if the conditionality correlation variance. When normality was not met we reject the null hypothesis twice if it was met assumption of conformity variances, it means that we have committed type I error in 20% of cases. The results of the simulation study for the 100 simulations are in Table 7, which indicates that the method is sensitive to ANOVA assumption of equal variances as the normality of the data.

 Table 7 Outup of simulation method Monte Carlo for $n=100$

	Normality	Equal Var	H_0 accepted	H_0 rejected	Freq.
A	yes	yes	96	4	4%
B	yes	no	89	11	11%
C	no	yes	92	8	8%
D	no	no	84	16	16%

Conclusion

The article is an example of Monte Carlo simulations for using ANOVA. It's proven to have the fulfillment of the assumptions of normality of data and correlation scattering on ANOVA results. In the event of failure of assumptions it can be used to compare mean values more than two core set of non-parametric tests, example Kruskal-Wallis test.

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MATHEMATICAL METHOD FOR FORECASTING AIDS PROGRESSION IN HIV-INFECTED PATIENTS

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Keywords: mathematical modeling, linear regression model, human immunodeficiency virus, acquired immunodeficiency syndrome.

Abstract: The article features a method developed for forecasting the development of AIDS in HIV-infected patients. Mathematical model is drafted and probability of the disease determined per stages. Method helps in the diagnosis and treatment of HIV infection and can be used in daily medical practice. Currently, the method is going through patent registration procedures (registration number of the application RU 2015123255 dated 18 June 2015). It is expected that the use of this technique will help penitentiary doctors take appropriate therapeutic measures for patients with high prognostic index on time thus preventing implementation of a negative prediction.

1 Introduction

A majority of people with HIV employed in the UK report that HIV has no impact on their working life at present, according to research conducted by City University on behalf of the National AIDS Trust. Although most of those who disclosed their HIV status at work had had a generally positive reaction, stigma and discrimination create more problems at work than ill-health. However, only a minority of people with HIV are fully aware of the provisions of the Disability Discrimination Act.

Although the quantitative findings only relate to gay and bisexual men living with HIV, the researchers also conducted focus group discussions with a more diverse mix of people with HIV, and they say that the points of similarity between the black Africans and the gay men were striking.

Previous research in other countries has identified barriers to employment for people with HIV, and levels of employment tend to be lower than in the general population. However improved treatments mean that more people with HIV are able to remain in employment.

While the experiences of people working in the UK remain under-researched, a previous study among HIV clinic attendees in East London did identify that white gay men were more likely to be in employment than heterosexual black African men and women. More part-

time working and financial problems were reported by Africans. White gay men reported higher rates of disclosure to employers than either black African heterosexuals or gay men from minority ethnic backgrounds.

The new research used focus groups to establish key themes. Three groups were held with black African heterosexuals, and two groups with gay and bisexual men (38 participants in total). Then, an online questionnaire was conducted with gay and bisexual men using the Gaydar website in order to quantify the insights of the focus groups. The researchers regret that there is no equivalent website which could be used to recruit a large convenience sample of black African people with HIV, and that other recruitment methods would have been too costly.

A total of 1830 HIV-positive gay male respondents took part in the online survey. (Moreover, some comparisons are made between these men and over 6000 HIV-negative gay men who also completed the survey.)

It's important to note that the research only included people with current employment, and the experiences of those who are no longer working are likely to be different. Twenty-five years ago the world received news about the previously unknown virus that destroys the human immune system - HIV (human immunodeficiency virus). This virus infection inevitably leads to incurable,

MATHEMATICAL METHOD FOR FORECASTING AIDS PROGRESSION IN HIV-INFECTED PATIENTS

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fatal disease – AIDS and then death. In a short period of time in human history the virus carried thirty millions lives away and so far more than 80 millions people in the world live with HIV.

Over half the respondents (58%) said that living with HIV had no impact on their working life at the moment.

Of those who reported an impact, the most common responses were to report feeling very tired (20%) and feeling very stressed or anxious (13%). One in ten (11%) said that side-effects from treatment were having an impact on their work.

Seventy per cent of gay men living with HIV had taken no HIV-related sickness days in the last 12 months, and took no more sick days than HIV-negative men. Only a third had made any changes to their working lives because of their HIV status, with the most common change being alterations to working hours.

On the other hand, initial diagnosis of HIV was a time when many respondents did report an impact on their working life. Forty-two per cent reported stress or anxiety, 32% needed some time off, and 28% were very tired. However, it is important to note that almost a third of respondents said that their initial diagnosis had no impact on their working life. There was some suggestion from focus group discussions that starting or changing medication was another ‘flash point’ when HIV had an impact on their working lives [1], [2].

2 Solution design

By the number of HIV infection occurrences and the spreading velocity of infection Russia is ranked in the world ahead of countries such as China, India, Ethiopia and Nigeria etc. 60 percents of people living with the HIV-infection are concentrated in 10 Russian regions. 80 percents of HIV-infected people in Russia are young people between 18 and 30 years. More and more women are being involved in the epidemic process, a growing number of children are being born by infected mothers.

In the last few decades we can see the rapid spread of drug addiction in the Russian society, and reduction in the quality of life in Russia associated with the epidemic of HIV and TB. That led to the increase in the proportion of people suffering from co-infected (HIV + TB) [3], [4], [5]. This problem is very actual for penal system, where is a high concentration of these patients. Thus, over the last 20 years the number of HIV-infected people in prison have increased more than in 800 times. Nowadays about 56 thousand people with HIV -infection and about 30 thousand TB patients are contained in Russian prisons [5].

The dynamisc of number of patients with HIV in Russian prisons is shown in figure 1.

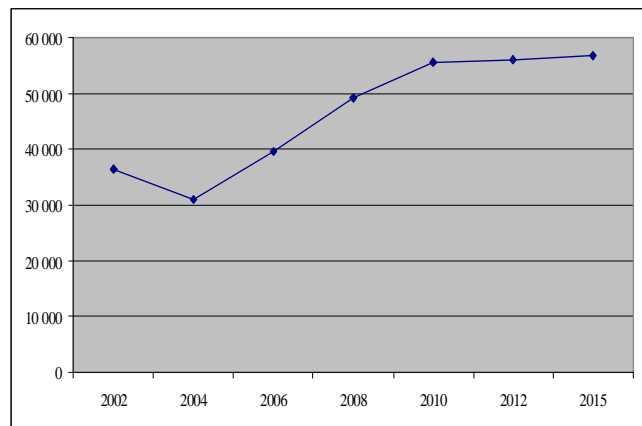


Figure 1. The dynamisc of number of patients with HIV in Russian prisons

It is widely known that the prediction of the final stage of HIV infection - Acquired Immune Deficiency Syndrome (AIDS) is not developed enough [6], [7] due to a large number of parameters that affect the course of HIV infection [8], [9], [10], [11]. This is especially significant for a prison, where there are many specific factors that might speed up the time of AIDS [12]. It is known that the combination of HIV and TB worsens the prognosis of the disease. The action of penitentiary factors in Russian prisons also leads to the progression of the disease and the onset of end-stage of HIV infection.

It is known that there are a number of indicators by which the medical men can determinate the risk of AIDS development in patient with HIV infection.

The aim of the study was to get a method of forecasting the development of AIDS in HIV-infected patients by means of mathematical modeling.

In accordance with the concept of developing the forecast [13], 49 covariates were initially considered as input variables (x_i) - the leading characteristics of the health status of HIV-infected people held in places of detention in the Russian Federation. Variable (y) is taken as a resulting factor reflecting the dynamics of the disease within a year upon completion of the study. The stable condition of a patient was taken as "1", and number "5" was to indicate the rapid development of AIDS, followed by lethal termination.

Statistical database on which the simulation was conducted according to function $y = f(x_i)$ included 30 observations. The review team included 37 observations.

Construction of a mathematical model in which factors x_i providing significant impact on the value of y were selected, was carried out by the procedure of stepped inclusion of the factor in the regression linear model $y = f(x_i)$. As a result, 4 of 49 variables were selected which make the largest contribution to the explanation of the variations in the dependent variable.

3 Mathematical formula

Mathematical formula takes into account the formalization of the patient's complaints (the presence of cough, muscle pain, loss of appetite and other results of medical tests). In addition, the border of liver according to the mid-clavicular line based on the M.G.Kurlov classical technique (1927) was further measured by percussion [14].

The method of least squares has determined coefficients of the linear regression of the following (1) form:

$$y = \alpha_1 \cdot t_1 + \alpha_2 \cdot t_2 + \alpha_3 \cdot t_3 + \alpha_4 \cdot t_4 + \alpha_5 \cdot t_5 + \alpha_6 \cdot t_6 + \alpha_7 \cdot t_7 + e, \quad (1)$$

where y is integral index,

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$ is weighting coefficients,

t_1, t_2, t_3, t_4 are measurable parameters,

e are residues.

The parameters of medical examination (such as the presence and stage of concomitant tuberculosis, severity of myalgia, increasing the degree of lymph nodes, presence of cough, liver size by Kurlov, laboratory tests, etc) as predictors in multiple regression formula used.

Calculations show that patients who have cough, are subject to AIDS progress risk by 0.352 units. Patients who have myalgia (muscle pain), are subject to AIDS progress risk by 69.7%, patients who have enlarged lymphnodes are subject to AIDS progress risk by 0.764 units. Stages of tuberculosis development also aggravate the situation of the patient.

The reseaches show that in case when the value of y was less than 3 units low risk of developing AIDS was predicted within the nearest year. While at a value within $3 \leq y \leq 4$ units the average risk of developing AIDS is determined within the nearest year, at a y value of more than 4 units a higher risk of developing AIDS within the nearest year of observation was predicted.

To assess the adequacy of the constructed model the coefficient of determination R^2 (the ratio of the explained dispersion to the total one) (2) (3) was used:

$$R^2 = \frac{RSS}{TSS} \quad (2)$$

$$\text{wherein } RSS = \sum_{t=1}^T (y_t^{mod} - \bar{y})^2,$$

$$TSS = \sum_{t=1}^T (y_t - \bar{y})^2 \quad (3)$$

If $R^2 = 0$ then the regression does not improve the quality of prediction y_t^{mod} as compared with the trivial prediction \bar{y} . If $R^2 = 1$, they say it means the

exact fit of the model, i.e., all observation points comply with the regression equation.

4 Known connection

The coefficient of determination $R^2 = 0,783$ shows that 4 of the variable estimates 78.3% of the variation of the result.

To determine the significance of the coefficients of the regression model, hence the importance of the entire model, the Fisher statistics (4) was used F :

$$F = \frac{R^2}{1 - R^2} \cdot \frac{n - k}{k - 1}, \quad (4)$$

where n is the number of observations,

k is the number of estimated parameters.

The main and alternative hypotheses are advanced (5), (6):

$$H_0 : \beta_i = 0 ; \quad (5)$$

$$H_1 : \beta_i \neq 0 . \quad (6)$$

When the main hypothesis statistics F has Fisher distribution with $(k - 1, n - k)$ degrees of freedom. Value F is compared with the tabulated value $F_\alpha(k - 1, n - k)$ at significance level α . If $F < F_{tab}(k - 1, n - k)$, then the main hypothesis that regression coefficients are equal to zero is accepted. If $F > F_{tab}(k - 1, n - k)$, then the main hypothesis is rejected in favor of an alternative.

For the estimated model Fisher test was 3.17. The probability to randomly get such a value of F-test does not exceed the acceptable level of significance of 5%. Therefore, the resulting value of the Fisher criterion confirms the statistical significance of the model.

Additionally, the average relative error of approximation has been calculated by (7) the formula:

$$\bar{\delta} = \frac{1}{N} \sum_{t=1}^N \left| \frac{y - y^{mod}}{y} \right| \cdot 100\% \quad (7)$$

Where N is the number of observations; y^{mod} is the model value of the index.

The average relative error of approximation was 8.2%. When checking the model on a test subgroup with HIV infection, acceptable values of correlation coefficient $r = 0,58$ between predicted and actual values of the prognostic index were observed.

Approximation error graph is shown in Figure 2.

MATHEMATICAL METHOD FOR FORECASTING AIDS PROGRESSION IN HIV-INFECTED PATIENTS

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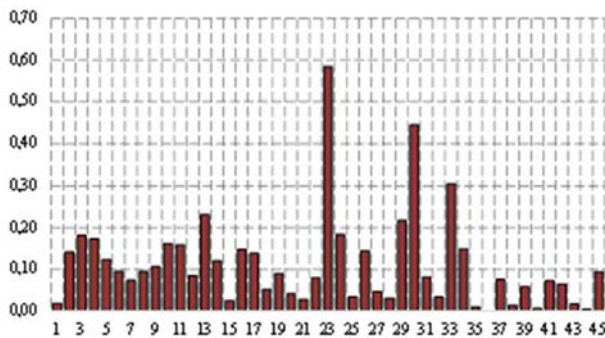


Figure 2. Approximation error for the multiple regression

Conclusions

In conclusion, in the course of research a methodology was obtained which, with reasonable accuracy, can indicate risk of AIDS development in HIV-infected patients who are serving their sentence of imprisonment in correctional facilities of the Federal Penitentiary Service of the Russian Federation. Currently, the method is going through patent registration procedures (registration number of the application RU 2015123255 dated 18 June 2015). It is expected that the use of this technique will help penitentiary doctors take appropriate therapeutic measures for patients with high prognostic index on time thus preventing implementation of a negative prediction. Mathematic method helps in the diagnosis and treatment of HIV infection and can be used in daily medical practice in prisons.

The advantages of the method are simplicity of definition, low cost, convenience, high accuracy, absence of threat to the patient health. Also there is no need for expensive equipment and the possibility of determining the risk of AIDS in HIV infected patient is high.

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Review process

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