FMS, DoE, modelling and simulation, optimisation

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SIMULATION IN FACTORY OPTIMISATION

Abstract

Many manufacturing systems must operate under resource constraints. Simulation can help to improve the operation of such manufacturing systems. This paper presents a practical approach how to conduct a simulation project. A Flexible Manufacturing System (FMS) was chosen for the simulation. The targets for FMS improvement were given. A set of measures was proposed to meet the given targets. Design of Experiments (DoE) was used to minimise the number of simulation experiments. There were simulated and evaluated various measures and control strategies and their influence on the FMS characteristics. Rough cost analysis of each simulated variant was done. Future research targets are presented.

1. INTRODUCTION

There are many problems in the practice of the design and operation of the complex logistic and manufacturing systems. The difficulty of evaluation and the huge amount of various variants give the designer or supervisor, by existing support tools, very small possibilties to choose an optimal solution. This is so called "*local optimization effect*" and it takes place both in the design and in the operation of complex systems. This problem will be especially complicated, if we want to speak about optimization from the point of view of the whole factory targets. The complex systems are usually designed on the basis of such narrowed criteria. If the project is too expensive, there will be probably done some adjustments whether to realize such a project at all. It is very difficult to speak about total optimization of the system parameters by the uncertain future demand, the time pressure, limitations in finance, not available modern software tools, etc.

So it will be obvious, that already in the design phase of the manufacturing systems there exist shortages that do not allow the full use of such systems possibilities. The supervisors have to solve besides own operating activities the problems of supplementary system changes too. Computer simulation appears as very advantageous for the solution of the described problems.

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2. SIMULATION AND INNOVATION

Simulation has proven to be an important computer tool in analyzing innovative manufacturing approaches. Simulation is a very powerful tool often used in the design phase of manufacturing systems. Performance of various layout alternatives can be studied using simulation. Moreover using computer animation, the operation of the whole factory can be viewed before implementation of various production control strategies.

Abundant literature is available on the application of simulation in the area of production systems. Many of published papers were oriented on the modelling and simulation of various production control strategies, both in traditional and just in time environment.

Gregor and Košturiak [1] used simulation and DoE for the analysis of an FMS. Mishra and Pandey [2] applied simulation for studying Flexible Manufacturing Systems using Statistical Design of Experiments. Kruse and Gregor [3] and Gregor et. al. [4] analysed FMS working in CIM environment.

Soon and Souzar [5] presented a hybrid approach using simulation based scheduling and neural network to solve the detailed scheduling problem in a manufacturing cell. Gregor and Košturiak [6] tested various simulation and analytical tools to be appropriate for the modelling and simulation of lean production systems. Gregor et.al.[7] used simulation for improvement of the whole company logistics and inventory reduction.

Many authors were delighted by push / pull cotrol problems. Sarker and Fitzsimmons [8] did a simulation comparative study on the performance of push and pull systems. Tavrou and Nagarajah [9] used simulation to compare push and pull systems of the production control for an assembly line of an electronic device. Wang and Xu [10] developed a strategy simulation software for flow-shop manufacturing systems controlled by the hybrid push/pull production control strategy. This strategy uses a structure model to describe the manufacturing and assembling process of any production line. This software was also used to analyse the control strategy of a practical production line.

Agarwal and Babu [11] studied the effects of variations in Master Production Schedule (MPS), Bill of Materials (BOM) structure, inventory supports, lot sizing, capacity planning, scheduling rules and shop floor conditions in a typical Material Requirements Planning (MRP) based production system with the simulation support.

Wu et. al. [12] used a simulation model to compare a new approach to manufacturing control - Drum-Buffer- Rope (DBR) with current practices. The simulation analysis indicated considerable savings in makespan when DBR replaces classical control approach. Guide [13] developed simulation model of Drum-Buffer-Rope (DBR) as a production planning and control methodology at the engine component division of Naval Avia tion Depot. The model experiments indicated that DBR is an extremely robust method of production planning and control and that DBR leads to better performance to schedule, lower work-in-process inventory and improved use of present resources. This paper also discussed some of the process improvements driven by the model.

Schroeder et. al. [14] studied Kanban control in the framework of the just in time environment. Chaturvedi and Golhar [15] studied the effects of stochastic demand and processing times and the number of Kanbans on production system performance. Yavuz and Satir [16] published research on articles concerning Kanban - based operational planning and control in assebly and flow lines focused on simulation models. Gstettner and Kuhn [17] analysed two different control systems Kanban and Conwip with respect to production rate and average WIP. Both analytical and simulation results were compared.

Gupta and Al-Turki [18] described a newly developed Kanban system which uses an algorithm to dynamically and systematically manipulate the number of Kanbans in order to offset the blocking and starvation caused by the said uncertainties during a production cycle (so called flexible Kanban system - FKS). The effectivness of this FKS was demostrated using an example simulation model. Gregor et. al. [19] used simulation to evaluate production system output parameters controlled by various push and pull control strategies (eg. MRP, Kanban, Conwip, LOC, DBR).

Huang et. al. [20], Sarker and Harris [21], Hearn [22], Fallon and Brown [23] and Sarker [24] developed simulation models and evaluated performance measures of JiT systems under different conditions. Welgama and Mills [25] described design problems of alternative cell desings with the use of simulation. Savsar and Jawini [26] developed simulation model to analyze just in time production system. The target was to answer the questions related to the performance of just in time systems, measured by throughput rate, work-in-process inventory, station utilizations, etc. Kanban system was used as a production control system. Savsar [27] did simulation analysis on maintenance policies in JiT systems with application of SIMAN package. The target of this analysis was to evaluate and compare the effects of maintenance policies on the performance of a multi-stage, single product JiT production assembly line.

3. SIMULATION PROJECT OF A FLEXIBLE MANUFACTURING SYSTEM (FMS)

In the next part the results of a simulation project done in the framework of a research project will be shown. In the firm ABC - AG a FMS was installed six years ago. Fig. 1 shows the layout of the FMS. In the FMS six full automatized workplaces worked. An industrial robot was used for clamping workpieces into pallets. For transport and handling an Automated Guided Vehicle (AGV) was used . All products had their individual process plans.

Market forecast showed that the double volume of the ABC -AG products could be sold so the production output of FMS should be increased.
Using the ABC analysis the project team identified three product families (P1, P2, P3) that represent about 70 % of the annual production costs (Fig. 1).

3.1. Problem Analysis and Project Objectives

Following problems occured in the FMS:

- Unsynchronized production.
- Too long throughput and delivery times and their variance.
- Worn out production facilities.
- Insufficient production throughput.

There are two basic project objectives:

1. Production rate increase of 100 %.
2. Throughput time reduction of 30 %.

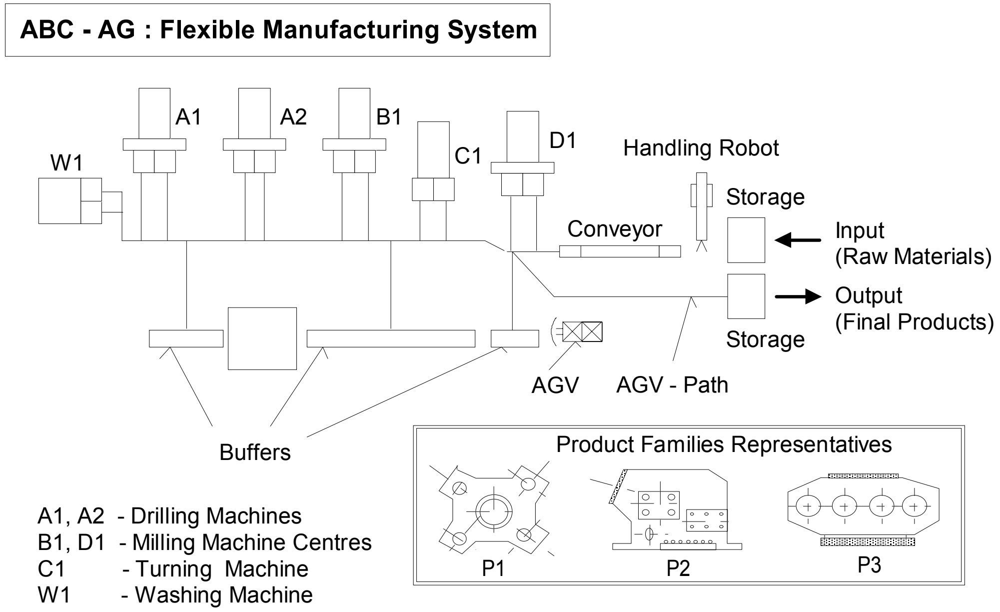

Fig.1. Flexible manufacturing system - ABC –AG

Fig. 2 shows the hierarchy of simulation objectives and measures.

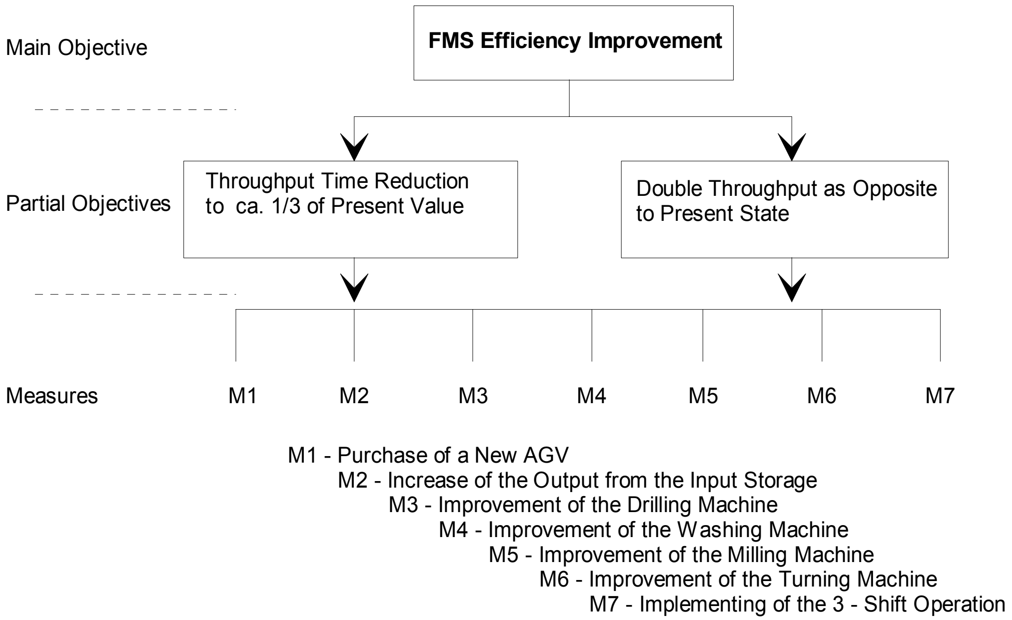

Fig.2. Hierarchy of simulation objectives and measures

The simulation project contains two main tasks:
1. Testing of the influence of chosen measures for the proposed project objectives achieving.
2. Testing of various control strategies and their influence on the production rate, inventory and throughput time.

3.1.1. Testing of the Measures to Achieve the Proposed Project Objectives

Following measures were tested :

- M1 - Purchase of a new AGV.
- M2 - Increase of the material output from the input storage due to modernization of the handling robot.
- M3 - Improvement of the drilling machine.
- M4 - Improvement of the washing machine.
- M5 - Improvement of the milling machine.
- M6 - Improvement of the turning machine.
- M7 - Implementing of the 3-shift operation.

The costs for the proposed measures are estimated in Fig. 3.

Nr.	Measures	Model Change	Costs
M1	Purchase of a New AGV	Two Vehicles in the Model	200000 DM per AGV
M2	Increase of the Material Output from the Input Storage Due to Modernization of the Handling Robot	Change of the Mean Arrival Ttime from 69.0 Min. to 41.4 Min. from 50.0 Min. to 30.0 Min.	200000 DM
M3	Improvement of the Drilling Machine A1 by Using New Tools and Fixtures	Change of the Process Time from 40.0 Min. to 24.0 Min.	50000 DM
M4	Improvement of the Washing Machine W1 by Using a New Motor	Change of the Process Time from 12.0 Min. to 9.6 Min.	50000 DM
M5	Improvement of the Milling Machine B1 Using a New Motor and Fixtures	Change of the Process Time from 42.0 Min. to 25.2 Min.	50000 DM
M6	Improvement of the Turning Machine C1 Using a New Motor and Fixtures	Change of the Process Time from 15.0 Min. to 4.5 Min.	250000 DM
M7	Implementing of the 3 Shift Operation	Change of the Simulation Time from 4800 Min. to 7200 Min. per Day	5000000 DM

Fig.3. Costs for the proposed measures and their effects

3.1.2. Testing of Various Control Strategies

Following control strategies and their influence on the production system were tested:
Various AGV control strategies, MRP control - push principle, KANBAN control - pull principle, LOC - Load Oriented Control, DBR - Drum Buffer Rope - Bottleneck oriented order release control.

3.2. Data Collection and Preparation

Fig. 4 shows the main relevant input data. The stochastic processes (machine breakdowns, repair times) were processed by using Chi-Square Goodness-of-Fit Test.

Process Plans	Process Time (Min.)	Products		
Operations		P1	P2	P3
A1 - Drilling Machine 1	40.0	●		
A2 - Drilling Machine 2	21.0	●		
B1 - Milling Machine -3-Axis	42.0		●	●
D1 - Milling Machine -5-Axis	14.0		●	
W1 - Washing Machine	15.0	●	●	●
C1 - Turning Machine	12.0	●	●	●

Transportation System	
Robot Handling Time	2.5 Min.
Conveyor Speed	2.8 Min
AGV - Speed	30 M/Min.
AGV - Load/Unload Time	0.5 Min

Fig.4. Some input data for the simulation

Fig. 5 shows the starting financial analysis before simulation.

Cost Analysis

Product	Variable Costs	Income	Marginal Profit	Pieces/ Year	Total Marginal Profit
P1	600	2600	2000	3150	6300000
P2	800	3000	2200	2350	5170000
P3	300	1900	1600	2300	3680000
				Total	15150000
				Fix Costs	15200000

* Number of the Working Days per Year: 250 (50 Weeks)

* 2-Shift Operation

Total Balance: - 50000

Fig.5. Starting situation financial analysis

3.3 Simulation Model Development

The simulation model was developed by using the object - oriented simulation system ARENA. ARENA is based on the popular SIMAN and CINEMA simulation and animation system. ARENA allows users to leverage the functionality of a language-based system in an easy-to-use object-oriented modelling environment. In the ARENA environment it is possible to create new objects for hierarchically defining operations. The user can use and modify or also build his new templates. Individual modules contain both animation and simulation funcionality, thus, models are constructed in a one-step way. Application Solution Templates (ASTs) create the user a friendly simulation environment useful for the whole factory so that simulation becomes more simplified. ASTs allow organizations to transfer simulation expertise from a centralized simulation support organization to other locations through the company. Fig. 6 shows the hardcopy of the simulation model layout from ARENA.

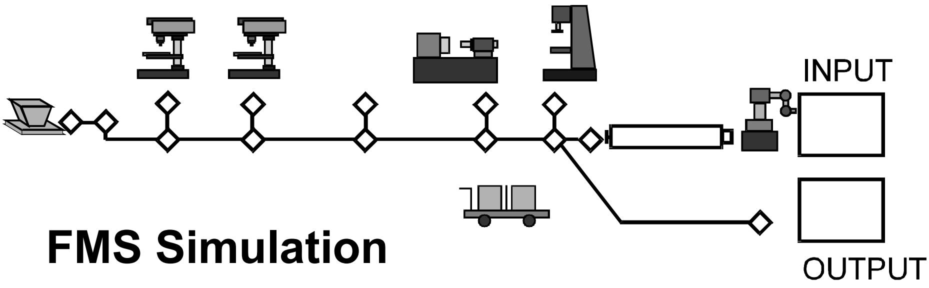

Fig.6. Simulation model – hardcopy

3.4 Simulation Experiments

After simulation model had been prepared and verified some pilot runs were done to validate designed model and to determine other needed conditions for simulation runs (e.g., warm-up period, etc.). Some results from the pilot runs are shown in Fig. 7 and Fig. 8.

Variants			V1 TE* = 480	V2 TE* = 1000	V3 TE* = 4800	V4 TE* = 20 000
Troughput [Pieces]		P1	7	15	63	262
		P2	2	5	42	186
		P3	3	9	44	188
Throughput Time [Min.]	P1	MIN	134.04	134.04	134.04	134.04
		AVG	247.57	269.20	434.23	466.03
		MAX	294.04	353.55	586.56	627.48
	P2	MIN	161.64	161.69	161.69	161.69
		AVG	193.97	453.41	739.18	674.60
		MAX	226.25	709.43	1673.35	1673.35
	P3	MIN	149.25	149.25	149.25	149.25
		AVG	203.83	272.32	488.95	523.40
		MAX	237.87	370.75	931.60	1277.82

* - Simulation Length [Min.] Warm-up Period : 100 Min.

Fig.7. Influence of simulation length on throughput and throughput time

Variants			V5 WP* = 100	V6 WP* = 500	V7 WP* = 1000	V8 WP* = 4000
Throughput [Pieces]		P1	63	65	62	63
		P2	42	43	48	48
		P3	44	45	43	43
Throuhput Time [Min.]	P1	MIN	134.04	228.35	318.99	347.28
		AVG	434.23	453.28	481.90	472.92
		MAX	586.56	623.09	623.09	623.09
	P2	MIN	161.69	485.73	485.73	498.52
		AVG	739.18	774.56	766.20	706.63
		MAX	1673.35	1673.35	1673.35	1673.35
	P3	MIN	149.25	247.18	413.01	387.67
		AVG	488.95	513.67	553.28	541.25
		MAX	931.60	931.60	994.77	994.77

* - Warm-up Period [Min.] Simulation Length: 4800 [Min.]

Fig.8. Influence of warm-up period on throughput and throughput time

3.4.1 Simulation of the Proposed Project Measures

As the first step, the static capacity balance of main workplaces was done. The results are shown in Fig. 9.

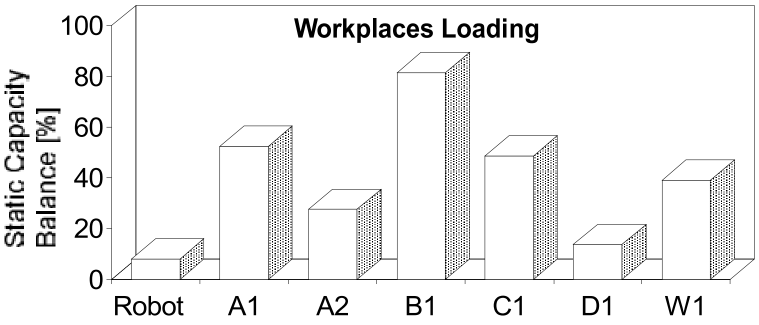

Fig.9. Results of the static capacity balance

A Taguchi-plan of the simulation experiments enabling a considerable reduction of the number of the simulation experiments (see Fig. 10) was developed.

Experiment Nr.	Factors (Measures)							Results
	M1	M2	M3	M4	M5	M6	M7	
1	−	−	−	−	−	−	−	R1
2	−	−	−	+	+	+	+	R2
3	−	+	+	−	−	+	+	R3
4	−	+	+	+	+	−	−	R4
5	+	−	+	−	+	−	+	R5
6	+	−	+	+	−	+	−	R6
7	+	+	−	−	+	+	−	R7
8	+	+	−	+	−	−	+	R8

Fig.10. Taguchi-plan of the simulation experiments

Calculation of the results (effects) of the single factors according to Taguchi-Plan is:
Factor A- = (E1 + E2 + E3 + E4) / 4
Factor A+ = (E5 + E6 + E7 + E8) / 4
The result of factor A is:
A = | A+ - A-|

In the same way other effects of all the factors are calculated. The largest effect is the main influence quantity. The optimal combination of the measures is determined according to the volume of the individual factors. The simulation results are shown in Fig. 11. Fig. 12 shows the solution searching path.

Experiment Nr.	Throughput (Pieces/Week)				Average Throughput Time (Min.)			
	P1	P2	P3	Total	P1	P2	P3	Total
1	63	47	46	156	474.4	645.8	528.1	1648.3
2	93	67	69	229	480.8	792.7	618.8	1892.3
3	95	68	69	232	438.4	598.7	520.3	1557.4
4	62	43	46	151	473.0	794.4	544.5	1811.9
5	144	104	104	352	121.2	114.4	104.5	340.1
6	79	57	57	193	283.5	340.9	322.6	947.0
7	120	88	88	296	313.9	252.6	223.8	790.3
8	119	86	85	290	303.9	354.1	338.4	996.4

Fig.11. Simulation results

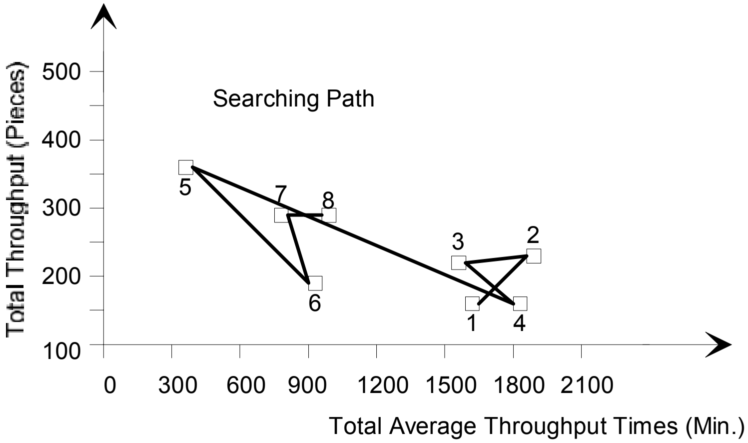

Fig.12. Solution searching path and the successive solution improvement

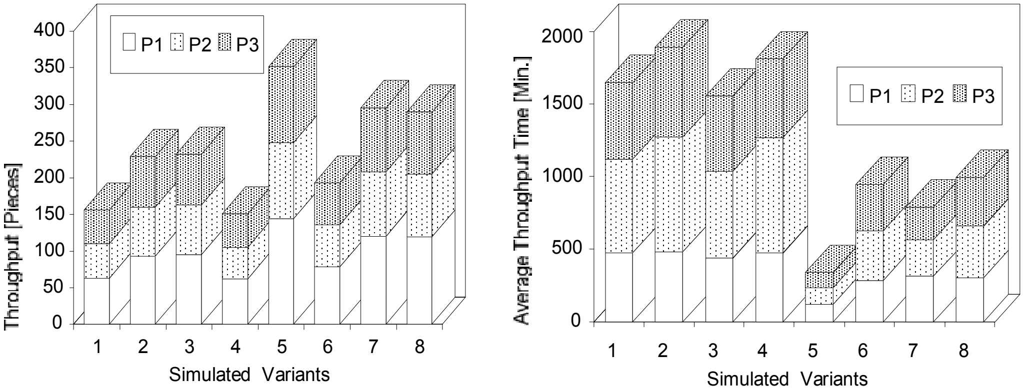

Fig.13. Graphical presentation of simulation results - throughput and throughput time for simulated variants

Fig. 13 and Fig. 14 show a part of the graphically presented results.

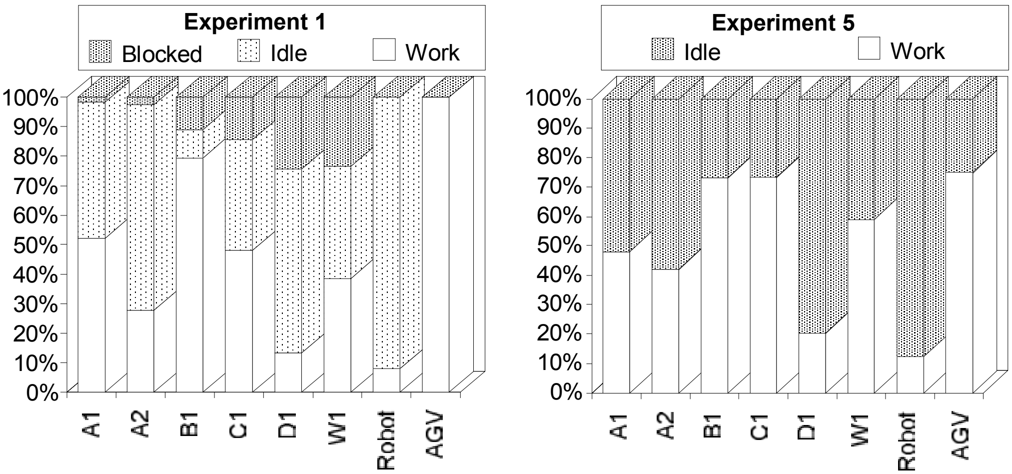

Fig.14. Statistics comparison - variant 1 and variant 5

Simulation Results

Product	Var.Costs	Sale	Contribution Margin	Pieces/Year	Total Cont. Margin
P1	600	2600	2000	7200	14400000
P2	800	3000	2200	5200	11440000
P3	300	1900	1600	5200	8320000

Measure	Costs	Costs for the Measure
Purchase of a New AGV	200000 DM	200000
Increase of the Output from the Input Storage	200000 DM	——
Improvement of the Drilling Machine	50000 DM	50000
Improvement of the Washing Machine	50000 DM	——
Improvement of the Milling Machine	50000 DM	50000
Improvement of the Turning Machine	250000 DM	——
Implementing of the 3 - Shift Operation	5000000 DM	5000000

Total Costs for the Measures	5300000
Fix Costs	15200000
Total Contribution Margin	34160000
Total Balance :	13660000

Fig.15. Final simulation results - financial evaluation

3.4.2. Results Evaluation and Interpretation

All the obtained simulation results were processed using the ARENA standard graphical and statistical methods and the external graphical tools.

The final simulation results of seven project measures (the fifth line in Fig. 11) are shown in Fig. 15. Their financial evaluation shows that their realization, which costs 5 300 000 DM, will bring the contribution margin of 13 660 000 DM p.a.

Further improvement of the obtained results is possible by reduction of the time period between arrivals on the FMS input (cycle time of the handling robot and conveyor speed).

Fig. 16 shows the comparison of existing potentials for individual simulated variants.

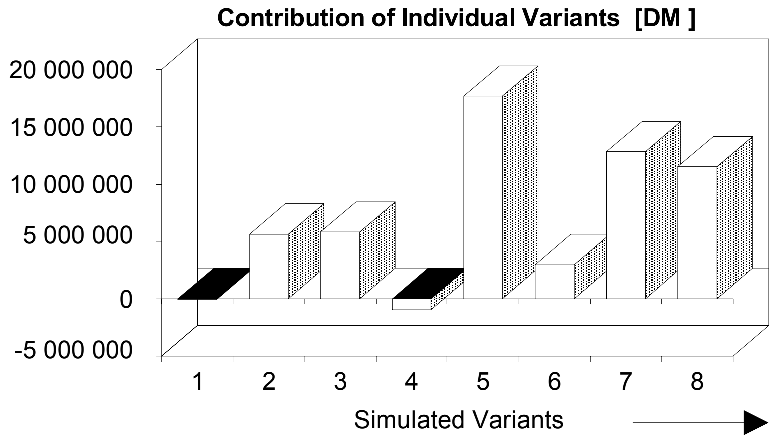

Fig.16. Statistics comparison

In Fig. 17 comparisons of profit, fix costs, and contribution margin for individual variants are shown.

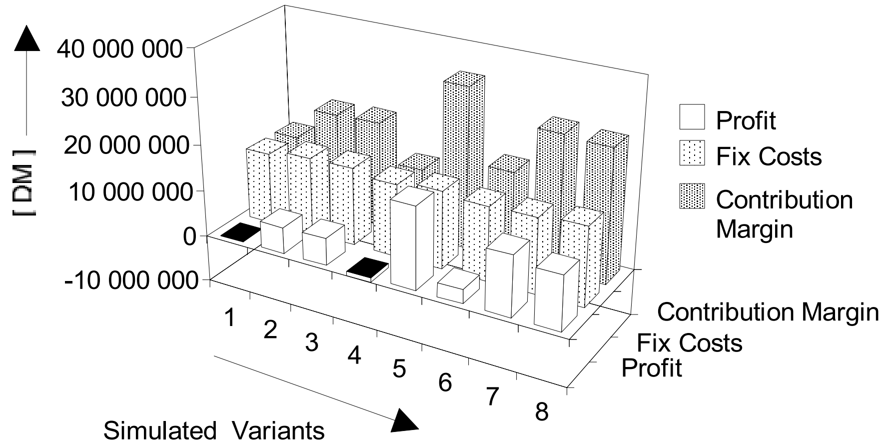

Fig.17. Statistics comparison

4. CONCLUSION

Nowadays "uncertain" situation at the domestic and foreign markets, known but hard "treated" problems in the production presents a new challenge for Industrial Engineers. The simulation is often used as a method of the "last resort". If the problem cannot be solved by using other methods the simulation should be used.

The Industrial Engineers should find the future improvement possibilities in the design of the new or in the analysis of present enterprise concepts. This process has to be continual. It means that after finishing one project another project for the discovery of potentials and continuous improvement should start. The Industrial Engineers have to develop and implement fully new methods and market strategies in this process that will ensure the production costs reduction, the shortening of lead times, higher quality level, etc. Computer simulation appears to be very advanatgeous technique for the solution of the problems described in the previous part. Fully new possibilities present such simulation tools that enable to simulate not only material and information flows, but value flows too.

This paper presents a systematic approach to the simulation of manufacturing systems. The influences of various measures to the system characteristics were verified. Some proposals to the system parameters and to the production control system based on the results of this verification were prepared.

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