Simulation and Modelling of Paths Processing Time in a Flexible Manufacturing System

Simulácia a modelovanie času spracovania dráh v pružných výrobných systémoch

Car Zlatan, Branimir Barišić, Marko Kršulja

Abstract

In manufacturing system planning and control of process time and its necessary scheduling activities are a common procedure. This paper shows a group of machines in virtual reality, visualization in three dimension (3D) space with *SolidWorks* software. With accurate simulation and analysis of flexible manufacturing system it is possible to influence and resolve spatial conflicts and other negative behaviours. Necessary times for processing ware calculated and optimised with the use of *eM-Plant Siemens Technomatix*. Milling and lathe machines are visualised and one robotic arm is used for transfer of workpiece between them. Robot travel path is calculated with *IntelliMotion Builder*. Final presentation is given in *avi* and *VRML* video format. Simulation increased the level of comprehensiveness of the manufacturing system modelling and it has given characterrization of structure interconnections.

Keywords: Modelling, scheduling, manufacturing, simulation

Abstrakt

Vo výrobných systémoch sú plánovanie a kontrola procesných časov a ich nevyhnutných rozvrhovacích aktivít bežnými procedúrami. Článok prezentuje skupinu zariadení vo virtuálnej realite, vizualizáciu v trojdimenzionálnom priestore so softvérom SolidWorks. Presnou simuláciou a analýzou flexibilného systému je možné ovplyvňovať a riešiť priestorové konflikty ako aj ďalšie negatívne vlastnosti. Nevyhnutné časy na spracovanie boli vypočítané a optimalizované s použitím *eM-Plant Siemens Technomatix.* Vizualizované boli frézovacie zariadenie a sústruh a jedno robotické rameno na transfer polovýrobku medzi týmito zariadeniami. Dráha robota bola vypočítaná v programe *IntelliMotion Builder*. Finálna prezentácia je vytvorená v *avi* a *VRML* video formáte. Simulácia zvyšuje úroveň zrozumiteľnosti modelovania výrobného systému a má určenú charakteristiku prepojenia štruktúry.

Kľúčové slová: modelovanie, plánovanie, výrobná simulácia

1 Introduction

Serious preparation before the realization of the job is necessary when a specific job demands complex execution and special conditions. Virtual models give the user the possibility of experimentation and testing of borders in a virtual system. It is important to view the process in a near real setting and therefore today the virtual reality represents a standard engeneering tool. Correct simulation gives a model that matches physical entities in the real environment. It enables engineers to identify problems and allows them to be corrected prior to actual operation. Object manipulation paths are a required knowledge prior to processing and in order to achive precise calibration and fine tuning of the given processes. In production planning the race is to transfer parts from machine to machine with a high flexibility and a good processing time. Traditionally jobs are grouped by their operation similarities in an effort to reduce production times. With several or more machines the idea is the same and the job similarities affect the group connected with a common problem. Furthermore the product variations affect the productivity and performance of the group as a whole. Processing times in industry for the flexible manufacturing system (FMS) depend on the behaviour of real job completion time that requires accurate estimations. Modelling simulations [1] of parts and tools ontrol decisions [2] are used to control process operations and their scheduling. In this paper general paths and times are identified and guidelines for FMS design are suggested. FMS is a production system in which groups of numerically or computer controlled machines (NC or CNC) and automated material handling systems (MHS) operate under computer control. Therefore it is important to achieve management of critical information's such as location and times of equipment positions. Processing time uncertainty (PTU) [3] addresses problems where performance of estimated times could affect the performance of scheduling policies. In manufacturing process there are many machining variables that could influence processing time and thus lead to uncertainty. Modelling and visualizing of process parameters prior to processing could minimise delays and avoid conflicts. Spatial conflicts between robot and other components located within the robot hand range are therefore considered ahead. Current idea is to achieve automatic generation of motions in 3D space [4]. It has been shown [2, 5, 6] that the collision free paths [7] and production scheduling with high accuracy is achievable in production planning.

The purpose of this paper is to attempt to obtain manufacturing system analysis and to increase the level of comprehensiveness of the manufacturing system modelling. One of the aims is also the development of a method for characterization of manufacturing systems based on its structure interconecctions [8]. In order to model process elements *SolidWorks* software was used, and the *eM-plant Siemens Technomatix* was used for process optimisation.

2 System modelling, interconnections

When the model is designed graphically in virtual space with the use of a computer program (figure 3), the resulting file is the beginning of electronic database of the products. With a virtual model manufacturing manager will be able to make better informed decisions towards improving the productivity and speed. Furthermore organizational efforts of simulating different "what-if" scenarios may help when making difficult decisions. The increase in productivity in the field of designing is that technology is not effectively implemented. Creation of design drawings of the new product is the first activity in the area of modelling systems for simulation, and the format must be consistent to the requirements of the company in order to share with other workers, a reusable reference model library. Therefore a library of models is created where they can be accessed depending on the companies needs, and simulations may be generated with several structural modifications.

It is usually very difficult to predict the impact of mutual dependencies within a complex system, especially if there is variability. Combinatorial complexity is related to the number of components contained in the system, i.e. with the number of possible interactive combinations that can be obtained. Figure 1 shows a flexible system with three machines in relationship. There are 6 interconnections that can be established between them.

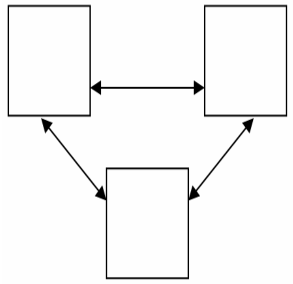

Fig. 1 *Simple system with 6 interconnections*
Obr. 1 *Jednoduchý systém so 6-timi prepojeniami*

In figure 2 an advanced system of 20 interconnections is shown.

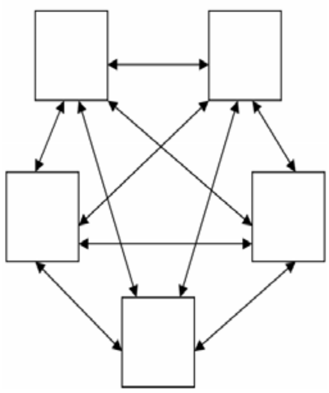

Fig. 2 *Advanced system with 20 interconnections*
Obr. 2 *Vyspelý systém s 20-timi prepojeniami*

The group of machines are simultaneously conducting the process during which the workpieces travel between them. With figure 2 it can be seen that by connecting machines into an effective group their production capabilities grows but with them also the complexity of scheduling. Therefore careful planning is required in order to implement different jobs into the group and calculate job completion time and analysis of the structural information of a manufacturing system.

In the figure 3 top view of the system model is shown, where the interconnections can be determinate. In this paper the connecting elements are a milling machine, lathe machine, robotic arm, storage 1 and storage 2. Number of possible interconnections in presented example ranges from 12 to more depending on the process operations, number of used tools etc. A simulation can deduce the necessary process times, the job shop dimensions, the safety procedures etc.

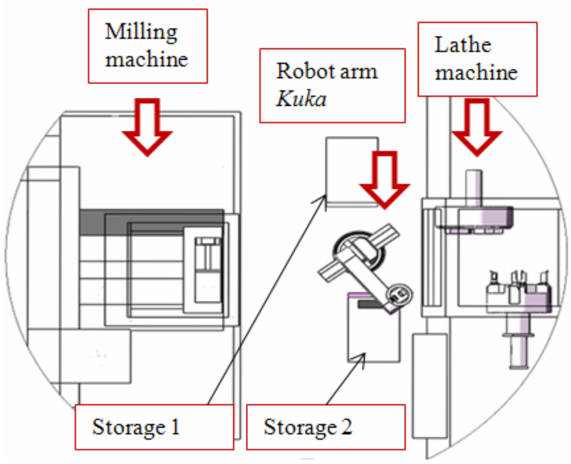

Fig. 3 *Simulated model of FMS*
Obr. 3 *Simulovaný model PVS*

3 Production accessories, equipments, dimensioning, machine - tool behaviour

Basic challenge in simulation modelling of manufacturing system is to construct models that can be understood. Therefore figure 4 shows real CNC machine and figure 5 shows its virtual representation.

Fig. 4 *CNC milling machine OKUMA MB-46V* [10]
Obr. 4 *CNC frézovacie centrum OKUMA MB-46V* [10]

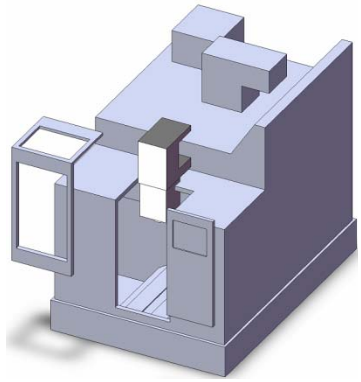

Fig. 5 *CAD model of OKUMA MB-46V*
Obr. 5 *CAD model - OKUMA MB-46V*

In order to achieve the best solution of model verification and validation the selected machine and its parameters have to be observed table 1, [9].

Table 1 *Characteristics of modelled milling machine [10]*
Tab. 1 *Vlastnosti namodelovaného frézovacieho centra [10]*

Name of characteristic	Unit	Size
Max. dimension of the blank	mm	560x460x460

Size of the work table	mm	460x760
Number of rotations per minute	1/min	50-8000
Power of the spindle motor	kW	7,5 (18,5)
Max number of tools in the storage	pieces	32

In presented simulation robot arm Kuka KR 3 [11] was used as shown in the figure 6. Maximal weight of object that can be manipulated is 3 kg, maximal reach 635 mm. There are 6 manipulative axes with the precision of repeating <±0,05 mm, maximum weight of the robot arm is 53 kg.

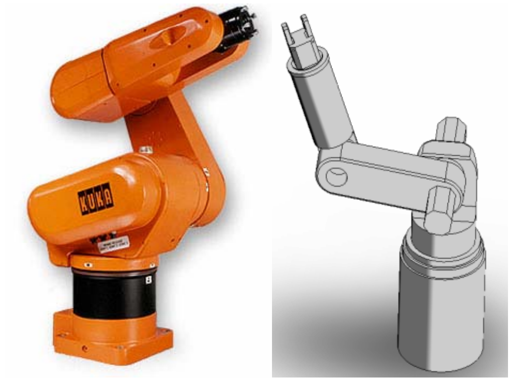

Fig. 6 *ROBOT KR3 of KUKA company and relative model*
Obr. 6 *ROBOT KUKA KR3 a kĺbový model*

In figure 7 it can be seen the concept of how these machines have been placed all together in a virtual space. The simulation is planned as 3D model in which the details will be shown in order to demonstrate the possibilities. For that reason only the most important parts involved in the process are shown (milling table, milling tool holder etc.).

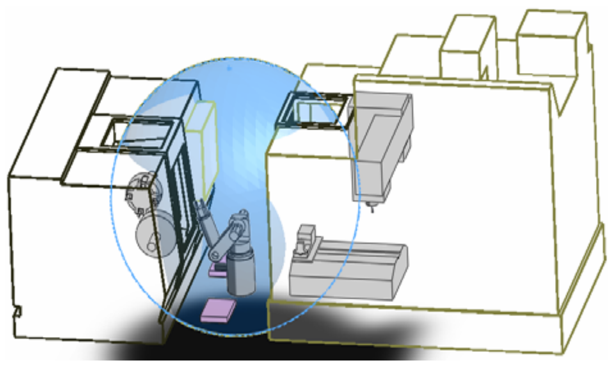

Fig. 7 *Milling and lathe machine are reachable with the robot arm together with given storage boxes*
Obr. 7 *Stroje na frézovanie a sústruženie sú spolu s paletami dosiahnuteľné ramenom robota*

There are complex assemblies involved in procedure and different catalogues ware used in order to more accurately represent the real process parameters. Figure 8 presents the procedure list of the modelling sequence and in table 2 some of the parameters of the model are show in order to visualize the complexity of the modelling process. Many components compose the model as shown in figure 8 such as milling and lathe tools, workpiece, holders, spindles etc. In this procedure it is possible to implement various other equipments in order to simulate different ''what ifs''. The procedure should always be saved with recommendation in order to facilitate retrieve and reuse by different engineers.

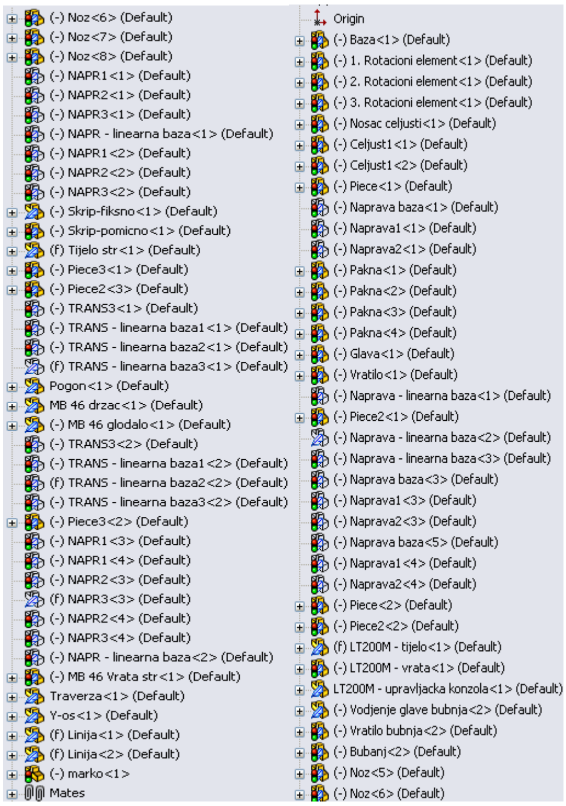

Fig. 8 *Procedure of modelling and assembly*
Obr. 8 *Postupnosť modelovania a skladania*

Table 2 *Characteristics of model*
Tab. 2 *Vlastnosti modelu*

Total number of components in Robot:	76
Parts:	76
Unique Part Documents:	42
Unique Parts:	42
Sub-assemblies:	0
Unique Sub-assemblies:	0
Unique Sub-assembly Documents:	0
Maximum Depth:	1
Number of top level components:	76
Resolved components:	2
Lightweight components:	74
Suppressed components:	0
Number of top level mates:	178
Number of bodies:	77

4 Defining positions and movements selection

In the FMS system the machines are serviced by a robot arm, therefore it is necessary for robot arm to reach specified targets, (figure 9). Specified targets are the fixture head of the lathe machine, storage areas 1 and 2 and milling machine fixture. Figure 10 shows some of the necessary tooling used in model.

By correct selection of a function with mutual dependencies the possibility is achieved through the virtual axial shift or rotation of individual elements and sub-elements of the virtual CNC lathe. For this type of manipulation it is necessary to define certain restrictions, so that for example, door can not move away from the outer dimensions of the machine. To achieve this goal it is necessary to select Advanced Mates functions within the command Mate, figure 11.

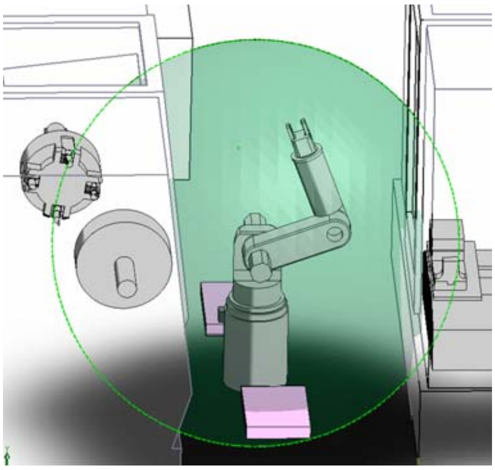

Fig. 9 *Maximal reach of robot arm is 635* mm
Obr. 9 *Maximálny dosah robota je 635 mm*

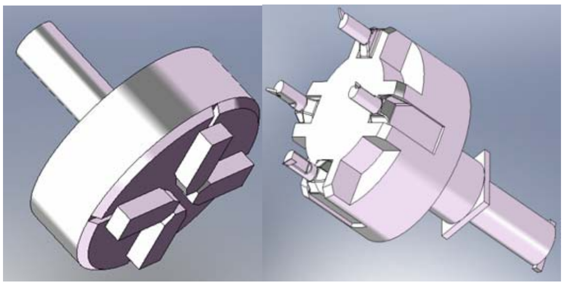

Fig. 10 *Model of fixture head and tool head holder*
Obr. 10 *Model hlavy prípravku a držiaka hlavy nástroja*

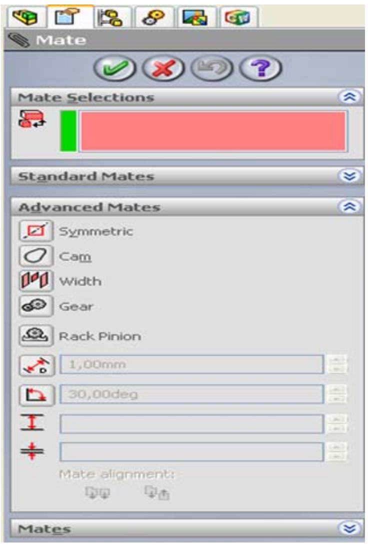

Fig. 11 *Selection of Advanced Mates functions*
Obr. 11 *Výber rozšírených funkcií spájania*

Restrictions of distance, angles and cantering, symmetry and more can be found within this group of commands. This way of defining reaches the virtual reality with the possibility of manipulation of individual elements of the machine. It is also possible in order to achieve a better visual effect to show the elements as transparent with visible external contours. This improves the visual impress-sion and allows centring the view on the main actors of the process.

Figure 12 shows the storage areas, the simulation requ-ested conveyer belts one for raw materials, and second for finished parts. Robot speeds ware taken in consideration and planed accordingly in the job time planning. The necessary times needed for completion of jobs ware calculated with the use of *eM-Plant Siemens Technomatix.*

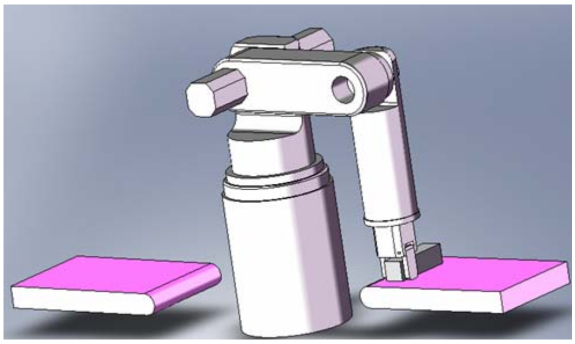

Fig. 12 *Model of placement of the workpiece in the storage area*
Obr. 12 *Model umiestnenia polovýrobku v oblasti zásobníka*

For simulation of the robot motions in *SolidWorks* software *COSMOSMotion* module was used. Mates ware selected and ground parts and motion parts ware selected. Then the sequence motions of the desired treatments are setup. Therefore it is necessary to select the function *Joints* within the "window" *IntelliMotion Builder* where all the physical sizes and the interdependency of individual virtual elements can be seen. For easier reference by complex simulations, it is possible to see exactly which physical quantities belonging to the corresponding models by selec-ting the "+" sign next to the names.

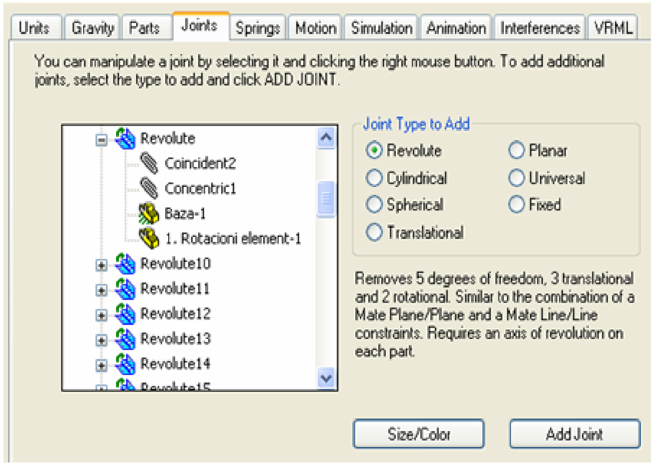

Fig. 13 *Window of IntelliMotion Builder*
Obr. 13 *Okno IntelliMotion Builder*

Every movement is given seconds needed for the exe-cution, figure 14. The basic motions are revolute and translation simulated with consideration of specified se-conds and distances.

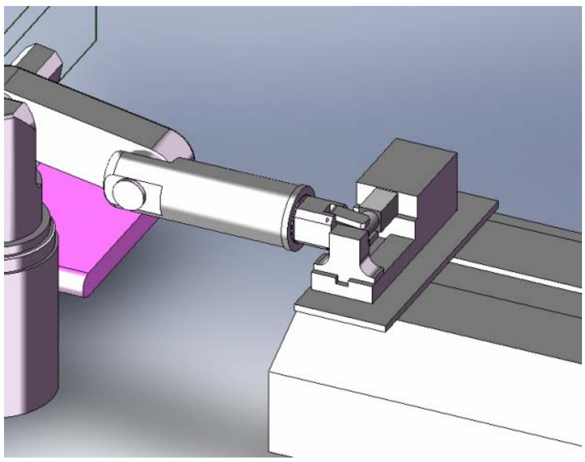

Fig. 14 *Placement of workpiece in the fixture head*
Obr. 14 *Umiestnenie polovýrobku v hlave prípravku*

5 Process planning

Individual processes normally operate as part of an integrated FMS consisting of a number of processes serviced by in our case a robot arm. Linking processes to the common robot handling service system creates interactions between the different processes through the utility system. If used properly, these interactions can be exploited to maximize the performance of the FMS as a whole. Simulation of the individual processes on a site can show the exchange of objects in such a way that efficiency of the production is maximized.

Before issuing the order for production, designs and formal specifications in all mechanical, electric, electronic and computer subsystems are required to be verified and validated before the first production run. After confirmation that the process is to be implemented all plans are finalized and orders are issued to the job shop and to suppliers. Then the final list of required tools is made, the programming is done on the machines, a team is established to guarantee the quality and production can begin. Figure 15 shows the initial dimension check of the distance betveen the lathe fixture head and milling tool head.

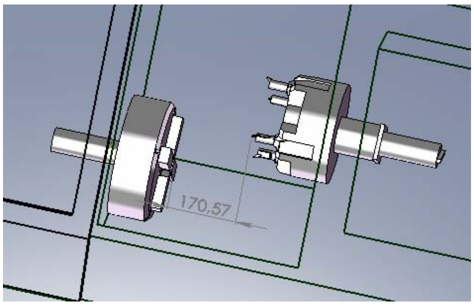

Fig. 15 *Distance of 170.57* mm *between the tool head and fixture head*
Obr. 15 *Vzdialenosť 170,57 mm medzi hlavou nástroja a hlavou prípravku*

For a comprehensive optimization of products, however, the production of the first series is only a step of the production cycle. New editions of the product or possibility of stopping the production and recycling are also questions that should have prepared answers. Only then the final optimization of the product, comes which closes the circle of development. Successful product in the future time will again start a circle of planning and optimizing as a product of a new generation. It can be said that simulation is the start of the process planning but also the end where optimisation is offered. Therefore a good process simulation represents the circle of quality improvement plan. After the necessary information from the virtual models and simulations are obtained the physically functional model is made. After the physically functional model is made optimisation with a virtual model by checking new ''what ifs'' can be made. Therefore the virtual modeling and simulation, which appears during prototyping, provide many advantages. How virtual prototypes significantly reduce the number of physical prototypes, they automatically generate savings in time and money.

6 Process analyses

The simulation presented a model of FMS serviced with a robotic arm. Workpiece was taken from the storage area 1 placed in the milling machine, from there the workpiece was taken for treatment to CNC lathe machine. After the treatment the workpiece was placed in the storage area 2. The simulation showed changes of tools during the simulation on the lathe machine. Total duration of simulation was 155 seconds and the number of animation frames was 500 frames. The video was saved as *avi* file and *VRML file* (figure 16).

Fig. 16 *VRML virtual simulation placed on internet page*
Obr. 16 *Virtuálna simulácia VRML umiestnená na internetovej stránke*

VRML type of file saving has a slight advantage compared to the avi because it offers the possibility to display the interactive process with the convenience by simply placing it on a website. *Avi* is still the type of files that film presentation shows simulations based on how the author wanted to show the process.

A secure online connection allows to control access to confidential information and the design can be offered to other experts for control and troubleshooting. If simulation is not as showing the desired elements or is not completely as engineer conceived it or wanted then the instruments that ware used for estimation are likely not appropriate. If the simulation is compared (or its impact on the participants) with the real conditions and the results are not coincident with the field of reality, then measured thing are wrong and the simulation is invalid. Therefore a great experience and knowledge are needed when conducting a simulation.

The process optimization was done with implementation of the model and time selection in the *eM-Plant Tecnomatix*. Modelling of the manufacturing processes was done by using libraries of standard and specialized components and with *eM-Plant* a well-structured, hierarchical model of FMS system integrated in production facility was done. This was achieved through powerful object-oriented architecture and modelling capabilities of *eM-Plant* software. The obtained results showed 18 % of cost system exploitation and the time neaded for construction and modeling with presented method was reduced by 23 % when compared with conventional methods.

There is a lot of information that can be obtained from the virtual model. Specifically in this model for lathe it can be:

- spatially manipulated and explored,
- any dimension can be captured, which may be required for accommodation of work in the machining area,
- be the basis for a complex analysis,
- check the accommodation in the virtual space in relation to other machines,
- transport routes for entry and exit positions for treatment can be seen,
- the ergonomic access to the machine and the required space for manipulation can be seen,

- the storage boxes with the tools for processing can be driven to the exact position of pre-treatment,
- virtual model of work can be drawn and inserted in the system placed and the accommodation and behaviour could be visualised with possibly to detect some unforeseen obstacles.

7 Conclusion

Structural patterns and combination sets interacting in various ways have been recognized as capabilities of manufacturing system and their limitations and implications have been considered in the research. Process time and its necessary scheduling activities have been determined for the presented FMS. A group of machines was visualized in three dimension (3D) space with *SolidWorks* software and an accurate simulation has been made. Necessary times for processing ware calculated and optimised with the use of *eM-Plant Siemens Technomatix*. Robot travel path was calculated with *IntelliMotion Builder* and a collision free path was achieved. Further more programming has shown that the targets ware served by the robot and process job was simulated to completion. Final presentation is given in *avi* and *VRML* video format and process possibilities have been shown. So it can be predicted that the same (or similar) solutions could be used for cost effective process planning. Some of the expected benefits are illustrated in case example. Benefits are expected in model building, verification, time optimisation and process planning. There is potential of aiding the ongoing research activities in the business process reengineering and performance measurements. More examples and processes should be simulated under different operational conditions in order to improve insight and gain these advantages. Some of future research should include simulation of specialised industry processes.

Zlatan Car, Eng., PhD
Branimir Barišić, Eng., PhD
Marko Kršulja, Eng., MsC
Technical University of Rijeka, Technical Faculty,
Vukovarska 58, 51000 Rijeka, Croatia,
tel.: +385-51-651478, fax: +385-51-651468
e-mail: car@riteh.hr, barisic@riteh.hr,
mkrsulja@riteh.hr

References

[1] D. J. van der Zee: Modelling decision making and control in manufacturing simulation, Int. J. *Production Economics* 100 (2006) 155–167.

[2] Z. Car, I. Hatono, K. Ueda: Reconfiguration of Manufacturing Systems Based on Virtual BMS. // *CIRP Journal of Manufacturing Systems*. 33 (2004), 1; 15-24 (ISBN 0176-3377).

[3] W. Ferrell Jr., J. Sale, J. Sams, M. Yellamraju: Evaluating simple scheduling rules in a mixed shop Environment, *Computers & Industrial Engineering* 38 (2000) 39±66

[4] Kevin Tantisevi, Burcu Akinci:Transformation of a 4D product and process model to generate motion of mobile cranes, *Automation in Construction* 18 (2009) 458–468, www. elsevier.com/locate/autcon.

[5] Qidong Cao, J. Wayne Patterson, Xue Bai c: Re-examination of processing time uncertainty, *European Journal of Operational Research* 164 (2005) 185–194.

[6] Z. Car, T. Mikac: Evolutionary approach for solving cell-formation problem in cell manufacturing. // *Advanced Engineering Informatics*. 20 (2006), 3; 227-232 (ISBN 1474-0346).

[7] J. W. S. Chong, S. K. Ong, A. Y. C. Nee, K.Youcef-Youmi: Robot programming using augmented reality: An interactive method for planning collision-free paths, *Robotics and Computer-Integrated Manufacturing* 25 (2009) 689 – 701, www.elsevier.com/locate/rcim.

[8] G. Brletić: *Production of manufacturing accessories models for production process simulation*, Master thesis 2007, Technical faculty Rijeka.

[9] N. Suresh Kumar, R. Sridharan: Simulation modelling and analysis of part and tool flow control decisions in a flexible manufacturing system, *Robotics and Computer-Integrated Manufacturing* 25 (2009) 829–838.

[10] OKUMA Europe GmbH, http://www.okuma.de, (2008)

[11] KUKA Robotics, http://www.kuka.com, (2009).