VIRTUAL ENGINEERING APPLICATION FOR MODELING THE FLEXIBLE MACHINE STATION AT THE ORDER HANDLED MANUFACTURING SYSTEM

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ABSTRACT

The paper deals with the virtual engineering application for modeling the flexible machine station (FMS) at the order handled manufacturing system (OHMS). The FMS virtual model is crated as alternative to decrease the manufacturing cost in OHMS companies where non-productive time is dominated. Two types of FMS as “In line layout” and “Loop layout” have been used examining parts’ and their work pieces 3D CAD models. The modeling is based on created mechanical parts’ design features (DF) classifier, DFMA method and mathematical dependences for machining time versus removed material volume from the part’s work piece during machining operation. This methodology for FMS operations forecasting of the manufacturing time has been applied. Developed virtual FMS model has been tested applying piloting procedure in Lithuanian OHMS Company X.

1. INTRODUCTION

Future manufacturing will be run by smarter software. During past two decades the growing of digitization in various manufacturing fields is widely noticeable, particularly in metal parts machining industry [1]. This phenomenon made an attractive manufacturing changing instead hard manual work to FMS (flexible machine station) systems by specialized software programs with robots, pallets and work piece containers, and other means seeking higher productivity. In fact was observed that machining processes using FMS with much material handling, transportation and storage operations are associated. Moreover, machining and material handling operations are interfacing during manufacturing process and are able to decrease the non-manufacturing time. The FMS layout configurations in general on various types of line are based because more efficient utilization of factory manufacturing area, machine tools and material handling equipment. Enhance of efficiency applying lines in manufacturing demands the high compatibility of various CNC (computer numerical control) machine tools, transport means and robotics and at least tooling in accordance of time. Another problem of efficient FMS utilization is the characteristics, properties and complexity of machining parts materials, configuration and their output volume. There, strong relations exist among the customers and producers producing a finished product or its parts and components. Lithuania is a country of producers when many small and medium enterprises (SMEs) produce various parts and components of different end products developed in West Europe. Such Lithuanian companies work as order handled manufacturing system (OHMS) having modern machining metalworking CNC facilities and the people with appropriate skills; these machines are able to achieve a higher flexibility level of the products output volume. On the other hand high manufacturing competitiveness has dictated a product price that permanently goes down; therefore, the companies manage to survive by satisfying this requirement of market places. At the current moment tooling and similar products of automotive, machine building, electronic industry and structural constructions require low cost solutions in design

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and production. Then increase of above mentioned product diversity and number of producers has grown up while the batch of produced parts and components is decreased. These entire factors make advanced the order handled manufacturing approach and increase competitiveness.

Order-handled manufacturing systems involve make to order production's operations and customer-tailored end products. Research and practical experience [2] shows that production planning and control procedures can be more difficult to carry out when jobs are produced to order rather than for stock, because the operations are complicated by inherent sources of uncertainty. The target of an OHMS operation may be defined as the manufacture and delivery of products as proper design and quantity to customers' specification with an appropriate guarantee of product functionality and quality and prompt delivery at an acceptable cost [3]. Two types of OHMS are considered in theoretical and practical research domain of manufacturing science: 1) with the developing, designing and manufacturing the product and 2) without product development when product manufacturing is only needed. First type of OHMS is more complicated and it rarely occurs in Lithuanian industry because customers often keep a new product development in their hands. This research considers the second type of an OHMS in manufacturing of a large number product types and low production volumes. Companies that work applying OHMS approach always feel a strong pressure of customers' inquiries requirements to product properties, characteristics and delivery reliability. The high competition exists among producers to win each order because customers have very big choice in various countries and companies. At the beginning of Global manufacturing (GM) era a lot of industrial production moved from the USA, Western Europe, Australia and Japan to the developing countries in South-East Asia and Eastern Europe, while in many industrialized nations the hollowing phenomenon of the manufacturing section is observed [4]. A hollow company undertakes itself the functions of marketing, new products development and delivery. Lithuanian industry can survive only successfully managing its activity with West customers. In biggest part of orders, unfortunately, the product development and design is made by customers' side and many quality and productivity questions appear to producers seeking low cost of an order. Design for Manufacturability and Assembling (DFMA) methods [5 - 7] applied by innovative products' developers in various manufacturing systems are differently understood and required modeling of new approaches and solutions at the early product design stage.

The main objective of this research is to develop a FMS model for virtual engineering application and consideration in the order handled manufacturing systems. The following tasks for solving this problem have been foreseen: 1) Creation a virtual FMS model for machining simulation of the precision tooling parts and components, 2) Development of manufacturing process and cost forecasting method at the early tooling design stage applying criteria of removed material volume and qualitative-quantitative parameters (QQP) of machined surfaces, 3) Application of DFMA approach in tooling industry seeking the cost minimization, 4) Consideration a case study of tooling parts machining using the created virtual FMS model in Lithuanian company.

2. DEVELOPMENT OF A FMS VIRTUAL SIMULATION MODEL

The FMS virtual model is created as alternative searching solutions and new ways to decrease the manufacturing cost in OHMS companies when production volumes are low and products variety is high. The non-productive time in such production is dominated and FMS could be an alternative to decrease it. The consideration of this approach consists of five stages as follows: 1) Development of a FMS virtual simulation model, 2) Creation of 3D CAD models of mechanical part and its work piece applying DFMA approach, 3) Development of mechanical parts' design features (DF) classifier, 4) Development of mathematical dependences or nomograms for machining time versus removed material volume from work piece for definition parts' manufacturing time, 5) Piloting of developed FMS virtual model in Lithuanian company.

The FMS model is based on simulation work as the man-computer system when all mental operations are left to the user while engineering procedures and controlling operations are divided to the model software. Latter has two main programing windows: first of them is used for data input and second is reserved for FMS work simulation. The input data as a part name and number, quantity, material, order's customer, part and its work piece mass should be specified. The created virtual model enables to select one from two available FMS types for part machining simulation: "In line layout" and "Loop layout". Every type of FMS has its own equipment with different CNC machines disposition. After

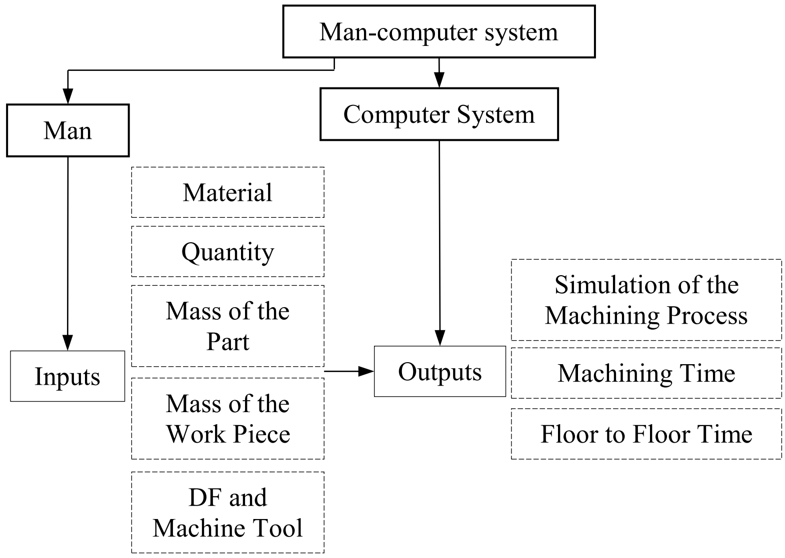


Fig. 1 Man-computer system for modeling the FMS virtual simulation model

input of a part general data, user has to specify part's design features (DF) and assign them to ranked CNC machine tool. The classifier of DF is created, which divides all available design features into two classes' level: prismatic form and rotational form. The production plan as operations' sequence is also left to man manual functions.

In-line layout virtual FMS model consists of the three CNC machines (two milling and one turning lathe), primary and secondary material handling systems including transfer devices, automatic pallet changers and automated stations for loading and unloading CNC machines by work pieces. Input data window of this type FMS virtual model is presented on the Fig. 2. In-line FMS for a small OHMS companies is typically used.

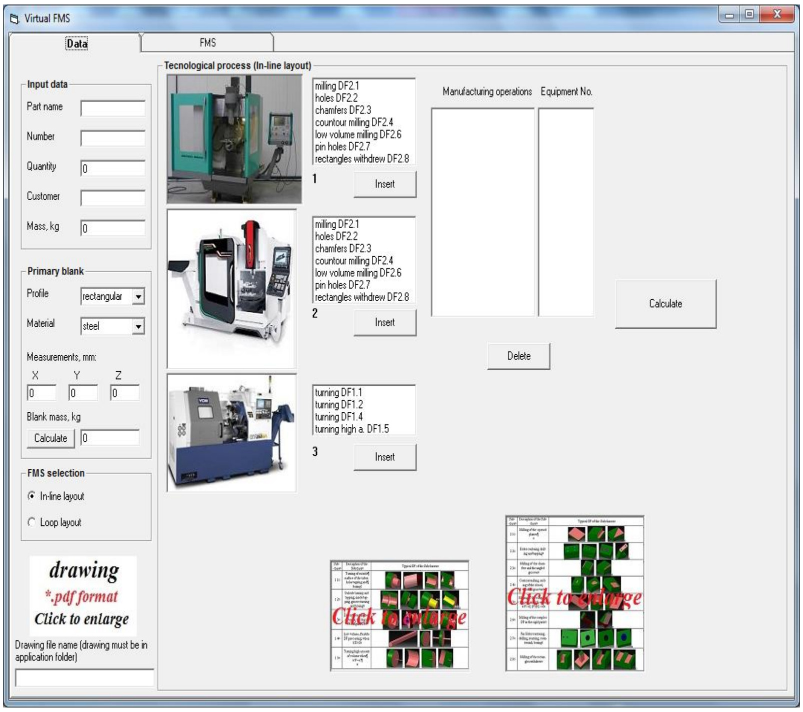


Fig. 2 Part data input to the "In-line" layout virtual FMS model

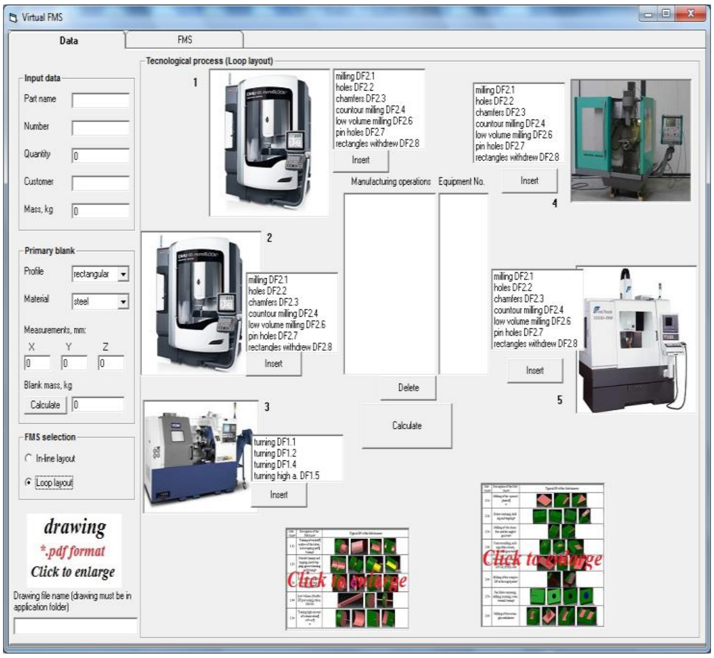


Fig.3 Part data input in Loop layout virtual FMS mode

Loop layout virtual FMS model consists of the five CNC machines (four milling machines and one turning lathe), and of above mentioned primary and secondary material handling systems and other means. Input data window of this type virtual FMS model is presented on the Fig. 3.Loop layout FMS is better to use to the medium size companies. The both types of virtual FMS models are realized applying the programming language Visual Basic 6. The purpose of developed model is to simulate the machining process of a mechanical part or component in virtual FMS manufacturing system including creation of a process plan, machine-tool and tooling selection, machining time and floor to floor time definition and simulation of a part transportation flow through shop floor.

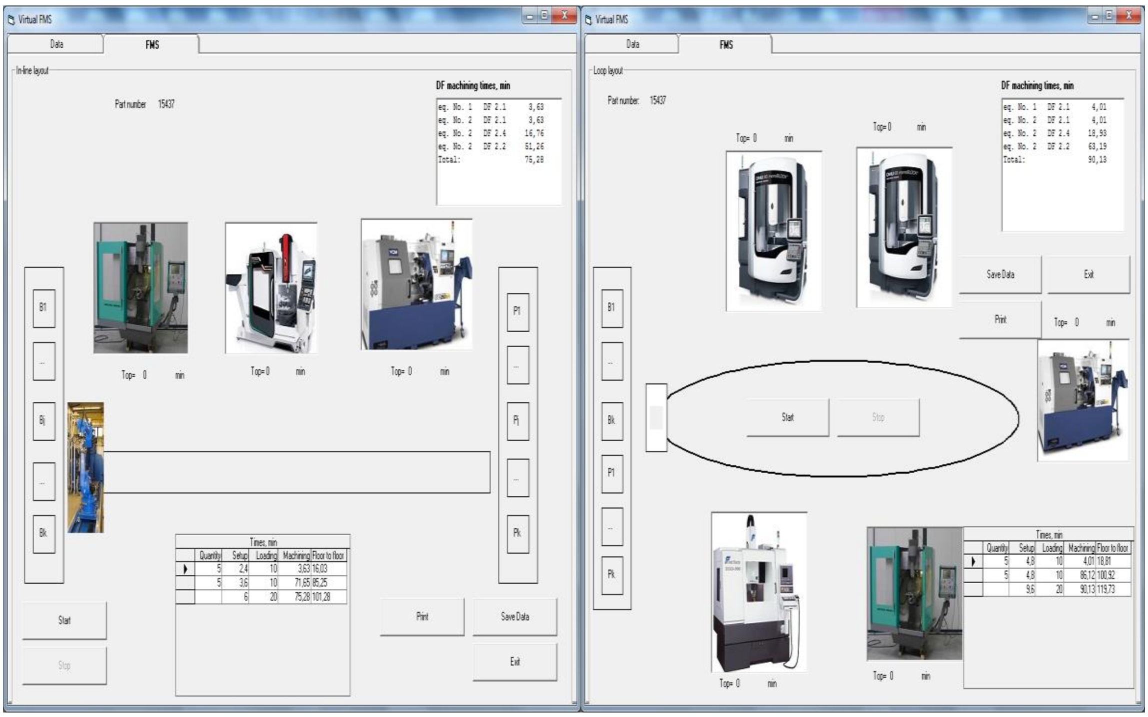


Fig.4 Part machining simulation windows at the both FMS virtual model layouts

The part machining simulation windows of both virtual FMS models layouts are presented on the Fig. 4. After the selection of virtual FMS model type user should fill part's data specifying its DF and appropriate machine tools in accordance of a machining sequence. The machining and floor-to-floor time for each assigned FMS operation is forecasted applying the mathematical formalization of dependency nomogram among the machining time and removed material volume from part's work piece [8]. The manufacturing time subjected to DF geometrical form, dimensions, tolerances and other QQP including material of a considered part and tools. An extraction of the part's DF and data input is performed at the interactive regime.
The removed material volume v from part work piece during FMS machining operation simulation as a main criterion of machining time T_m has been used. The appropriate dependences T_m and v have been created for every DF class level in nomogram form. It is said that other factors influencing to the value of machining time T_m as material (t_1), accuracy and surface roughness (t_2), tool material (t_3), production volume (t_4) and specific peculiarities of the part (t_5) are conditionally constant and are evaluated in forecasting approach by correction coefficients. The other manufacturing time constituents that also influence to the rate of floor-to-floor time as load and unload machine tools by work pieces, setup and transportation time are conditionally constant and are kept in the DB of a developed model.
There is described a methodology of creation a mechanical part and its work piece applying 3D CAD parametric multifunctional model for automated definition of removed volume the each DF. Multifunctional 3D CAD model has a structure which leads it to be work–friendly for engineers, especially for the producers. Each mechanical operation must be added or removed as a separated body to the part seeking a mentioned result. This option leads to design 3D CAD model to be useful to users and designers to make easiest changes for the part geometry. Besides those functions models provide engineers correctly estimate parts characteristics and functions in a virtual environment. It is also imitation of technology design in virtual environment.

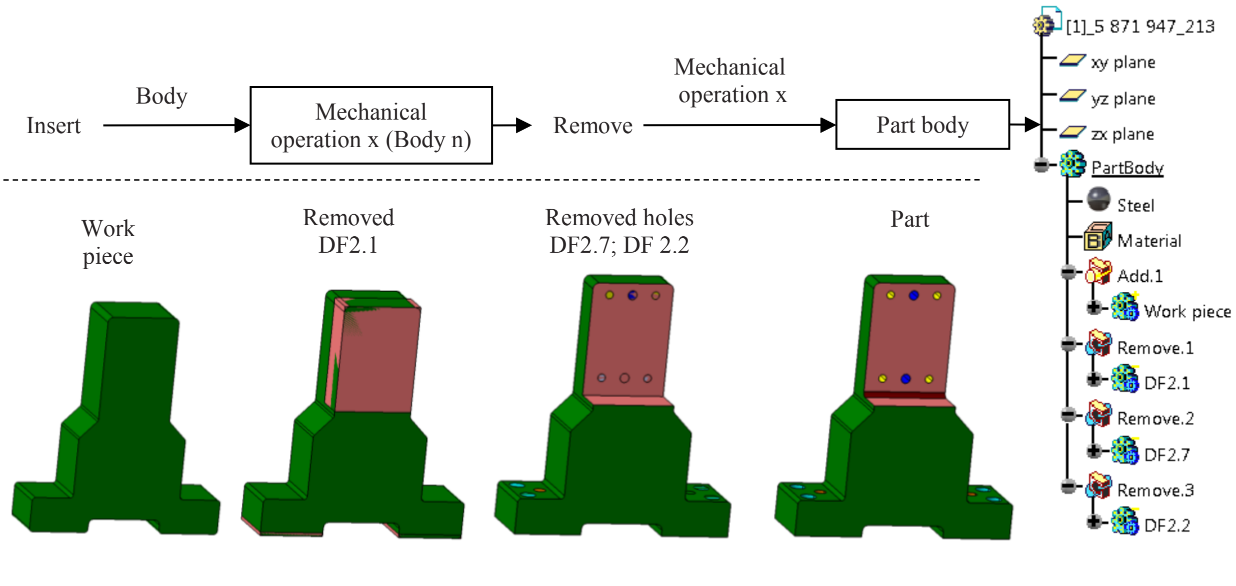


Fig. 5 Multifunctional 3D CAD model and its design sequence

Fig. 5 shoes the sequences how work piece becoming a part when each following inserted body of. DF becomes a mechanical operation removing material from the work piece. The presented methodology of a work piece creation using part's 3D CAD parametric model leads to the fast its design method defining the material volume v that is removed from the work piece body forming the every DF. Defined material removed volume is applied in mathematical formalization of forecasting the machining time T_m of each FMS operation.
Long experience of co-operation among automotive tooling design and assembling company in Germany and the OHMS manufacturing company X in Lithuania that produces such parts and

components established productive relations enhancing work effectiveness due to the DFMA approach in tooling industry. There were created and proposed DFMA guidelines for designers' the automotive tooling parts and components field. The application of such guidelines helped to facilitate and accelerate the production process of tooling parts applying FMS. The main focus is concentrated to avoid machining operations of secondary surfaces of tooling parts and increasing the number of machining surfaces on one griping tool in CNC machine. Introduction of mentioned DFMA approach signally decreased the production cost of automotive tooling parts and components. The development of flexible pallet magazine (FPM) system seeking higher efficiency loading and unloading FMS machines by work pieces have been used in this research. The decision to use FPM in FMS line provides a cost-effective alternative instead traditional completing by specialized fixture tooling in manufacturing companies.

The question when is better to use the FMS cell or FMS system in OHMS machining companies was considered in this research. FMS cell is a very attractive alternative for SMEs and individual entrepreneurs arranging loading the FPM by work pieces in overlapped work place outside of CNC machines achieving twenty four hours' work per day. The fixture tooling of FPM has been designed that would help to decrease the number of re-loading procedures of work pieces during FMS machining operations. For this reason not only fixtures' design and FMS machining plan has a key influence; customer and product designer has to look possibilities applying DFMA approach to decrease the number of machining surfaces and their qualitative-quantitative parameters (QQP). Designer has to look solutions of the customer's part final geometrical form with less number of flats with DF and less machining operations. In this case final customer part and its work piece must keep closer as possible geometrical form and dimensions. Such collaborative design can propose apply water jet or gas cutting operations for work piece and minimal production cost. The mentioned problem is discussed in the third chapter of this paper.

3. THE PILOTING OF A VIRTUAL FMS MODEL

The efficiency as cost, manufacturing time and twenty four hours' work of equipment for machining components on the FMS in OHMS companies is main criteria. The piloting of a virtual FMS model is related with three main reasons: manage risk, validate benefits and work force motivation. Manage risk in piloting procedure is limited in its process and organizational scope, so it is important to design the pilot to be able to test the most contentious risk areas, i. e. investment, manufacturing time and cost and reliability.

A pilot project is a great opportunity to validate benefits by applying the solution concepts in a limited-scope fashion. There were considered various tooling products design and manufacturing process interaction and productivity increasing possibilities. Every tooling product and its part or component has many properties and characteristics distinguishing it from other products. Such characteristics and properties are result of including the different DF and requirements of QQP as well as material, surface precision and roughness, manufacturing conditions, and so on. Classification of products or their DF is aimed to facilitating and accelerating the process of developing manufacturing process and its realization cost at the early product design stage. Applying classification has been defined statistical average of distribution various DF in tooling parts and components, which was applied for cost forecasting. Twenty eight prismatic parts' groups and total number over 500 collected parts have been analyzed and dependence of statistical and real machining times upon removed volumes has been defined. The nonproductive costs of loading and unloading FMS by work piece searching machining on one machine tool only have been also considered and evaluated.

An important emphasis of the project benefit was the piloting of a virtual FMS model. Seeking to improve FMS model performance and to enhance the accuracy of the research results eleven students from UA (University Angers, FRA), UM (University Le Mans, FRA) and KTU Mechanical Engineering and Design Faculty have been involved for the FMS virtual model piloting process. This allowed us to adapt and improve the parts cost evaluation process in the early process design stage. Each testing participant designed multifunctional virtual 3D CAD solid model by the given task. Those 3D CAD models led the students rapidly evaluate the characteristics of the testing parts in a virtual environment at the early process design stage. By applying virtual simulation model and operating mentioned data the statistical and FMS floor to floor times were forecasted. Simulations of the manufacturing process were loaded in the FMS model environment. Data gotten during the model piloting process are presented in Table 1. Material selected for the each involved part during the simulation is mild steel. The 2D drawings of the parts are available in FMS software in a “pdf” format. The configurations of the some parts and the work pieces are available in presented Table 2.

The housing parts of tooling presented in Table 2 have been redesigned on the recommendations of DFMA approach [9]. Main requirement was to use two or three flats with DF that require machining operations. The result achieved is decreased number of work pieces reload in FMS CNC machines that is a main factor of decreased floor-to-floor manufacturing time. The redesign of various housing parts of automotive industry tooling called the exchange of their structure and assembling schemes that have been checked by every tooling functionality and manufacturability and assembling indices in the virtual reality (VR) environment.

Table 1 Statistical and FMS floor to floor times of disseminated parts

Part No.	Mass of the Part, kg	Mass of the Work Piece, kg	T_s Floor to Floor, h	FMS Floor to Floor, h	*P*, %
1	2,84	4,08	6,15	7,31	18,94
2	6,65	7,93	6,19	7,21	16,55
3	8,37	9,47	8,04	7,23	10,1
4	7,43	11,37	13,89	17,64	27
5	2,12	2,57	3,85	3,33	13,61
6	1,52	1,98	5,29	4,50	5,05
7	4,50	5,39	4,38	3,99	15,22
8	5,06	6,06	10,24	8,85	19,56
9	6,62	8,54	6,24	9,63	36,41
10	2,89	3,83	5,60	5,05	4,77
11	0,53	0,98	5,16	3,79	26,61

**P*- the bias between parts’ theoretical and FMS Floor to Floor times

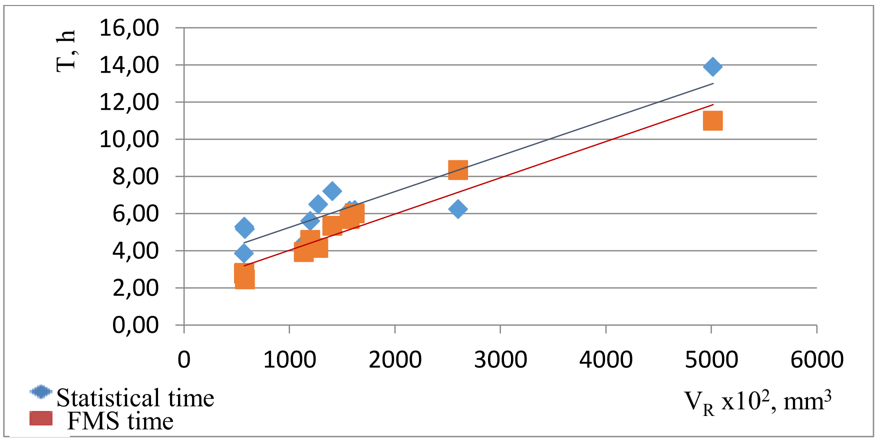
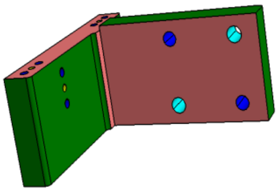
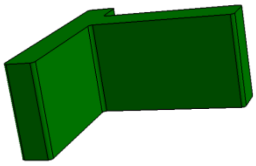
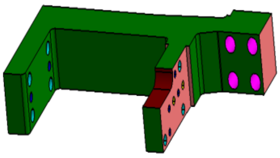
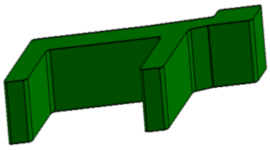
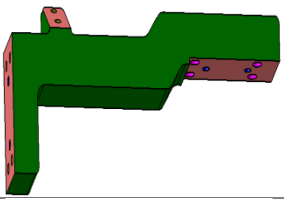
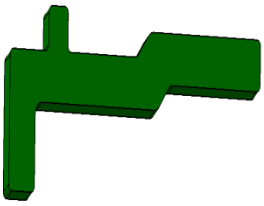
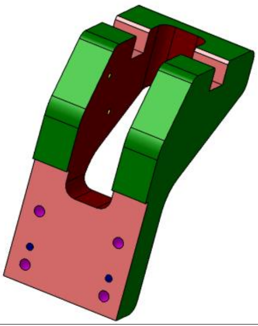
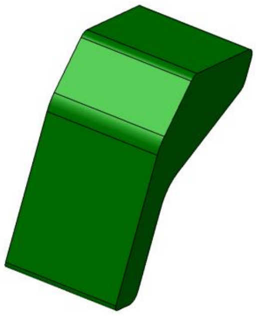
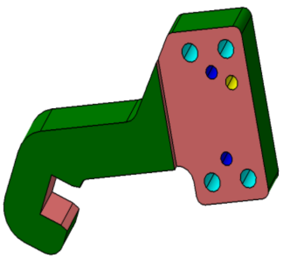
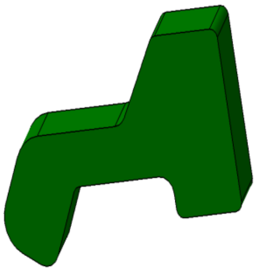
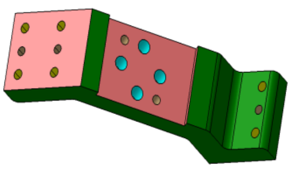
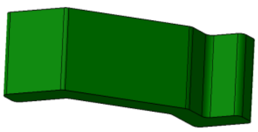


Fig. 6 Graphical representation of the statistical and FMS floor to floor times

Table 2 The result of redesign the mechanical parts becoming manufacturing friendly applying DFMA approach

No.	Part's, 3D CAD model	Work Piece's, 3D CAD model	Part's overall dimensions, *mm*	Work Piece's overall dimensions, *mm*	Number of reloads	
					Before DFM	After DFM
1			70x148x147	70x148x154	3	2
2			50x162x322	50x167x332	3	2
3			60x145x385	60x145x390	2	2
4			100x150x200	100x150x200	3	2
5			30x117x182	30x117x182	2	1
6			50x114x167	50x124x167	3	2

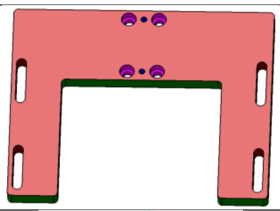
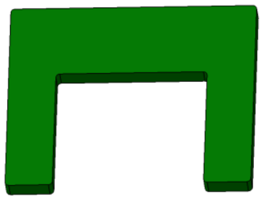
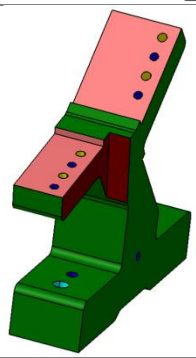
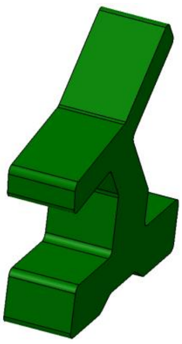
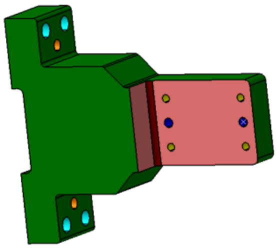
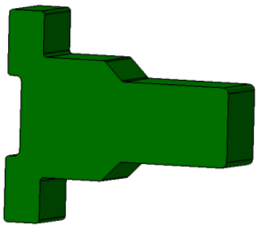
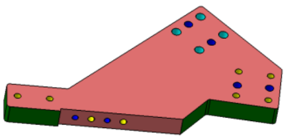
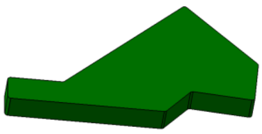
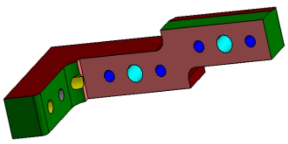
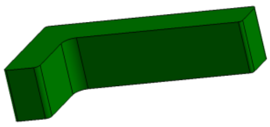
7			18x215x260	20x215x260	2	2
8			50x186x215	50x193x215	4	2
9			55x185x205	55x185x208	3	2
10			20x154x257	25x154x257	3	2
11			30x65x135	30x65x138	3	2

Fig. 6 represents results of the Company X statistical and the modeling of virtual FMS floor-to- floor manufacturing time in hours. Statistical data is based on the results of some manufacturing divisions that work by separate CNC machines in accordance of job-lot.

4. IMPLEMENTATION AND FURTHER RESEARCH

The developed virtual model or its separate parts are implemented in industry and technological universities and colleges in the Lithuania. The implementation results in some organizations have shown that the model is able to generate some alternatives for a work piece and a process plan in virtual reality environment. It is applicable for the optimal process planning. Application of the virtual model makes it possible to determine whether it is feasible to produce the part with appropriate resources and reduce the time to 40 – 60% of alternative process plan evaluation. Comparing the results of manufacturing cost calculation obtained using the created model and traditional methods the noticeable inadequacy does not exceed 8-12%. On the other hand the implementation of a model requires changing the former order of organization activity preparing and sharing the information for the product and process design. Sometimes it causes the dissatisfaction of the employees in an organization. The appropriate re-training program of engineers is necessary seeking their more effective work in the integrated manner.

It is planned to investigate and to upgrade the structure of a virtual FMS model seeking more effective interfaces among various computer systems employed for generation of necessary information. Our future work is devoted to the new tooling products and processes development increasing the collaboration and creativity among manufacturing people.

5. CONCLUSIONS AND FINAL REMARKS

The research of this paper presents the virtual engineering application for modeling the flexible machine station (FMS) at the order handled manufacturing system (OHMS). The developed model examines available machining and parts' design alternatives in virtual environment applying DFMA approach. The advantages of this model are several: the originated definition of FMS operations manufacturing and floor to floor time, first examine to use FMS in OHMS and application of DFMA method for parts design and manufacture in FMS. It is also very attractive for industrial employees' vocational training and for manufacturing people working at the front with customers discussing parts' cost.

The modeling method that has been developed in this paper accomplishes the objective of this research. However, this is not the only modeling method currently available because there are many propositions in Internet and other virtual reality sources related to FMS systems. Most of them are showing FMS layout and parts transportation systems without technological and manufacturing definitions. The advantages of current model are several: the originated forecasting of FMS operations manufacturing and floor to floor time, first examine to use FMS in OHMS and application of DFMA approach for auto moto tooling parts design in collaborative with producers. The principal shortcoming of a developed model is insufficient use of media FMS means of the virtual reality.

6. ACKNOWLEDGMENT

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