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NON CLASSICAL APPROACH TO OPTIMIZATION OF MANUFACTURING PROCESSES

I. Introduction

In recent years optimization and virtual reality plays significant role in a design process but specially in a manufacturing planning process [1,2,3]. Big companies put emphasis on research in this way. Usually in every branch of industry before anything will be produced or even executed in the form of prototype are carried out a computer simulation. It involves a lot of benefits where the most important thing is saving of the cost.

The other are: possibility of a planning product logistic, estimation of a manufacturing time and cost, a safety area, possibility of caring out a breakdown simulation, workers' training and so on. Mistakes which have not been detected in the conception, design and simulation phase – generally in the first stage of a creating any product - are causing huge costs in manufacturing phase. It is repeatedly bigger than in case of detecting fault and other shortcomings in the first stage manufacturing.

The description shown above can be treated anything what is connected with an industry and not only. An object can be a car, a part of car's body, and also a factory, its department, a manufacturing line or even a single production process. In connection with this an essential element of a production is simulation. A simulation which allows to optimize a manufacturing process.

Currently on the market exists not too many applications, which enable to execute planning processes that are integrated with CAD/CAM. One of them is Virtual Reality Modeling Language – VRML. In the paper the classical optimization problem is formulated as the mathematical description of design principles. The non classical formulation of optimization is proposed in opposition to fully mathematical approach. This approach is based on realistic simulation generated in virtual reality environment. The optimization criteria in computer aided design and specially in design of assembling processes are considered. The simulation and optimization of assembling of gear box is presented in VRML environment.

II. Classical Optimization Problem

Considering a technical process which has to be planned there are two basic principles, called general design principles [1] to follow. They represent two different points of view: From actor's the point of view

I. The action should satisfy all given conditions and rules

From external point of view:

II. The result of the action should be "best solution" with respect to assumed criteria of optimization

It should be stressed, that any action which follows the first principle is a good-solution-action. Generally, there exists a set of good actions, i.e. a wanted good result may be achieved by more than one specific action.

The results satisfying the second principle are optimal, also with respect to multiple criterions. It is to be emphasized that the meaning of a good solution is relative. It can be truly good or bad depending on definition of conditions imposed on the action. These conditions are adjusted to the requirements to be fulfilled by the production plant.

For the sake of clarity let us write the project design principles in a mathematical form [1]. The project should fulfill the functionality condition to the equal or higher extent from that assumed. Each designed system can be described uniquely by all structural parameters (geometric, material, dynamic). If we allocate to each feature of designed structure a single number or a set of numbers then we are able to describe the entire project structure uniquely by the set of N numbers. The structure can be regarded as a point x in the N-dimensional Euclidean space

$$x = (x_1, ..., x_N) \qquad x \in R^N \tag{1}$$

The coordinates xi can be separated into a group of the imposed parameters and a group of the coordinates to be fitted in the course of the design process. The latter group represent the so-called set of decision variables. Thus the structure can be described by n decision variables and P parameters:

$$x = \underbrace{x_1, ..., x_n}_{\substack{\text{decision} \\ \text{variables}}}, \quad \underbrace{x_{n+1}, ..., x_N}_{\substack{\text{parameters} \\ N-n=P}} \tag{2}$$

The project which satisfies all requirements (satisfies the first principle of design [1]) has to belong to the allowable set Φ. Thus the mathematical description of the project has the following form:

$$x \in \Phi, \qquad \Phi \subset R^n \tag{3}$$

The second design principle [1] says that from all the allowable solutions (in the set Φ) one should choose the optimal solution, i.e. that one for which the objective function assumes an extreme value (either minimum or maximum). The objective function is a function of decision variables. The point at which the objective function reaches its maximum or minimum value will be called the optimal solution (optimal project): The second design principle can be thus formulated in the following form:

$$\left(x_{opt} \in \Phi\right): \left\{\forall\, x \in \Phi \quad Q(x) \geq Q(x_{opt})\right\} \tag{4}$$

Designer usually should consider many objective functions. It leads to multi-criteria optimization [1]. When model of optimization (decision variables, feasible domain, objective functions) is defined it quite easy find the optimal solution. The selection and description of optimization goals is not easy. For the objective function one chooses a function related to individual conditions, such as efficiency, output, functionality, quality. Very often it is related to costs. The objective function can be a combination of numerous conditions. As an example, following criterions for an assembly process may be registered:

- Value Added / Non Value Added Ratio for each operator,
- Number of operators,
- Workload of each operator (for instance cumulated ways, loads),
- Required production per hour, Desired cell cycle time

III. Non Classical Approach to Optimization Problem

If we talk about the process quality in the machine design and in manufacturing / assembly one should note that the design and optimizing procedures run in a very different manner. Whereas to both theoretical methods of optimization may be applied, the role of the human seems to be considerably different. According to design and manufacturing experience all the actions done by human operators run under normal or distorted conditions. Since work analysis under distorted conditions during the product design phase takes place in special adjacent areas of work psychology studies, the focus on human work in manufacturing is evidently chained to the basic industrial engineering practice. Much research has been assigned to studies on human performance, a state-of the art may be found in [2]. Especially in case of manual assembly lines like the final assembly of a vehicle, factors such as: work environment, physical characteristics of individual worker, motivation and supervision, group dynamics have a great influence on the overall quality and efficiency of a line.

A concise characterization of practicably approved methods for assembly line design and optimization may be found in [3]. Assembly line balancing (ALB) problems are widely investigated in literature considering the stochastic variability of task duration and it's assignment to a particular worker. A similar line of reasoning also applies in solving workforce planning problems where the planed assignment is based on nominal human performance data. A very vague problem of modeling worker behavior is the individual variation of properties in time, namely in the short run like during the particular shift as well as in the long run where factors like the actual condition of company (e.g. possibility of job loss) and personal feeling (social, personal situation) shape the performance profile.

Considering all aforementioned remarks about the human factor it may be said, that an assembly process may be modeled and optimized under the assumption that the included workforce meets fully the demands of the overall line output, an assembly process may be modeled and optimized under inclusion of the individual and specific behavior of the workforce.

These two cases may be differentiated through the allocated probability to those decision variables which stand for a particular worker operation. Generally, case (2) says more about the actual process quality because the likely changes in the human behavior will be included. And that part of the optimization procedure shall be called non classical or "expert" optimization. Expert optimization depends on a reliable set of variables allocated to a given manufacturing respective assembly operation. There is a question how a set of sound worker-allocated variables can be won. Following sources may be outlined:

- Allocation of probability factors
- Allocation of sets based on findings of work psychology
- Derivation of sets from data mining
- Derivation of sets from virtual worlds

These procedures are not really independent, since all depend on practical experience of the process planning specialists. Based on a preceding research of the authors [2,4,5,6] the non classical, expert optimization may be favorably accomplished by modeling the individual behavior of workforce in the virtual environment. The main difference to the conventional approach is that the simulation runs in "a real world", where real humans (avatars) and real machines may be seen and felt. If such a simulation is being run by an experienced planner then the quality of reasoning towards an optimal solution would be more probable.

It has to be said that the models behind the avatars come, at the present, from traditional optimizing methods. New approach should provide avatars with agent-like characteristics who search and follow optimal work functions according to the given constrains. Here again, the possibility of analyzing "real" process in virtual environment by expert engineers give more chances to getting an efficient and safe process. Additionally, such a virtual environment may be made available through network to a planning team spread over different locations.

The actual abstract procedures of assembly process planning are difficult to explain to the workforce in the development phase. Standard approach is building mockups of the assembly cell for the training course. The line balancing takes place in the subsequent video analysis. Developing a virtual future line in the virtual environment makes possible omitting mockup phase entirely.

The complexity of the data behind the virtual workforce can be very different: in the first approach the known algorithms of ergonomics and psychology of work may be applied to "standard" workers; in the future the actual data of a specific cell may be collected. Even a data on a specific team may be won and such a team my follow and evaluate itself working on future project in virtual environment. The comparison of the steps of assembly process development using the conventional and the virtual reality technology shows all advantages of VR approach. Both procedures are preceded by known steps of data acquisition and conventional optimization.

First step - data acquisition for a new process,

- product structure (3D models in a full and simplified form),
- volumes and cycles required,
- operations strategy, e.g. to build a new or to adapt an existing assembly line,
- developing a rough logical layout concept.

Second step - conventional optimization of the layout

- derivation of the constrains,
- search for the optimal solutions,
- trade offs for the multiple solutions,
- release of the line design.

IV. Example of Non Classical Optimization

As an example of non classical solution of optimization problem in Virtual Reality environment the assembling process of the gear box from Mazda car was selected. The following criterions for an assembly process were proposed:

- value added / non value added ratio for each operator,
- number of operators,
- workload of each operator (for instance cumulated ways, loads),
- required production per hour,
- desired cell cycle time,
- safety,
- ergonomics,
- quality.

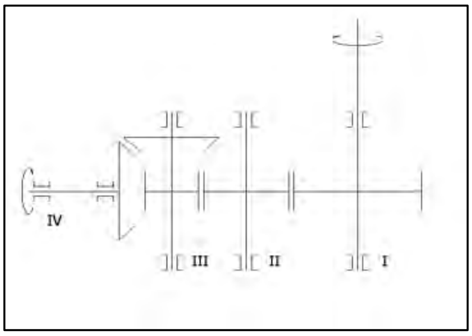

Fig. 1. Schema of gear-box

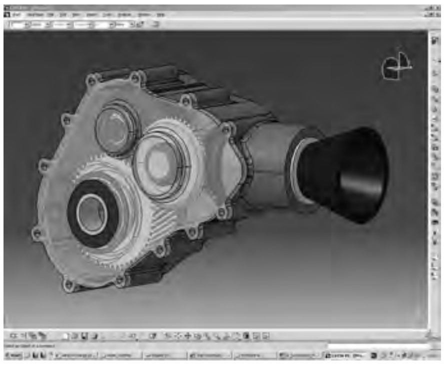

Fig. 2. CAD model of gear-box

Some of this criterions are very easy to calculate but some (safety, ergonomics) are recognized and evaluated during simulation in virtual reality environment

The schema of gear box is presented on fig. 1. The CAD model of this gear box created in Catia system is presented on fig. 2. Assembly process is realized on assembly line, where is operated by three workers and it takes 8 assembly stages. Two of them are fully operated by robots. The whole assembly process consists of 28 operations. The schema of assembly process is presented on fig. 3.

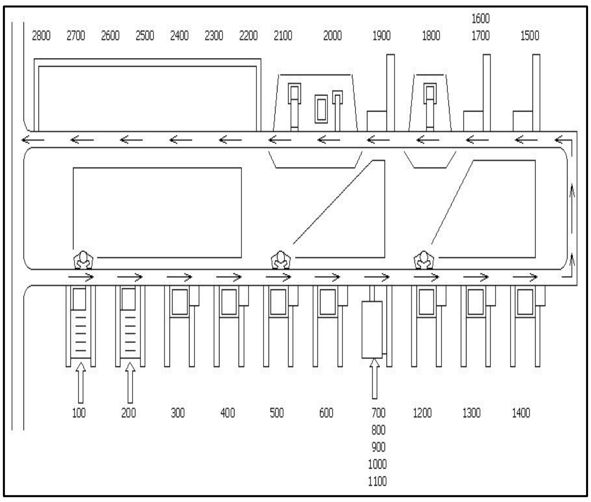

Fig. 3. The schema of assembly process

General view of assembly process and view worker in assembling process, created in VRML environment is presented on fig. 4 and 5.

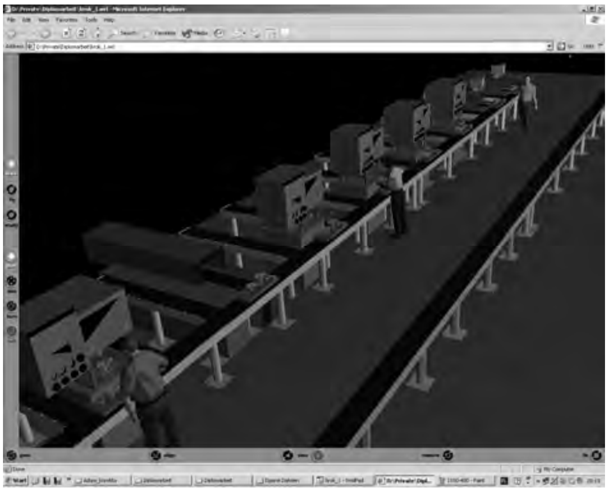

Fig. 4. The view of assembly process

Fig. 5. Worker in assembling process

In final result of this non classical optimization, after many simulation session and analysis, all considered criteria were reduced.

In conclusion one may say that virtual reality tools can be efficiently attached to the optimizing processes in industrial engineering. They are especially useful to support of experience- and intuition based areas of production planning with high share of manual work like an assembly processes.

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