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COLLABORATIVE PRODUCTION SYSTEMS DESIGN THROUGH USIT METHOD

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ABSTRACT: *The Bulgarian industry is strongly focused on the EU markets. One of the most promising directions for development of the Bulgarian industrial enterprises is the development of business partnerships with industrial enterprises from the European Union. Most problematic for the development of such partnerships are the unsuitable characteristics of the production systems in the Bulgarian industrial enterprises. The present work suggests a process for development of the production systems characteristics, based on an Unified Structured Inventive Thinking method (USIT). The main characteristics which should be possessed by the production systems of the contemporary industrial enterprises are described. There is a description of the stages of the suggested process for elaboration of the production systems characteristics.*
KEYWORDS: *Production systems, small and medium enterprises, Inventive thinking, cellular manufacturing systems*

INTRODUCTION

Manufacturing industries are under the economic pressure to compensate increasing cost and create added value. Under these conditions it is necessary to change the paradigms from former cost orientation to competition, added value and sustainability. Manufacturing is the key area which has the potential for change. But it is not only a question of research and engineering, it is even a question of business systems and activation of the human resources to implement innovation as fast as possible to change the practice from cost and profit optimization to competition, innovation and sustainability.

A revolutionary change from tayloristic to sustainable manufacturing is required to solve the coming problems in the industrial world: sustainability of enterprises and business; sustainable technologies in products and processes; global environmental and social standards of work.

CHALLENGES FOR THE MANUFACTURING ENTERPRISE TO ACHIEVE SUSTAINABLE DEVELOPMENT

Manufacturing enterprises are striving to achieve sustainability through changes in products, processes, and systems. Refocused efforts on the development of sustainable technologies can further aid continuous improvement and stimulate revolutionary advancements industry-wide. Current and future challenges facing the manufacturing industry are addressed in terms of manufacturing enterprise, product life-cycle design, and manufacturing processes and systems.

Small and medium enterprises as subcontractors. *Small and medium-sized manufacturing companies (SMME) play a significant role in today's economy [1]. 99 % of the companies are SMMEs [2]. Many SMMEs are subcontractors to larger companies [3] and are therefore highly dependent on them. Historically, a subcontractor works for a limited number of larger customers [4]. Competitive advantages have been low price and whether the subcontractor is located near the customer [4]. This is however changing and more and more SMMEs are aware of this challenge and try to increase their customer base.*

The challenges for the SMMEs have increased [4] during the last years. The challenges come from the increasing globalization and the increasing customer demands. The globalization increases the access to new technologies, to new knowledge, and to new markets, but the competition also becomes more severe.

Supporting Function of Lean Production Systems in Small and Medium Enterprises. *Small and Medium-sized Enterprises are facing the hard competition of global markets and the more specific and higher requirements of the customers everyday. In order to cope with these challenges many enterprises implement a lean production system. For the implementation of a lean production system a continuous support of a well-structured qualification background is necessary.*

Lean production systems do not only help to reduce waste in the production process but also allow the enterprise to focus on customer value [5], [6], [7].

ENGINEERING DESIGN THEORIES OF CREATIVITY

Theories of engineering creativity draw on theories of creativity in general. However, limiting the focus to engineering domains enabled researchers in engineering creativity to present their theories in less abstract, more concrete terms.

- ***Creative Design as Case Based Reasoning**. The process of engineering design draws to a large extent on the retrieval of past designs or design principles which are then adapted to current requirements. Past designs can be stored in two different granularity levels, both of which can potentially give rise to creative designs: pieces of elaborate design solutions at a low granularity level, and first principles at a high granularity level.*
- ***Creative Design as Increasing Dimensionality**. Cagan and Agogino [8] express a concept of creative design that is similar in view of the creative process in general: "Non-routine Design differ from routine designs in that the latter are derived from a fixed space while the former are characterized by an expanded design space". Based on their definition of non-routine design, Cagan and Agogino suggest a computation mechanism that uses optimization information to make decisions on how to manipulate and expand the design space by introducing new variables, thus increasing its dimensionality.*
- ***Creative Design as Overcoming Contradictions**. According to Altshuller, a design is creative when it resolves a conflict but not through tradeoff or compromise [9]. Altshuller generalized his theory by observing a large number of engineering inventions and juxtaposing them with ordinary or routine solutions suggested for the same problem.*
- ***Creative Design as Function Sharing**. Function sharing in mechanical design, according to Ulrich [10], is the simultaneous implementation of several functions in an artifact, by a single structural element. Ulrich states three main reasons for the importance of function sharing in engineering design: first, designs that exhibit function sharing are in most respects better than those that do not (fewer parts, easier assembly, less required maintenance, better performance due to decreased size and weight etc.); second, awareness of the process of function sharing allows the designer to think in a modular, decomposed fashion with the option of subsequently using function sharing to make the design more efficient; third, function sharing is one of the sources of novelty or interest in mechanical design.*

METHODS FOR SUPPORTING THE CREATIVE PROCESS

Four of the most popular, creativity enhancements methods are used currently by corporations. The methods differ in their underlying principles, reflecting the various theoretical approaches for the creative process presented in the former sections.

- ***TRIZ**. TRIZ a Russian acronym for Theory of Inventive Problem Solving (or TIPS in English) was developed by Altshuller [9] and is continually being developed and modified. TRIZ is composed of a few distinct problem-solving and problem-definition procedures and principles as well as a unifying algorithm called ARIZ.*
- ***Brain Storming**. Brain Storming [11] is perhaps the most popular and most widely used creativity enhancement method. It is a group method that divides the thinking process into two main phases: idea generation, and idea evaluation. The strict rules of brain storming prohibit any sort of evaluation within the idea generation phase. In this stage, 'crazy' ideas are most welcome; producing as many ideas as possible is encouraged.*
- ***Synectics**. Synectics means joining together of different and apparently unrelated elements. According to Gordon, who developed Synectics [12], problem-solvers often fail to discover a creative solution because the problem may be either too familiar or strange. Synectics uses analogies and metaphors as a means to turn the familiar into strange and the strange into familiar. Synectics, like Brain Storming, encourages suspension of judgment, and also 'play with apparent irrelevancies' during what is called the excursion stage. In the excursion stage, different analogies are used to view the problems from different directions and to direct the thoughts toward a creative solution.*
- ***Morphological Analysis**. Morphological analysis [13] is used mainly to invent new products rather than solve problems. Using this method, the inventor first constructs a list of the properties of an existing product and the possible set of discrete values the property can assume.*

OVERALL STRUCTURE AND OVERALL PROCEDURE OF UNIFIED STRUCTURED INVENTIVE THINKING METHOD (USIT)

***Basics of Unified Structured Inventive Thinking (USIT)**. USIT was developed by Ed Sickafus [14] in 1995 and intensively used at Ford Motor Co. At first he adopted Israeli SIT (Systematic Inventive Thinking) [15], which was a much simplified version of TRIZ, and then he introduced a new framework and built USIT. Nakagawa have introduced USIT in Japan since 1999 [16] and have extended it further by reorganizing TRIZ methods of solution generation into the USIT framework [17].*

***Overview of USIT**. The goals and characteristic features of USIT may be summarized as follows [18]:*

- *USIT is a methodology concentrating in the "Concept Generation Stage", which is at the uppermost in the course of product/technology development.*
- *USIT intends to be applied to real practical problems for rapidly generating multiple conceptual solutions.*
- *USIT provides a clearly defined simple procedure for applying the methodology. The procedure is composed of three stages, i.e. Problem Definition, Problem Analysis, and Solution Generation.*
- *The technological system of the problem is described in clearly-defined terms of Objects, Attributes, and Functions.*
- *Elements of techniques in USIT are simple and well explained in guidelines. Especially, there are only four techniques used for the solution generation, and they are used in correspondence to the concepts of Objects, Attributes, and Functions.*
- *No outside knowledge bases and software tools are used in USIT.*
- *Engineering details, such as specifications, figures, numbers, costs, deadlines, etc., are put aside the consideration during the USIT procedure. This choice aims to make the concept generation as freely and widely as possible.*

Overall Procedure in USIT*. The Overall Structure of creative problem solving is realized in USIT by the use of Overall Procedure as shown in a Flowchart in Figure 1.*

Problem Definition Stage: The process for converting user's specific problem into Well-defined specific problem. This process is usually carried out through a group discussion in the USIT project team.

Problem Analysis Stage: In order to obtain the understanding of the present and ideal systems in the Well-defined specific problem, the following three analysis methods are carried out in sequence:

- *Function and Attribute Analysis of the Present System: The present system in the problem is analyzed with the following two methods in sequence: Functional Analysis; Attribute Analysis.*
- *Space and Time Characteristics Analysis: Draw some diagrams for revealing characteristic features of the system/problem with respect to space and to time.*

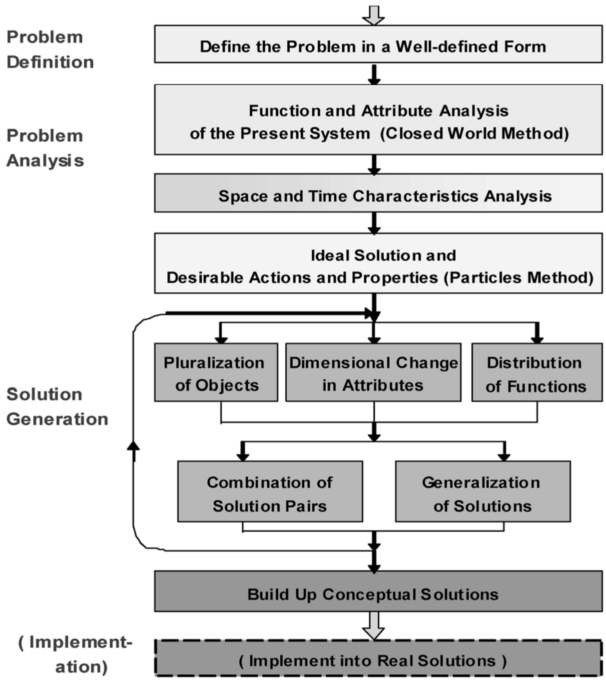

Figure 1. Overall Procedure in USIT

- *Particles Method: A process for identifying Ideal Solution and imagining desirable actions and desirable properties is carried out in the following sequence: Sketch the present system; Sketch an Ideal System; Imagine an ideal result and draw it, without trying to draw any means to achieve the result; Draw 'Particles' with x marks; Draw x marks at the positions where the sketch of the Ideal System differs from that of the present system; Imagine Desirable Actions and draw them in a hierarchical diagram; Ask the magical Particles to achieve the goal of the ideal solution, and then break down the actions that the Particles are imagined to be doing for us; List up desirable properties*
- *Solution Generation Stage: Process of generating many pieces of new ideas and then building up conceptual solutions for new system(s). Five solution generation methods in the form of USIT Operators are applied repeatedly without any fixed order: Pluralization of Objects; Dimensional Change in Attributes; Distribution of Functions; Combination of Solution Pairs; Generalization of Solutions.*

These five USIT Operators are always applicable to the elements of the present and solution systems expressed in terms of Objects-Attributes-Functions, and to the known and newly-generated solutions.

- *Implementation Stage: Conceptual solutions are to be evaluated, experimented, prototyped, designed, manufactured, installed, tested, etc. so as to make them real into successful specific solutions for users. This stage needs technical and business capabilities and decisions, and hence is out of the range of USIT as a creative problem solving methodology.*

CASE STUDY

This is a case study report of solving an everyday problem. Simplified and unified process USIT have been used in this study in a rather informal manner. The present problem is related to the design of manufacturing system capable of supporting business partnership of SME in furniture *industry. For the solution of the problem, the author has led multiple discussions on the causes of the problem and on possible solution ideas with managers of Bulgarian enterprises from the furniture industry. The results of these discussions are documented in reports which were used as a basis for development of the requirements for the production systems in the furniture enterprises. Afterwards, the author has worked further to build up the conceptual solution. The whole process of analyzing the problem, generating ideas, and constructing a solution was described in the report of a pilot scientific-research project. The present paper is based on this report.*

Setting the problem

Start of the work. *A producer of furniture gets an offer for business partnership by a partner in Italy. The Italian partner possesses designer developments of furniture for dining rooms and bed rooms. The conditions for the business partnership are very favorable but the industrial enterprise in Bulgaria has some doubts that its manufacturing system is not flexible and adaptive enough in order to produce the requested quantity of furniture within the deadlines required by the Italian partner. Concerned is a great variety of products, produced in small quantities of only several items.*

Confirming the focus of the problem. *The production system of the Bulgarian enterprise is equipped with contemporary computer controlled machines (CNC). These machines create at the Bulgarian market product portfolio similar in complexity and scope to the one in the Italian partner order.*

The machine operators and the people responsible for the furniture assembling are qualified enough. However, a shortage of staff could be felt and therefore most of the operators have two or three working places. This is also the reason for the recent delays with clients' orders.

Another serious disadvantage is the relatively high amount of work in progress. The reason is the production organization as well as the bottle neck in the production system planned for the cutting machine.

Due to some organization problems, the rhythm of the production process is not satisfactory and overtime work is needed during the weekends. This approach to the production organization has two negative consequences: considerable labor costs and unforeseen quality of the manufactured products.

Because of the insufficient skills of the technologist, production organizer and dispatcher the functionality of the production equipment is not fully exploited and the efficiency of some working centers (machines) is inadmissibly low.

Relatively high is the level of technological waste which is mostly due to technological problems.

A number of efforts have been put to elaborate the production system but up to the moment they are futile because of the excessive workload of the staff.

Important problems of the production system are the multiple motions of details and furniture units between the working centers during the manufacturing of the products. The reason is the close fitting area of job shop and the irrational location of the equipment.

Problem definition. *USIT (Unified Structured Inventive Thinking) has been used as the main process for problem solving. The discussions at the initial stage may be summarized in the style of Problem Definition in USIT:*

- *Unwanted effect. In case of business partnership with the Italian party there is a risk of delay with the implementation of the orders and unstable quality of the manufactured products.*
- *Task/goal. To reconfigure the existing production system of the enterprise in order to increase its flexibility and consequently, to evade delays of the orders and instability in the products' quality.*
- *Sketch of the problem situation. The problem situation is displayed on fig.2.*
- *Plausible root causes. Inappropriate arrangement of work centers, incomplete and ineffective usage of the equipment, inappropriate system for shop floor control are the main reasons for the insufficient flexibility and adaptability of the production system. This, on its side, generates risk of undue implementation of the orders and unstable quality of the manufactured products. (e)*
- *Minimum set of relevant objects. Product portfolio; structure of business processes; manufacturing system; production planning and control system.*

Analysis of the problem

In the stage of problem analysis, have been used various methods in a flexible way. The analysis processes are described in a logical way as follows:

Space and time characteristics analysis. *A furniture manufacturer produces economical living room and bedroom furniture. Products include night tables, dressers, chests, entertainment units, headboards, wardrobes, wall units and a number of other products made of particle board, solid pine or oak. Approximately 112 unique products, considering color and style, are manufactured.*

The production system is situated in one working premise on an area of around 630 m^2 and the system is composed of 14 work centers.

The five main operations for manufacturing the products include cutting, edge banding, drilling, pre-assembly and assembly. Typically, the required components for the parts are processed over two days.

Current methods for product manufacturing. *The characteristics of the existing situation include a re-configurable building and a production system with straight line flow and layout designed for high volume production, components produced to intermediate stock, lower product delivery lead time due to an assemble-to-order production technique, doweled products which contribute to lower flow time, and simpler material handling with clearly de-marked work-in-process buffers at each section and at the machines.*

Throughput satisfies the functional requirement for orders' deadlines and defines the process capacity of each operational section. The process capability and capacity at each of the five operational sections matches the total required throughput of the system.

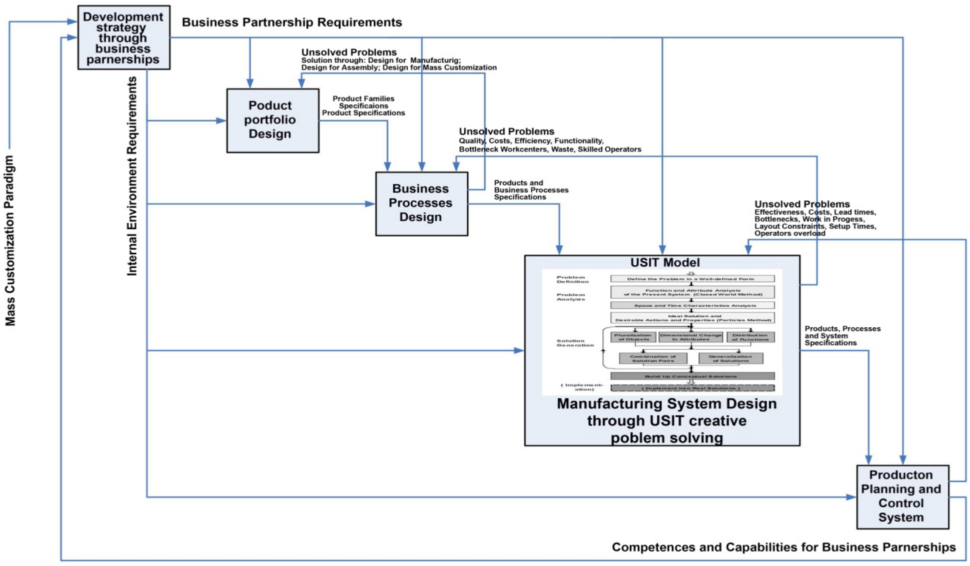

Figure 2. Problem situation

Understanding the overall structure of the problem. *Throughout these analyses from multiple points of view, were memorized various facts, observations, views, solution ideas, etc. For the purpose of understanding the overall structure of the problem, first was applied the grouping technique. On the basis of thorough literature research as well as the personal experience of the author, was reached the conclusion that for the solution of the problem should be created a new production system which corresponds to the requirement of providing customized production.*

In order to come up to this requirement, the current production system should be substituted with cellular manufacturing system, possessing complicated structure of requirements. These requirements should be arranged in four main groups.

Understanding the essence of the problem. *Summarizing the whole analysis, the essence of the problem can be described as follows: First and foremost, should be defined the functional requirements of the system at the highest level of its hierarchy in the functional domain.*

At this stage many functional requirements should be established. Each functional requirement established at this stage should lead to a completely different manufacturing design. Therefore, close attention should be given to all functional requirements before a single functional requirement is adopted at this highest level. In this work the following has been selected as the highest functional requirement - Providing customized production.

The following lower functional requirements set is defined for decomposing the functional requirement of providing customized production, determined above.

- *To classify and group products/parts and machines for simple material flow*
- *To develop resources capability based on product specifications*
- *To rearrange resources to minimize waste*
- *To provide production based on customer demand.*

Classification and grouping products/parts and machines. *This is a very important step for the success of transition from traditional manufacturing to cellular manufacturing.*

The first step in this branch is to establish the high volume products through Product-Quantity (Pareto) analysis.

Resources capabilities development. *In this stage, activities including waste elimination, for the design of a lean process, rearrangement of resources in agreement with the takt time, fixing training needs and motivation of the workforce are accomplished.*

***Resource rearrangements**. At this stage lean manufacturing principles are the guiding principles of the design step. In this step, the focus is the waste elimination. Therefore, in rearranging the resources waste due to motion, material handling and imbalances between resources is minimized.*

***Production control**. Satisfying customers by right amount and just-in-time production can only be accomplished through pull system. However, just-in-time systems require a steady pull on all products in the family. In order to ensure a steady pull, a leveled/mixed production schedule must be established.*

Generating ideas and constructing solution concepts

As a next step, these ideas were examined more closely the range of solution ideas was expanded. During this stage were made efforts to figure out ideas so as to expand the current state of technology and to think of new approaches in relation to psychology and social behavior.

Design parameters, which satisfy the functional requirements, established in the previous step, were selected on the basis of the author's conclusions reached as a consequence of discussions with managers of furniture enterprises.

In order to make the correct design parameter selection, a design parameter set corresponding to the functional requirements set established before, must be exhaustively generated. The design parameter "Cellular manufacturing system design (CMS)" has been selected to satisfy the main functional requirements provided above – "Provide customized production".

The production system, which can answer customer's needs in an efficient way through elimination of waste, reduction of lead time and improved quality is a CMS designed with lean manufacturing principles in mind.

In satisfying the four functional requirements stemming from the main functional requirements provided above – "Provide customized production", the following design parameters are in response: Development of Procedure for defining product/part families and machine groups; development of Procedure for working out production resources capability; Design of Product oriented layout; Design of Pull production control system.

***Solution ideas to the problem of Classification and grouping products or parts and machines**. In this stage, final assignments of parts to cells are realized. Particular attention is given on eliminating of exceptional parts for decreasing inter-cell part movements. Furthermore, due consideration is also given to reassignment of machines to different cells for elimination of inter-cell movements.*

***Solution ideas to the problem of Resources capabilities development**. In this stage, activities including waste elimination, for the design of a lean process, rearrangement of resources in agreement with the takt time, fixing training needs and motivation of the workforce are accomplished.*

***Solution ideas to the problem of Resource rearrangements**. At this stage lean manufacturing principles are the guiding principles of the design step. In this step, the focus is the waste elimination.*

***Solution ideas to the problem of Production control**. Satisfying customers by right amount and just-in-time production can only be accomplished through pull system. However, just-in-time systems require a steady pull on all products in the family. In order to ensure a steady pull, a leveled or mixed production schedule must be established. This leads to developing the appropriate Heijunka schedule and the necessary visual management tools including Kanban system for successful implementation.*

Conceptual solution of a new cellular manufacturing system

On the basis of the ideas generated above, has been built a consistent set of conceptual solutions addressing the present problem. They are presented in details at the report of the pilot project.

CONCLUSIONS

This paper has applied the USIT methodology to the problem of development of Cellular manufacturing system, which ensures providing customized production in the sphere of furniture manufacturing and allows to the analyzed Bulgarian industrial enterprise to accomplish fruitful business partnership with the Italian contractors.

The analysis of this problem has revealed that a simple technical approach is not suitable at all, but rather complex approaches are necessary and more appropriate. Thus the problem was analyzed from multiple aspects, including product families, business processes, production control etc.

A number of root causes and corresponding contradictions have been revealed and solved one by one to find basic directions for a new solution system.

The process of proceeding to the solution was described. Then, on fragments of such ideas, a consistent conceptual solution was built.

On the basis of this overall view, the new basic choice in the technical aspect is expected to have solved most of the problems.

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