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Availability of material streams in hybrid push/pull shop floor control system

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Abstract: The paper presents practical aspects and example of integration of hybrid system controlling production system inputs including raw materials and components based on analytical and managerial expert system. The research is based on demand analysis of a large industrial company providing a wide range of assortment of about 150 final products manufactured according to made-to-order and make-to-stock strategy. The goal of the research was increasing availability of material in production system for multi-assortment production cells fed with hybrid pull/push strategy.

Keywords: hybrid push/pull system, indoor material flow, expert system

1. INTRODUCTION

Companies nowadays are facing numerous problems emerging from globalization, advance in technology and communication techniques and more and more sophisticated requirements of customers. These phenomena however are not only sources of risk but also of competitive advantage. Businesses capable of turning dynamics and complexity of contemporary markets into opportunities are potential winners. Agility is strategy that allows companies to successfully cope with dynamics and complexity of contemporary market and to respond to global customers' needs and requirements efficiently and economically. In their report on 21st century manufacturing enterprise strategy introduced in 1991 at Leigh university (Emigh 1999), the authors suggest that various production resources, including people, funds, technology and facilities should be integrated and managed as a whole; thus optimizing the utilization of resources and taking full advantage of advanced manufacturing technology and computers. Since its introduction agility, which has basically two meanings: flexibility and reconfigurability, has become a very important characteristics of a modern manufacturing enterprise. Generally, flexibility aspect refers to ability to make adjustments according to customers' needs, while reconfigurability is the ability to meet changing demands (Li (2009).

Meeting customers' demands is one of the most important goals of contemporary companies, especially as doing their business they have to follow the next contemporary paradigm, which is sustainable management. One of the firsts, and the most popular explanations and definitions of the term "sustainable development" is the statement from the WECD report from 1987 (also called Brundtland Report) – "at the present stage of civilization development sustainable development, which is development thanks to which needs of today's generations can be met without decreasing chance of future generations for meeting their needs, is possible". The report proves, that contemporary civilization has reached the level of welfare which can be maintained only when properly managed. The model of such economy assumes, that relation between economic growth, care for environment and human health should be created (Rutkowski (2008). Hence, sustainability interfaces with economics through the social and ecological consequences of economic activity.

Sustainability economics involves ecological economics where social, cultural, health-related and monetary/financial aspects are integrated. Modern approach to the idea of sustainable development starts exactly where three ideas: natural environment, society and economic results meet (Jasiulewicz-Kaczmarek, Drożyner 2013). The idea refers to J. Elkington's theory, in which he suggest simultaneous analysis and balancing of three crucial dimensions (the Triple Bottom Line): economical, ecological and social or the approach presented at the 2005 World Summit on Social Development, where it was noted that this requires the reconciliation of environmental, social equity and economic demands - the "three pillars" of sustainability or (the 3 Es) (UN 2005) which are not mutually exclusive and can be mutually reinforcing. The following paper presents a case study on solving problems of availability of materials in a production systems with the approaches before mentioned and some elements of AI.

2. EXPERTS SYSTEM TO SUPPORT MATERIAL FLOW MANAGEMENT

There are numerous definitions of artificial intelligence, some more precise and others less. Some of the definitions are focused at psychological approach, while the others suggest that machines perform tasks more efficiently than humans or they are not able to mimic human behavior in an exact way (Rich *et al* (1991), (Russel *et al* 1995). In the following paper, the definition by Z. Bubnicki is used. According to this definition, artificial intelligence is a field of computer science, which deals with algorithmization and formalization of processes of thinking and concluding, as well as these of learning, perception, recognition etc. (Bubnicki 1993). As human intelligence is a capability, which allows to process information, solve problems, adjust to new tasks and situations, as well as understand, compare and contrast facts, learn and remember, develop thesis, theories and conclusions, analyze and think creatively (Rutkowski 2006) authors believe, that the definition mentioned above is the one presenting the idea in the best way possible.

The basic methods of artificial intelligence are: expert systems, genetic algorithms (Coley 1991), (Goldberg *at al*, 2003), (Man 1999), neural networks (Kosinski *et al* (2007)), fuzzy sets (Yen (1998)). Expert systems (ES) are a discipline of artificial intelligence, which gained numerous practical applications as the first on from the above list (Zielinski 1991). However, practically, hybrid systems are often used, as they benefit from combination of two or more types of systems. What is an expert system then? It is an "intelligent" computer program, which uses knowledge and concluding procedures to solve problems requiring human (expert) experience earned by long-lasting activity in a predefined field (Rutkowski (1991). Hence, the starting point for developing expert system is analysis of the problem to be solved. Undoubtedly, role of an expert (person who knows the field well enough to take efficient actions) at the stage of general design cannot be overestimated.

Expert systems work is based on realizing three basic, independent though cooperating modes i.e. knowledge base, concluding machine (concluding mechanism) and user's interface (Bubnicki 1993). However its structure may vary. It mostly depends on its application (Knosala 2007). Generally, expert system works thanks to implementing expert's knowledge to the knowledge base, defining concluding mechanism based on information available and designing user's interface to enable communication (Rutkowski 1991). Knowledge base of an expert system includes facts and rules and while facts information which is accepted and can be used by an expert, rules are logic phrases, which lead to new facts definition and enable solving problems defined.

Application of ES leads to numerous benefits for an enterprise (Pawłyszyn *et al* 2010), (Pendersen *et al* 1997). which makes them really popular managerial tool (Chwiałkowska *et al* 1991) as they provide companies with much cheaper expertise comparing to „real" experts; they work much faster than experts, which results in cost and labor savings; they improve quality of expertise thanks to consequent concluding and smaller number of made mistakes; they provide higher flexibility of production and customer service and reduce time of work, which is expensive; they usually react faster than experts, especially when the problem solving requires operating with large quantities of data; they enable solving complex problems, too difficult for an individual or requiring knowledge larger than that of one man.

Expert systems are used in almost every area of human activity (Chwiałkowska *et al* 1991), performing lots of activities supporting human activities. However, each area requires different, individual and often unique expert system, which should be constructed by analysis and gathering data in the predefined field, choice and application of proper concluding methods (concluding machine) and, in the end stage, designing an interface to enable communication between users and computers. More detailed description of stages of expert system construction can be found in (Hayes-Roth *et al* 1993).

3. BUSINESS ENVIRONMENT

The research was carried out in industrial engineering in complex environmental conditions of production. This was an specializing in technology, multi-departments environment, with multiple streams of values and a wide range of products (about 500 items). The work was carried out under the transformation of the production system from the "push" logic of flow to "pull" logic of flow (see more: Hadaś & Cyplik 2012).

The discussed company's functioning can be described as traditional, with a hierarchical and centralized planning structure supported by an MRPII/ERP system. On the level of long-term planning (1 year), annual sales plans/forecasts are drafted to verify revenue and costs and to roughly balance the demand for output capacity in terms of machines and staff. On the level of medium-term planning (1-2 months), sales plans and confirmed orders are used to develop production and supply plans. In the short term, production is ordered to start in the foundry (the department beginning the production process). Orders are pushed along further departments (the push flow logic) all the way to the Assembly Department (where the final product is prepared to put on the market) or the processing department (orders for a partner in the supply chain). The planning of machine duties is tentative and the assignment of tasks to individual workstations is planned according to their technological profile.

In our analysis of the production planning and control system, we identified the following issues:

- on the long- and medium-term level:
  - low level of plan integration, both vertically (Management Board–Managers) and horizontally (supplies–production),
  - low level of the implementation of MRPII/ERP (marked C according to the ABCD Checklist),
  - low planning discipline (no clear process owner);
- on the short-term and running control level:
  - numerous conflicts about resources,
  - chaotic, spaghetti-like flow for the Processing Department,
  - large batches,
  - variability of production priorities.

In conclusion, the production system displayed significant instability in the duration of the production lead time. The variations in the production lead time were directly related with high (and expensive) level of work in progress both on the shop floor (in the process) and in inter-department storehouses. Under these circumstances, it was difficult to ensure a high logistics service level. The level of service essential for the Management Board from the perspective of the credibility of the supply chain was achieved at the cost of high levels of stock and expensive interventions in production plans (overtime work, priority changes, short batches).

4. IDEA OF THE LOGISTICS SUPPORT SYSTEM – ASSUMPTIONS, CONSTRAINTS AND SOLUTIONS

4.1. Reorganization of logistics system

Authors assume that a production and logistics system will be construed as a set of elements of a production system, composed of premises, humans, machines, and equipment, software, procedures and the decision-making process, linked by mutual interrelations with a view to executing a logistics strategy (Cyplik *et al* 2014). The transformation of a production and logistics system is understood by the Authors as changes which are process and/or structural in nature. Process changes denote a modification in the operation of a production and logistics system as regards the mechanisms in control of material streams flow in order to meet the objectives of the logistics strategy which had been adopted. Structural changes denote a change in: type, number, location (arrangement into a layout) or capacity (throughput) of particular resources combining into production-logistics system.

The work on reorganization of production and logistics subsystems undertaken in the company to increase its efficiency at assemble department included among others development of assembly feeding subsystem (see. fig. 2. Department 3 – Assembling cells – marked by the frame). The crucial assumption was that Assembly Department (Department 3) supply system cooperates with management system developed for Department 2, where because of high variety of assortment push logic proved to be more resistant to disturbances and resulting in througput (see more: Hadas *et al* 2013)

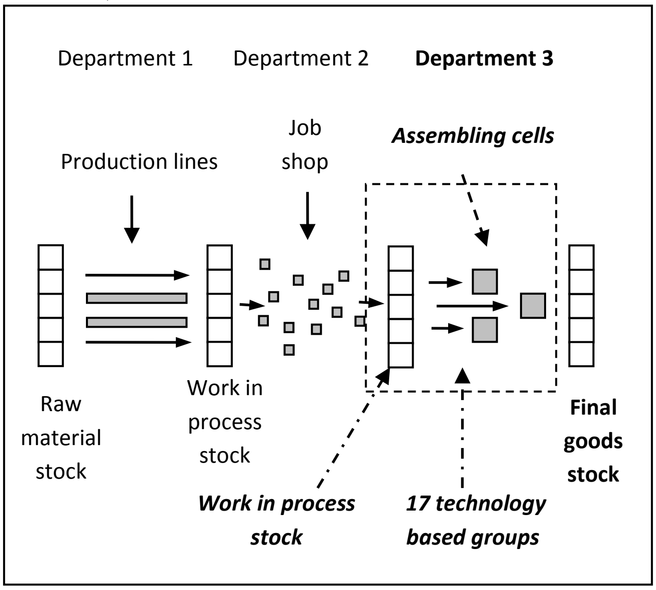

Fig. 1. Multi-departments production structure – flow type and work in process stocks localization. Source: Own study

Analysis of previous enterprise practices in this field led to the decision that material requirements planning system based on demand should be replaced with material requirements management based on use. The main goal of the project was defined as:

- **Elimination of waste emerging from material unavailability**
- **Limitation of managerial activities** (scheduling and job assignment for assembly department).

They were the weakest points of traditionally functioning system based on decentralized control enabling operators individual and self-made decisions concerning material needs and orders.

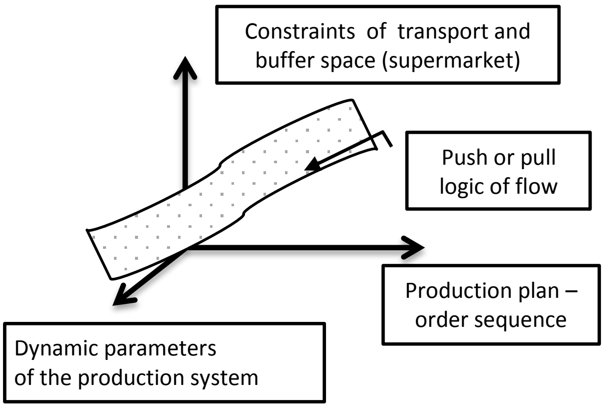

Fig. 2. Three-dimensional space of configuration of flow management solutions. Source: Own study

The first step of work required identification of "decision-making space" available in the enterprise (see Fig. 2.). the approach provided preliminary validation of experiment space conditions. to avoid developing solutions inadequate for real working space. „Decision-making space" is composed of three-dimensions and is coherent with available configuration of flow management solutions. First dimension is "Constraints of transport and buffer space" which refers to available resources within transport and assembly area. The constraints are strong limitations because of high variety of assortment of final products and components. Second dimension is "Production plan – order sequence" representing typical sequence of flows. The tool applied for analysis was ABC methodology (for flow size) and XYZ methodology (for frequency). The „Dynamic parameters of the production system" dimension represents the features of the production system impacting the flow (and simulation) performance such as disturbances level or operation times fluctuation. The space identified (defined) was the arena for development of dynamic flow management system based on mixed push and pull logic.

The project is based on analysis of requirements concerning components with respect to time and quality. Because of a large number of components emerging from large variety of final products (more than a hundred were sold during last few years) there was no physical opportunity for providing all the assembly stations with all the parts and components and required by organizing "supermarket" racks.

Thus, hybrid system was developed combining requirements control based on use with the one based on requirement. Hence, final products assortment was divided into two main groups: "A" group (large number of items produced, repeatability of production on everyday basis), "B" group (small number of items produced, low repeatability of production)

For each group different approach was developed. "A" group should be controlled with use and availability of components should be high, provided at workstation. Replenishment at workstation should be performed on every day or every shift basis (depending on production size and number of shifts). Use should be organized thanks to one or two container system.

Group "B" on the other hand should be controlled with requirements. Components for assembly should be provided in traditional way, basing on orders. However, it is also possible to provide dedicated parts according to orders and provide standard parts (used for numerous final products) at the workstation.

After segmentation of assortment items, the next stage of project included definition of inspection frequency and replenishment schemes for "A" group as it was to be controlled with use. The modification suggested referred to size of production factor. The criteria used allowed for dividing "A" group into three smaller groups depending on production size and opportunity to store the components at the workstation as follows: "A1" group – replenished every hour, "A2" group – replenished every shift, "A3" group – replenished every day.

The frequency analysis is dynamic and can be modified depending on changes in production programs, as a consequence of f.ex. increase of orders number during high season.

Shared components and dedicated components for every assortment group should be identified to significantly reduce variability at workstations.

The next step of reorganization process is definition of principles of recording material flows. Material management based on use is not linked with production plans and warehouse documents (to make it as simple as possible) there is a need for periodical verification of number of components used. The procedure that can be applied in this case is so called "back flushing". Real number of parts (physically counted) is confronted to number of components which should be used according to bill of materials and production size. Hence, the number of components is counted "back" and compared to real use in a warehouse. Procedure identifies discrepancies resulting from inadequate bill of materials (f.ex. number of parts required) as well as losses and thefts.

„Back flushing" procedure should take quality problems into account as well as imprecise identification of small standard components (identified with their weight not the number: screws, tops, nuts).

4.2. IT support in process management

The assumption made for the research is that the following organizational aspects/units should be considered: warehouse (feeding assembly processes), handling and transport, storage at workstation.

For the warehouse, the most important aspects to be managed are frequency and sequence of issuing. For handling and transport the most important aspects include identification of final address and dues, while for storage at workstation it would be providing availability of wide assortment of components within limited space and in dynamic conditions (the most important and in the same time the most difficult). The procedure developed to present application of the expert system to be used is discussed and presented below.

Decision making algorithm consists of two main stages: „Configuration process" and „Verification and calibration process". Configuration is rough identification of items to be controlled with push or pull logic based on analysis of decoupling points allocation (MTO, MTS, ATO) for each item and work repeatability analysis in week time horizon (based on forecasts (MTO – rate of recurrence 1 month) and orders (ATO and MTS – rate of recurrence 1 day or 1 week). Analysis of repeatability is based on lot size and its repeatability in production plan. Indicator α is compared to α_L (limited) defined and typical for each production system in reference to average load of machines (assemble cells).

„Verification and calibration" stage is analysis of rotation in warehouse, capacity of supermarkets and transport operator rhythm as they are limitation to application of pull logic to material flow control in production system with stock buffers located at workstations.

The key aspects are combination of information from production plans and warehouse data, dynamic management of „push" and „pull" deliveries. The result can be achieved by integration of warehouse with production process, especially for variable and dynamic assortment.

The next stages of the research to be done include integration of the expert system presented with ERP class application used in the company. Such approach makes full recording and cost analysis possible, and these aspects are crucial for controlling system to be improved in the nearest future. The work included development of implementation sequence for the solution in business running conditions (see Fig. 4.). The implementation procedure consists of configuration of transport lot size and realization of transport process which is connected with analysis of availability of material followed by verification of segmented items.

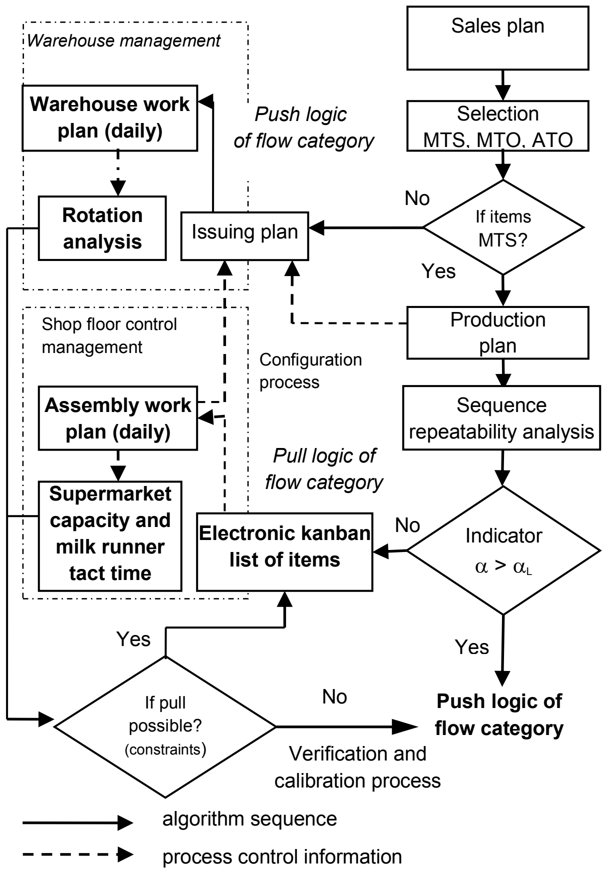

Fig. 3. Experts algorithms of material flow management system for hybrid push/pull system and its embedding in process control. Source: Own study

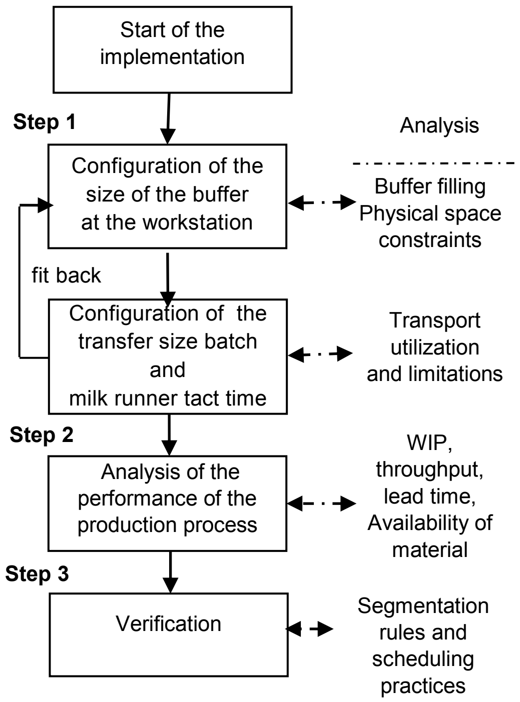

Fig. 4. Implementation sequence of material flow management system and its verification. Source: Own study

5. CONCLUSION

Summing up, application of material requirements planning and management system is on one hand very important for efficiency of production and on the other demanding, thus choice of the solution to be applied should be based on thorough analysis of assortment used. When the assortment is wide and varies, alternative for simple solution would be application of a hybrid system combining benefits from several solutions, like pull and push logic. However, because of the dynamics and complexity of such system its management requires IT support equipped with AI elements, f.ex. expert algorithms. The combination allows to achieve full integration of the warehouse and production with respect to all the limitation and constraints.

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