Study of inter-operational breaks impact on materials flow in flexible manufacturing system

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Abstract. Present development of advanced technologies in production and logistics, orientation for a customer needs and global, competitive market determines a creation of flexible manufacturing systems. Each FMS consisting of the automated and robotized subsystems of production, assembly, inter-operational transport and storage should be treated as a complete logistics system in which the efficient flow of materials is realized, at every stage of processing. The efficiency of the system is based on possibility of quick, automated retooling and reprogramming for the manufacturing of new products, especially in the production for individual order. Except that, according to modern concepts of enterprise management, one of the factors to improve material flow is to minimize unnecessary inter-operative interruptions. The inter-operational breaks include many factors: handling and transport, waiting for a technological operation and assembly, quality control, unpredictable failures. While technological times are almost impossible to shorten, all issues related with logistics are possible to improve. The inter-operational breaks don't create added value, they're only waste. They often remain outside the research sphere or are treated marginally as a loss included in the manufacturing process. The article describes study on an effective method of searching for negative inter-operational breaks in advanced manufacturing processes and eliminating them. Advanced software for off-line programming of machine tools, robots, automated transport and warehouse systems and general-purpose simulation software for production and logistics gives possibility to conduct research on limiting the impact of inter-operational breaks on FMS.

1. Introduction

The customer-oriented contemporary market requires the costs reduction at manufacturing, assembly and delivery processes. Searching for these savings is the only way to achieve a competitive advantage in terms of product price, while its quality and short delivery time should be preserved [1,2,3, 11]. Every modern manufacturing and assembly system, executing production for the individual client's order, and including all internal logistics aspects, aspirates to be called a flexible manufacturing system (FMS). According to the definition the FMS [4] is a set of automated flexible CNC working stations (any kind of machining tools, thermal, chemical treatment and modern incremental technologies devices) complemented by not-manufacture units (assembly cells, washing stands, stationary or portable measuring machines, work in progress buffers and warehouses) connected by use of an automated manipulation, handling and transport subsystem (advanced industrial robots, conveyors, automated guided vehicles - AGV, automated storage and retrieval systems - ASRS,
forklifts, hand pallet trucks). Inside FMS it's possible to manufacture products with similar technological characteristics, but different design, constructions and dimensions. All changes in manufacturing, assembly and material flow processes (logistics) in FMS should be able to easy implement in production enterprise reality.

In the matter of manufacturing technology optimization (understood as a manufacturing processes realization with right / optimal parameters giving possibility to obtain required quality) producers receive almost ideal solutions. Similarly, in terms of orders scheduling with use of priority rules, but in area of internal logistics optimization, especially in relation to inter-operational breaks in material flow, is a lot to improve.

In the undertaken research, the authors attempted to find all wastes (understood as a "dead" time, which doesn't give added value to the final product) in the material flow system in an exemplary production system. It's according to the concept of the Lean Production concept (although it's better to say Lean Logistics [1,5]). The article focuses on the precise determination of the inter-operational breaks as the largest loss in the production system and an attempt to eliminate these, taking into account possibility of computer simulation software oriented to production and logistics.

2. Impact of inter-operational breaks on material flow in FMS

In professional literature [1,6] in the field of production engineering and logistics, the manufacturing lead time consist three main categories. In included below figure 1 the authors present their own proposal of the manufacturing lead time scheme based on [1]. They present only one inter-operational break between any two phases of manufacturing or assembly.

Described, by authors, manufacturing lead time categories are following:

- operation / technological time (T, where: T - setup time and T - cycle time on all machine tools for manufacturing ordered batches - B); we assume, during the research, that it is optimized by technologists and CNC programmers,

- administration time (T - a time required to release and complete customer order), the time is related with all material flow phases, but this time may be "parallel" run with respect to different raw material, parts and final products, because these aren't all needed from the first moment of the batch production start; the time is depended of the managers and supply units,

- inter-operational time (T - understood by authors as an inter-operational break (I-OB) on material flow through micro-logistics system of production company):
  - wait time (T - buffering time before or after technological operation e.g. connected with different duration of machining in neighbouring production cells, collecting parts before assembling, waiting
for service, manipulation or transport, picking of loading units, quality control, etc., it can be understood as a: not technical waiting time before or after technological operation (respectively: $T_{bw1}$, $T_{bw2}$), technological waiting time (similar to above: $T_{sw1}$, $T_{sw2}$), transportation time ($T_r$ - manipulation and handling realized by industrial robots, moving, transition and distribution of parts or loading units between production cells and warehouses, realized by staff, conveyors, forklifts, AGV, ASRS, other equipments); in the scheme we present only transport after technological process phase ($T_a$),

- remaining break time ($T_i$ - associated with undefined or unforeseen or known disturbances, e.g. equipments breakdowns or planned stop time connected with repairs or maintenance); the first kind of time (in context of unknown damage and its repairs) are difficult to predict, so better is doing intentional and known maintenance processes, for security to obtain correct / accepted material flow times through the FMS system.

The authors approach research in area of material flow and logistics, so they do not consider improving technological processes, assuming that these are appropriate in terms of manufacture part quality and optimal operations time-consumption which is connected with obtaining right product parameters.

Citing the words of researchers, in the field of logistics and supply chain management [1], even up to 80% of manufacturing lead time in the production company (starting from the decision to accept the customer order (management system), through delivery of the raw materials (in the supply sub-system), all processing / manufacturing and assembly phases, ending with final products packaging and preparing them for shipping (final product warehouse and distribution sub-system), can be associated with inter-operative breaks and administration time what can be little surprising in modern production. From other hand, producers tell, that really wastes are less, but they right now and all the time are looking for more and more savings in material flow in production company, as last and only way to minimize real manufacturing costs. In this sense: if you don't improve production flow and logistics, you will not get any savings, because in terms of technology you are usually only a competitor in the customer market, usually not a technology leader.

3. FMS modelling for a computer simulation research in aspect of limiting the impact of inter-operational breaks on the materials flow

The authors, looking for effective solutions, in the matter of minimizing the inter-operational breaks time, try to use of simulation software for testing the manufacturing and logistics processes. It seems justified in area of handling and manipulation, transport and storage sub-system at every stage of production. Wherever savings can be created / or found them in the flow of materials, computer simulation can be applied an almost non-invasive and effective method of attempting to make changes to the FMS in the future.

Available computer simulation software (e.g. Enterprise Dynamics, FlexSim and other) gives for the authors the possibility to conduct research on the impact of inter-operational breaks during internal logistics process realization for minimizing their impact on the production processes and material flow [5,6,7,8]. In the figure 2 an example of the flexible manufacturing system model is presented. The virtual reality model of internal logistics flow consists of typical FMS components, which have important impact of inter-operational breaks and disrupt effective material flow.

In specification below, first are described real sub-systems with components included inside; in brackets, the authors, show virtual representation of FMS elements in Enterprise Dynamics - Logistics Suite (ED), that were used during modeling process and also, important flow parameters (fp.) with impact on inter-operational break were presented.
There are indicated the following logistics sub-systems in the FMS:

- warehouse in area of supply sub-system: raw materials and commercial parts inputs, including some direct deliveries into assembly stations (ED: a set of Products connected with incoming Sources; fp.: types, size and number of products, times till first product delivery for every batch, inter-arrival times between parts or batches),
- manufacturing sub-system with CNC machine tools and automated assembly stations (ED: a set of Servers, Multi-Services, Assemblers, Unpacks; fp.: Setup time, Cycle time, Input and Send strategies, Batch rules, estimated Time to failure: MTTF/MCBF and Time to Repair: MTTR/MTTR for cycle; Bill of materials, Unpack quantity), also with service staff, treated as a product flow shops (lines) or job shops (cells) with manipulation and handling industrial advanced robots (ED: Robot and Advanced Vertical Articulated Robot (AVAR); fp.: Load and Unload times, run Rotation speed, handling Capacity, Manipulation and process time, closely correlated with the AVAR robot program created inside Enterprise Dynamics, Input and Send strategies) and, in some places, with short-distance transportation using different types of conveyors (ED: Fast and Advanced Accumulating or Non-accumulating Conveyors with Intersections; fp.: Size parameters with Elevation changes and Rotation, Capacity, Speed, Spacing rules, Response rules, Input and Send strategies),
- inter-operational buffering sub-system (ED: Queues, Kanban Bin - sometimes treated as an element non-existent in industrial reality; fp.: Capacity and very important: Input and Send strategies or Queue discipline, affecting the logic of the effective material flow and Initial inventory, Reorder level in case of Kanban) and inter-operational transport sub-system where AGV and forklifts are driven in order to overcome the space-time gaps, between supply and distribution warehouse, of course, through production and assembly stations (ED: Advanced transporters driving through Networks located on industrial layout connected with Dispatcher and Destinator, when in system are many interchangeable transporters, also with option of energy consumptions; fp.: Capacity and Load / Unload time, Speed on network, and even Turn and Lift speed and Limits, Battery capacity and Energy consumption during different phases of modern AGV transport, and of course Recharging time),
- final products distribution warehouses - distribution sub-system, more often, treated technically as cargo handling supported by automated storage and retrieval systems with storage places optimization, but sometimes modeled in aspect of realizing cross-docking procedures for individual customer orders (ED: Warehouses with use of an Advanced ASRS or Ground Storages operated by Crane and Sinks understood as a external market; pf.: information how to realize Input strategy, location on warehouse - Put in row / columns, creating of cargo units for customers - Product...
to send or Distribution batches, Trigger on entry to "open" input customer market channels, understood as a delivery in the reality).

During modeling flow processes inside FMS, it is necessary to obtain the original, real data from the production system, usually before its qualitative improvement, to do research on finding better solution of logistics, especially in area of inter-operational breaks minimizing. This can be done by direct measurements on the production layout, first, the engineers need to know the locations of warehouses and production / assembly cells, and also capacity of transport routes. It can give to researchers understanding of real layout and vision of solution field to finding losses and creating savings in used area of company manufacturing halls and in material flow inside them. Next step is finding the time of realization of the all stages of flow processes (production and assembly - based on technology cards, because optimal solution was found, but also in base of the off-line machine tools programming software: e.g. Emco WinNC), while logistic parameters (manipulation, transport and distribution) require chronometric measurements or using the available options of dedicated off-line programming software (modules like: sequence of operations) for industrial robots (e.g. ABB Robot Studio, Process Simulate) and continuous or discrete transportation devices (e.g. Ipos).

In context of minimization and optimization inter-operational breaks in internal material flow the transport, handling and manipulation are possible to improve. Referring to the above, readers need remember that industrial robot trajectories should be optimized in terms of the operational movement length and its time-consuming, in the same way, the number of robot auxiliary activities should be minimized [9,10]. In figure 3 are presented some simulation results, taken during simulation research, where the impact of robot’s program optimization to the performance of the assembly process was considered.

![Simulation Results](image)

**Figure 3.** The simulation results: comparison of selected equipments statuses, connected with impact of the inter-operational breaks; before and after system improvement and optimization.

In the issue of inter-operational transport, authors were looking for savings in shortening routes between production cells by creation of new layouts - more closer production / assembly equipments location and warehouses / inter-operational buffers, also regarding the direct supply of semi-finished materials to the workstations in manufacturing line, without time-consuming transshipment process in supply sub-system. The further research, in area of inter-operational breaks, was conducted in direction of choice and the number of internal transport equipment, like forklifts, AGVs etc. and application of modern optimization techniques for creating the internal routings which will be economically accepted; e.g. "milkman’s problem" solutions with inter-operational inventory controlling realized with early detection of demands in every stage of manufacturing process.

4. Conclusions
The authors tell knowingly, that article is just a proposal to finding for an effective, universal solution for the optimal flow of production and the implementation of logistics activities with minimization of any losses. Probably this is not a method to apply everywhere, in any manufacturing system, but in most typical manufacturing companies it has a chance, after little modifications related to the specificity of the description of industrial subsystems: production, transport, storage and others connected with them. The conclusions are following:
Current development of existing computer simulation software, in the scope of production and especially logistics, gives the opportunity to conduct research (and implementation in industrial reality) on the functioning of the production / internal logistics system, for a new, different than existing, unique manufacturing / material flow conditions (other, unusual customer orders, unique manipulation activities, individually oriented inter-operational transport processes, specific packaging and picking activities).

Acquiring a reliable information, about production / internal-logistics system is the main basis for the effective implementation of simulation model that generates future-oriented (or present), located in manufacturing reality - results, that could be a norm for the manufacturing / logistics actions, which can be realized into company and treated as an only determinant of achieving the enterprise business goal.

Taking into account various aspects (and the aspirations of managers) to shorten the time of material (product) existence in the production system, possible time of savings can be estimated to several, maybe up to more than dozen, percents. Saving of handling and manipulation processes time (robotized) can be estimated about 10% in relation to the current state, internal transport can be 20% shorter by reduction of routes length (production layout area reduction) and optimizing the flow, using e.g. Kanban system with adequately earlier internal orders (e.g.: "milkman's problem" efficient solution) or possibility to change number of AGVs driving inside system, depending on the degree of orders complexity.

Regardless of the computer simulation results, as a manager of your own enterprise and as a businessman, you should be guided by your own experience and instinct, when conducting your enterprise in competitive market.

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