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Distributed Scheduling in Cellular Assembly for Mass Customization

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Abstract. Industry 4.0 has many objectives; among them is increasing flexibility in manufacturing, as well as offering mass customization, better quality, and improved productivity. It thus enables companies to cope with the challenges of producing increasingly individualized products with a short lead-time to market and higher quality. In Mass Customization, manufacturers are challenged to produce customized products at the lowest possible cost with minimal lead-time. This increased customization increases complexity in production planning. The main challenge becomes planning production for lots of one and for high product variety and volatile market demand. Moreover, the customer requires real time update on his order status, and is less tolerant for delays. Nevertheless, in a make to order or assembly to order supply chain, many disturbances (supplier delay, machine brake-downs, transportation network disturbance, ...) may highly increase the customer order delay. Hence, production planning in this context becomes more complex requiring real-time information exchange with all stages of the supply chain. This paper tries to answer this challenge by proposing a distributed production scheduling approach for mass customization in a cellular assembly layout.

Keywords: Mass Customization, Distributed Scheduling, Cellular Assembly, Smart Scheduling.

1. Introduction

Most of the research and industrial road maps and directives such as the European Union roadmap project titled “IMS2020”, the German Industry 4.0 plan in 2013, the Chinese white paper of “Made in China 2025” [1] aim at producing customized products and offering an individual experience for every customer by using smart, flexible and autonomous manufacturing systems.

Among flexible and autonomous manufacturing layouts, the cellular layout lays half way between the line and job shop process [2]. If well designed, it has the ability to capture the benefits of both systems: large quantities from line or product process, and high variety of job shop process. Hence, it is a suitable layout for mass customization.

To offer Mass Customization (MC), manufacturers are challenged to produce high quality customized products at the lowest possible cost with minimal lead-time. MC manufacturers should set a strategy that makes their production reflect the ever-changing and customized market and should manage the increased manufacturing complexity due to MC. This complexity is induced by a very volatile demand and high product variety, and impacts highly the production planning and scheduling. Moreover, MC requires real-time tracking of the order and quick response to customer order, hence manufacturers need to use digital technology and be connected to the entire supply chain. In MC context, any disturbance in the supply chain whether in the transportation network, production, or replenishment from suppliers, can delay the order and reduce customer satisfaction. About this disturbances and changes, Zhang (2019) mentions that changes to the schedule are inevitable, and become more critical in mass customization and adaptive manufacturing. Changes like emergencies, new orders, cancelled orders, machine failures interrupting the whole system is unacceptable. Therefore, smart factory with smart distributed scheduling is demanded in the future.

The question remains about which information to use in real time, to optimize the scheduling for MC in order to reduce overall generated costs and respect the customer required order delay. This paper is a first attempt to answer this question, by proposing a framework for smart distributed scheduling for MC.

This paper is organized as follows. Section 2 presents a literature review related to mass customization, cellular assembly and scheduling for mass customization and for cellular assembly. Section three presents the proposed framework, and section four concludes this paper and describes the future works related to this research.

2. Background and Related Research

2.1. Mass Customization

Mass Customization (MC) is a major tenet of Industry 4.0. It provides customers with customized features for their goods and services. MC is a trio of product attributes meeting customer needs, robust process design (that can re-use or recombine resources), and supporting customers in finding solution with minimum complexity [5]. MC is applied in many businesses like cars, clothing, and computer manufacturing, food industry, among others [6].

Mass customization is classified based on product life cycle (PLC), from concept to use, in the cyber physical consumer durable (CPCD) environment. [7] defined seven types of MC: (1) Co-customization, (2) Custom-fabrication, (3) Assembly-by-company, (4) Assembly-by-customer, (5) On-delivery-customization, (6) Embedded-customization, and (7) Standard-customization.

In this research, the focus is on assembly-by-company MC. A customer chooses to order from a catalogue of available options. The operation realized after order receipt, is

an assembly one, meaning that pre-fabricated parts and components are available, and the value added is in assembling the product using options and adds-on from the catalogue that the customer used to order. In other words, the customer order decoupling point positions just before the assembly activities.

2.2. Cellular Layout

Cellular layout is made up of different cells, and each cell contains several workstations. Orders start in one cell and continue to the other until they finish, depending on the process sequence. [8] discussed the optimum number of cells and number of machines in each cell. Each machine type can perform one or more operations (machine flexibility). Likewise each operation can be done on one or more machine type with different times (routing flexibility).

According to [9] Multi-cell environments include several independent manufacturing cells located in the same plant and they allow high-volume productions or multiple product types by exploiting all the available manufacturing resources. Cellular manufacturing (CM) has many advantages including reduction in material handling costs, setup times, expedition costs, in-process inventories, part makespan, and improvement of human relations and operator expertise [10]. The primary objectives of cell layout are the minimization of movement cost, minimization of backtracking and maximization of throughput [11]. Its ultimate goal is converting the make-to-stock production system (push production) to make-to-order production system (pull production [12].

2.3. Scheduling for Mass Customization and for Cellular Assembly

A production schedule identifies and controls the release of jobs to the shops, ensures required raw materials ordered on time, whether delivery promises can be met, and identifies resource conflicts [13]. Scheduling involves the allocation of the available production resources in a workflow generated in a previous planning stage. In a sense, to find a schedule π of jobs over machines yielding an optimal value $F(\pi)$, where F denotes some objective function [14].

There are many types of scheduling problems, including the Job Shop Problem (JSP) defined as an optimization problem in which various manufacturing jobs are assigned to machines at particular times while trying to minimize the makespan [15]. It is classified into basic type JSP, the multi-machine type or flexible job shop scheduling model FJSP, the multi-resource type MrFJSP, the multi-plant and transportation MpFJSP, and finally the Smart Factory SFFJSP which is highly dynamic scheduling, incorporates real time data from all the factory [15]. [14] and [16] defined Dynamic Scheduling as planning for unforeseen events and problems. They divided problems into 1) shop-related (machine breakdowns, operator illnesses, unavailability or tool failures, loading limits, delays in the arrival or shortage of materials and defective materials) and 2) job-related (rush jobs, job cancellations, due date changes, early or late

arrival of jobs, changes in job priorities, changes in job processing times). For [16], dynamic scheduling falls under 3 categories:

1. Completely reactive scheduling: A dispatching rule is used to select the next job with highest priority to be processed from a set of jobs awaiting service at a machine that becomes free.
2. Predictive–reactive scheduling: most common dynamic scheduling. Schedules are revised in response to real-time events, by minimizing effects of disruption, in shop efficiency and schedule stability.
3. Robust pro-active scheduling: focus on building predictive schedules which satisfy performance requirements predictably in a dynamic environment. The main difficulty of this approach is the determination of the predictability measures.

According to [15], and under industry 4.0, scheduling problem should shift towards SFFSJP incorporating both a dynamic and a distributed approach with multi-resources, multi-plants, transportation and smart factory. Yet many challenges are still to be overcome to implement SFFSJP [15]. The distributed approach, requires also a set of rules to when to require the centralized approach, and when every sub-system can handle its decentralized dynamic scheduling when disturbances occur. This was discussed by [14], who discussed more precisely the efficient screening procedures, or Tolerance Scheduling, in their approach to Smart Scheduling. Tolerance Scheduling tries to identify the range of scenarios in which a given schedule keeps being optimal or acceptable and hence do not require to go up to the centralized optimization.

Implementing SFFSJP, and according to [15] requires five steps, each with its associated scheduling problem: (1) construction of IoT and network management system associated with its Multi-objective Optimization algorithm, (2) information transfer between smart jobs and the system: each job optimizes separately, (3) information transfer between smart jobs associated: each job optimizes separately and selects its own operation sequence with selected machine according to system rules (4) information is transfer between smart jobs and smart machines: each machine optimizes and selects job by itself (5) information transfer between smart jobs and smart multi-resources, where Each resource optimizes and selects the job by itself. Hence, the traditional centralized system no longer handles alone the effects of schedule changes, but rather the autonomous smart subsystems can adapt and react to and even predict changes, and respond accordingly. The main inconvenience of this proposed approach is the high complexity of its implementation.

In this research we are interested in scheduling for MC and smart cellular assembly. Table 1 summarizes some of the works addressing scheduling either for MC, for cellular assembly, or for both. It shows that the main objective functions for scheduling are reducing cost and meeting due date.

Table 1: Summary of works related to scheduling for mass customization, cellular assembly, and real-time scheduling.

Ref	System Description	MC	SCM data	Real-time data	Objective Function		Solving method
					Cost	Tardiness	
[8]	Cell formation				X	X	NP
[9]	Flexible cells			X	X		distributed GA
[11]	Cellular manufacturing				X	X	GT layout
[12]	Cellular manufacturing		X		X	X	Axiomatic Design
[13]	Cellular system	X			X	X	Fuzzy Logic- Matlab
[14]	Smart Scheduling			X	X	X	Tolerance scheduling
[15]	Smart Manufacturing			X	X	X	AI Approximate Method
[16]	Manufacturing system			X	X	X	Agent-based scheduling
[17]	Cellular network			X	X	X	Bidding
[18]	Manufacturing Cells	X		X	X	X	Sequencing part families
[19]	Supply chain scheduling	X	X		X	X	DP
[20]	Network for services	X	X		X		Ant algorithm
[21]	CPSS		X		X		MOO
[22]	Smart Manufacturing	X		X			KBE
[23]	Manufacturing	X		X			5-layer framework
[24]	production /fabrication	X		X			NP hard
[25]	Manufacturing	X			X	X	NP
[26]	Cellular Manufacturing	X		X		X	Multi-agent System
[27]	Cell Formation				X		hierarchical GA
[28]	Fabrication & Ass.			X		X	Meta-heuristic
[29]	Component manufacturing	X			X		SA
[30]	Manual manufacturing	X				X	distributed scheduling
[31]	Cellular Manufacturing		X		X		Re-scheduling
[32]	Manufacturing	X		X	X		Adaptive Scheduling Engine
[33]	One machine	X		x		X	Combinatorial Auction
[34]	Production system	X				X	combinatorial auction. Bidding
[35]	Manufacturing	X				X	Makespan Minimization in a Job shop

Ass. = Assembly; CP = Cyber Physical; CPSC= Cyber Physical Social System, CPCD = Cyber Physical Consumer Durables; DP = Dynamic Programming; GA = Genetic Algorithm; GT = Group Technology; MC = Mass Customization; NP = Non-linear Programming; SA= simulated annealing, MOO = constraint Multi-Objective Optimization, KBE = Knowledge Based Engineering.

The table shows how many authors tackled interesting topics such as scheduling for mass customization and supply chain management (SCM) integration like [14,15,16], or scheduling for mass customization using real-time data such as [15,17,18,19]. It also shows the different used methods to solve the scheduling problem, such as genetic algorithm, non-linear programming, simulation annealing, etc. Of the proposed approaches, [13]. Suggested fuzzy logic technique to select the routes based on WIP, processing time and distance.

Of the works focused on scheduling for cell manufacturing systems, [17] discussed the bidding system that chooses the cell that can finish the job based on earliest finish time. It is made up of four steps for dynamic task assignment: (1) task announcement; (2) bidding (3) bid evaluation; and (4) task awarding. As for types of cell he defined 1) flexible cells (wide range of operations) 2) product-oriented cells (certain type of product made) and 3) robot assembly cell where robots put assemblies together. In task announcement the cells have deadline to respond, bidding depends on processing time, waiting time in queue, and travel time between cells, and awarded based on early finish time. [18] differentiated between cell scheduling CS (where family of parts are assigned to a cell) and group scheduling GS is that in CS the jobs of a part family follow a known order of machines. Whereas in GS jobs can go to all machines, because they don't belong to a family. [22] explored the possibility of determining Cell Formation, Group Layout and Group Scheduling decisions concurrently using genetic algorithm-based procedure. Their computations took long time and needed heuristic mutation to speed up the convergence. But could not find where exactly the proper heuristic knowledge can come into play.

What is noticeable in table 1, is the lack of literature that covers all the aforementioned parameters (MC, SCM, real-time data) simultaneously. Even though [15] presented a full approach for scheduling in a smart factory, all related mathematical models and implementations were not presented. Also, the whole approach requires that every resource, machine, and job are smart and imbedded with their own optimization and decision capabilities, this is highly complex to implement. Conflict can easily be created between the job made decisions and those of the machines and resources which can highly increase computation time and cost as well as the cost of information sharing.

3. Proposed Framework: Distributed Scheduling for Mass Customization

This paper adopts a smart factory flexible job shop scheduling approach for cell manufacturing system and for assembly-by-company mass customization. The cells are flexible, hence offer a wide range of operations.

The system consists of mainly an assembly operation of a menu-driven demand, meaning that some fabrication or machining takes place but mostly assembly. In other

words, a job representing an MC customer order, is formed of a sequence of mainly assembly operations that can be done on one or several cells to create the whole product as customized by the customer.

The aim of the smart scheduling approach is to define which machine of which cell will do each of these operations at which time. This while respecting system constraints, and customer requirements in the context of a smart factory. The smart factory job shop scheduling includes real-time data from all the supply chain stages and from each cell within the cellular assembly system. This highly complexifies the already complex mathematical problem of scheduling for mass customization that is usually a job shop problem. Job shop scheduling is NP-hard, especially when three or more machines are assumed [31]. Hence smart scheduling is based on dividing the problem into several subproblems by using a distributed approach. According to [26] the distributed environment leads to better product quality, lower production cost and lower management risks. It also facilitates rescheduling due to disturbances. The smart factory flexible job shop problem is also based on dynamic scheduling.

The distributed model, presented in Fig. 1, is made up of two scheduling modules that are separate yet integrated through real-time feedback. These are master scheduling and cell scheduling.

The master scheduling module is connected in real-time to the different supply chain stages: supplier, distribution, transportation, and customer orders. After the customer customizes his product, the master scheduling module receives the order including chosen product components, quantity per product, and order due date. Since we are in an assembly-by-company customization, it is important to know the current level of inventory per product component. This information is received in real-time from the Warehouse Management System or ERP. It also receives real-time data from the supply chain partners (shipment schedules, quantities) and delays from transportation network. This information is needed to prioritize customer orders depending on supply chain availability. The master scheduling module has access to every product assembly sequence/process, and to assembly related times per product and per cell. The master scheduling module is associated to a multi-objective optimization problem. Its aim is to define which cell will do which operation for each job.

The Master Schedule handles the assignments of jobs to cells. It makes sure there are enough material and are on time and place for the set of jobs for the scheduled period. It uses the cloud and the ERP, as well as the information from suppliers and distributors and the logistics. This schedule allows the distribution of orders on the different cells based on their capacity and availability, in order to reduce total related cost and minimize tardiness. This decision is then communicated to the cell scheduling modules.

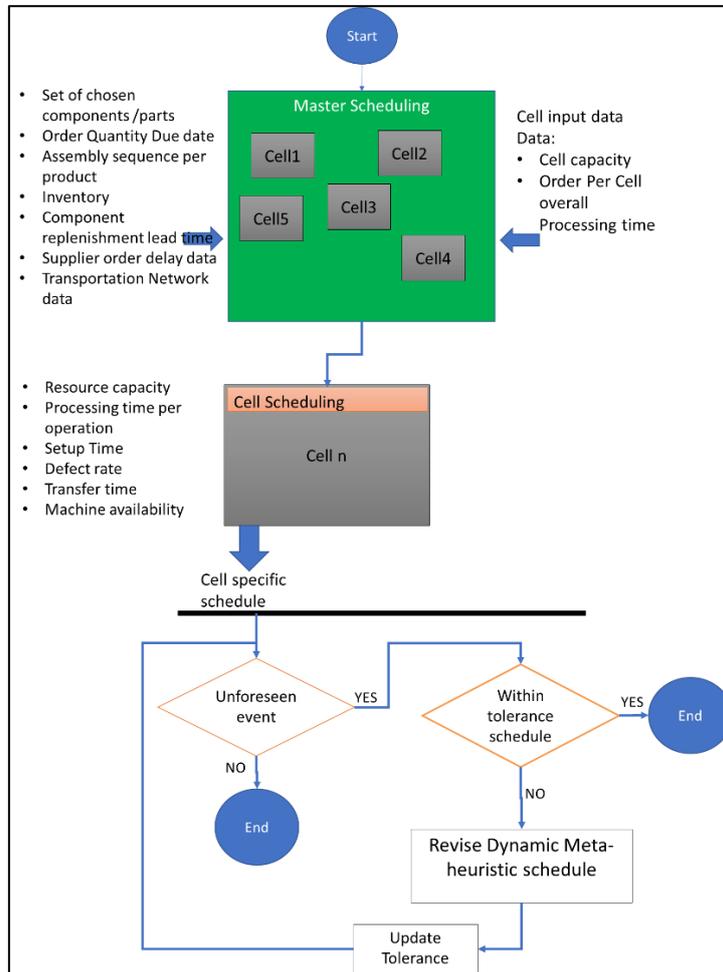


Fig. 1. Distributed Scheduling Approach for MC in Cellular Assembly

At the cell level, and for every cell, the master scheduling decision is an input for its specific scheduling module. The cell scheduling module receives input from each machine in the cell regarding its availability, current state, lack of materials, and relates it to the master schedule module. The output of the master schedule module becomes input to the cell schedule. Required inputs are order quantity, due date, assembly sequence by product, machine capacity and assembly processing time, machine setup time, distance and transfer time, machine defect rate and availability. What comes out of every cell is the cell specific schedule. This output is fed back to the master schedule. Fig. 2 presents the smart cell scheduling schema.

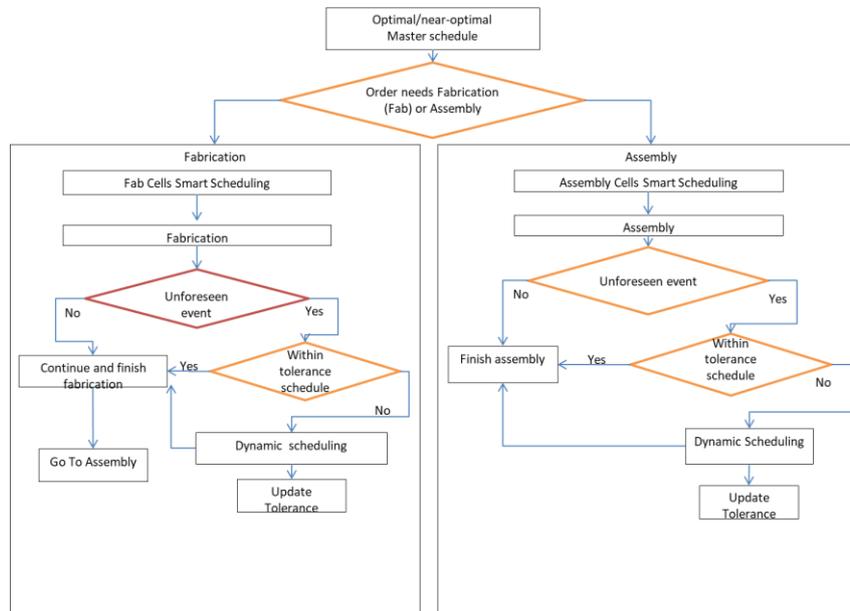


Fig. 2. Cell Scheduling Schema

The cell schedule starts when the Master Scheduling module sends the order to either the assembly or fabrication local smart scheduling modules. A job could need only fabrication or assembly or both.

Each fabrication cell, named fab cell, is a flexible job shop, made up of clusters of similar machines, laid out by function. Inside each fab cell is a smart scheduler that uses the bidding system to assign jobs and operations among machines, based on processing time (p), queue time (q) and transportation time (t). If an operation needs processing for example on a milling machine, and there are several milling machines, then the bidding system inside the cell chooses the appropriate machine based on (pqt). The same applies if the operation needs a different process, like drilling.

When an unforeseen event occurs, then a tolerance scheduling system could take place, based on a weight or inertia, the schedule either is redone or not. If the tolerance scheduler decides to re-run the schedule, then different scenarios can occur, like right-shift schedule repair, or rescheduling within the cell, or rerouting jobs and operations to other fab cells. After finishing fabrication, and the job needs assembly then it is handled by the assembly cell smart scheduler.

Here, each assembly cell has a set of workstations where the job needs to move along. This is due to the fact that this model is about customized assembly, meaning that the master scheduling module receives order from customers based on a menu-driven set of options. Each option has a set of routing and material specific to it. Inside

each assembly cell, the job could use all or some of the workstations found, and these workstations are not duplicate, meaning that one operation can be done on only one workstation. Each assembly cell could handle a family of jobs that have a certain commonality to be assigned a cell.

When an unforeseen event occurs, if tolerances are exceeded, a tolerance scheduler, which handles the assembly cells, will decide which dynamic scheduling approach is most suited and if a job is to be assigned on another cell. Afterwards, the assembly finishes, and the tolerance is updated.

The main advantage of this approach is simplifying the mathematical problem by dividing it into two connected problems. This allows to reduce the considered variables per problem. For example, the first integrates supply chain real-time data, whereas the second considers machines availability. The first problem schedules for cells whereas the second schedules for machines within each cell.

4. Conclusion and Perspectives

Mass customization is a reality, and requires flexible manufacturing systems such as cellular ones. It complexifies the production planning and control especially in an industry 4.0 context where the entire supply chain is connected and real-time data can be acquired and integrated. In this context, production scheduling has to evolve to smart scheduling based on distributed and dynamic scheduling. This paper proposed a distributed and dynamic approach for scheduling for MC and cellular assembly in the context of smart factory. This approach divides the problem into two sub-problems: master scheduling and cell scheduling. Future works include developing the mathematical models and choosing the most suitable method for solving the master and cell scheduling problems, and testing this approach on a case study.

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