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Pursuit of Responsiveness in SMEs Through Dynamic Allocation of Flexible Workers: A Simulation Study

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Abstract. The aim of this research is to study production responsiveness in Small and Medium Enterprises (SMEs) in Italy. Responsiveness is considered as the ability of a production system to achieve its goals in the presence of disturbances. The main issue this research tries to address is “how responsiveness can be achieved in production environments facing recurring uncertain disturbances in demand?” This research is particularly focused on the “worker flexibility” as a lever to achieve responsiveness. In this regard, alternative control logics for decision-making, regarding use of workers with varying levels of flexibility, have been evaluated through simulation for their potential impact on production responsiveness. It is found that, contrary to general belief, higher flexibility does not always guarantee higher responsiveness; it is the right level of flexibility combined with the proper decision-making logic which leads to higher production performance in the face of recurring uncertain disturbances.

Keywords: Responsiveness · Simulation · Demand variability · SMEs · Flexibility

1 Introduction

Mass customization has emerged as a new business strategy to respond to customers' demand for high product variety. It has brought many challenges for manufacturing industry, particularly for small and medium-sized enterprises (SMEs) operating in global market. Mass customization is characterized by high demand variability, which adversely impacts production performance [1]. In fact, mass customization production companies face swings in demand and thus vary in their capacity utilization [2,3]. Demand variability has been recognized as having the broadest negative impact on plant performance and it represents a pure measure of dynamic complexity [4]. If not properly and timely addressed, demand variability may cause productivity loss as well as human errors with negative impacts on production performance [5]. Furthermore, uncertain demand disturbances cause snow-ball effects such as delays on customer orders, logistics errors and high level of work-in-progress inventories [6].

However, in order to compete in the global market, companies need to respond to such uncertain disturbances in demand quickly and effectively. Therefore, many companies are pursuing responsiveness as one of their main performance priorities and are looking for ways to achieve higher responsiveness in their production environments [7].

In line with contingency theory, the required level of responsiveness that every company needs is different and depends on their individual business strategies [8,9]. Hence, the basis for competitiveness must be designed individually according to the company's own particular circumstances [7] which may vary according to country, industry, company size and/or other contingencies. In this regard, this research particularly focuses on uncertain demand disturbances in SMEs and the use of "worker flexibility" as a lever to achieve responsiveness. Thus, the paper tries to answer the following question: How SMEs can properly use their worker flexibility to achieve responsiveness to recurring uncertain disturbances in demand?

In this regard, to evaluate the impact of different alternative control logics regarding use of worker flexibility, a simulation study has been designed in collaboration with an Italian SME. For simulation purposes "Plant Simulation" software is used. Simulation is performed based on real production data and with real system constraints. Performance for alternative control logics is measured based on their ability to meet the average monthly demand across different product models. Simulation results for alternative control logics are analyzed and compared to identify the best solution for adaptive decision-making in the face of recurring uncertain disturbances in demand.

2 Worker Flexibility

The purpose of this study is to investigate the use of worker flexibility to address demand variability in a production layout made of assembly cells. Previously, in literature, different terms have been used to conceptualize "worker flexibility", such as multi-tasking [10] and multi-functionality [11]. This conceptualization of worker flexibility implies that the workers have the capacity to perform more than one task. However, researchers in group technology argue that multi-tasking alone is not enough, in fact workers should be able to perform different tasks in different areas (or call it cells) according to the needs. In this regard [12], for example, argues that "labor flexibility is the ability to assign varying number of operators as needed to perform different tasks. This requires training of operators to perform various tasks as well as their flexible assignment between different cells". In a similar vein [13] argued that "the presence of worker flexibility is characterized by cross-trained workers and the ability of workers to move between cells". Therefore, we can conclude that worker flexibility has two dimensions: i) capacity to perform more than one task, i.e. multi-tasking ii) dynamic allocation between tasks, i.e. flexible assignment. In this research, these dimensions are conceptualized as following: multitasking (worker characteristic) is the capacity of workers to carry out tasks within their assembly cell as well as tasks required

in other cells; dynamic (re)allocation between tasks (system characteristic) is the possibility, by the system management, to be able to (re)allocate workers among different cells according to needed tasks, thanks to their capacity of multi-tasking.

3 Case Company

This research has been performed in collaboration with an Italian SME. The company produces slicers and offers more than 55 different models of slicers. These slicers are divided into two macro families which are i) vertical slicers, and ii) inclined slicers. This division arises from the fact that the assembly operation of a vertical blade differs from that of an inclined blade (which is a critical operation and requires different skill set). These macro families have further sub families (micro families). In total there are 8 micro families of slicers each consisting of different product models. Fig. 1 shows the product family tree and how different products belong to the micro and macro families.

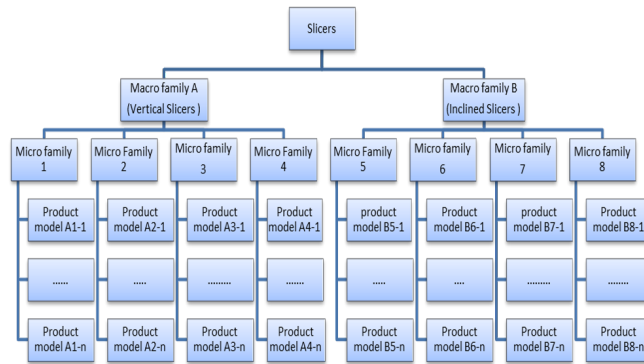


Fig. 1. Product family tree

The company organizes production according to assemble-to-order (ATO) strategy where individual components are produced and stocked beforehand. Final assembly is performed only when the actual orders arrive. The assembly of all slicers consists of five phases which are 1) Preassembly operations on the motor; 2) Preassembly operations on the blade; 3) Assembly of the motor and related components on the base; 4) Assembly of the blade on the base and its fitting with the motor; 5) Calibration of blade. The precedence of assembly phases is shown in Fig. 2. LSW are workers with no specialization and they lack skills to perform final assembly phases. Therefore, the final assembly phases 3, 4 and 5 are performed only by the high skill workers (HSW) who are well trained and experienced. However, workers can perform assembly operations only within their own macro family. This constraint is put by the management to achieve high quality in assembly as assembly of both macro families require different

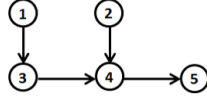


Fig. 2. Precedence of assembly phases

skill set and experience. This constraint is particularly important for this study as we try to understand its impacts on responsiveness when evaluating different alternatives. The sub division of high skill and low skill workers in an assembly cell is given as in table 1.

Table 1. Subdivision of workers within a cell

Total number of workers in a cell	Number of LSW	Number of HSW
2	1	1
3	1	2
4	2	2
5	2	3

Company uses 8 different assembly cells, where each cell is dedicated to a particular micro-family. The demand for different product models varies during the year and company needs to make some adjustments in its existing configuration at shop floor to meet the new demand. Company is looking for other better ways and capabilities to achieve a quick and effective reconfiguration in response to recurring uncertain disturbances in demand. In this regard, different alternative control logics for adaptive decision-making regarding reconfiguration are being considered which are discussed in in next section.

4 Control Logics for Adaptive Decision-making and Simulation Design

Control logics for adaptive decision-making are built on dynamic allocation and multi-tasking. Regarding dynamic allocation, the company has two options: shift the product/workload from mother-cell to a host-cell or move the workers from an offering-cell to a cell-in-need to meet the demand in that cell. Furthermore, regarding mul-titasking there are also two options: train workers to perform assembly operations within one macro-family (basic level multi-tasking) or train workers to perform assembly operations on both macro families (high level multi-tasking). Thus, there are four alternatives that can be evaluated through simulation as shown in Fig. 3. Correspondingly, two are the decisions that will be compared: i) the dynamic allocation of workers versus the dynamic allocation of workload between the cells; ii) the level of worker flexibility, with the purpose

to understand if capacity to perform tasks on both macro families is actually better or not, despite this would lead to a loss of efficiency due to less experience of workers on some tasks. The efficiency value for worker is 100% if he performs assembly operation within his family, 90% when he performs operation on other family but within the same macro family, and 80% if he performs operations on family outside his own macro family. These values are validated by the company manager who collaborated in this research. He has served for several departments before assuming his current position.

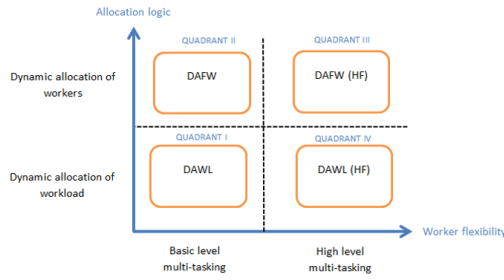


Fig. 3. Alternative control logics

From Fig. 3, it is apparent that there are four quadrants and each quadrant has its own control logic which is designed according to the requirements of the production context in SMEs: it should be easily and quickly manageable. To verify the effect on performances, the models for all control logics are developed. Because of space constraint in this paper, we discuss in detail only the control logic and the model for dynamic allocation of workers with basic level multi-tasking (DAFW). In order to develop such logic, the following procedure is adopted at the end of every week: a) calculate the current amount of workload present in each cell (workload as a function of number of slicers allocated to each cell); b) calculate the production capacity as function of the number of high skill and low skill workers currently working within each cell; c) calculate the remaining number of working days from the current moment till the end of the month; d) with the information provided by 'b' and 'c', calculate the number of slicers that can be assembled by the end of the month in each cell; e) if this quantity calculated in step 'd' is greater than that specified in step 'a', start an iterative process from step 'b' and calculate the production capacity with one worker less than the previous condition; f) after second iteration, for any cell, if the quantity calculated in step 'd' is still greater than that specified in step 'a', that cell becomes an offering-cell and makes available its worker to the whole macro-family, i.e. worker can be used to meet the capacity requirement of a cell-in-need within the same macro-family. In fact, if a cell is generating a delay of one week with respect to the end of the month (it is the cell-in-need), then it can receive a worker from another cell (depending on availability of worker) to increase its production capacity.

Overall, it is worth pointing out that when a cell has a worker to offer to the system, the worker leaves only in the case when there is need in another cell. Similarly, if a cell is expected to mature late delivery and one or more of its workers are allocated to other cells-in-need, the cell will get its workers back regardless of the situation in host cells. With these constraints the quality and workers performance loss (due to inefficiency when working outside of their micro-family) becomes less influential, while the cells with delayed delivery can get extra workers from offering-cells to increase their production capacity. In order develop a mathematical model for the control logic explained so far, we need to calculate the total number of needed hours, based on current workload for both HSW and LSW, in each cell, then comparing it with total number of remaining hours, both for HSW and LSW, in each cell till the end of month. In this regard, following indexes are used:

X_i : the total number of slicers of micro-family i currently present in the cell
 T_i : the total average time for the production of a slicer of the micro-family i
 α_i : the share of total average time spent by the final assembly operations
 $1-\alpha_i$: the share of total average time spent by the pre-assembly operations
 glr : the remaining number of working days until the end of month
 nl_i : the number of low skill workers present in cell belonging to micro-family i
 nh_i : the number of high skill workers present in cell belonging to micro-family i
 xh_i : the number of remaining working hours for HSW till the end of month
 xl_i : the number of remaining working hours for LSW till the end of month
 wh : number of daily working hours available for both HSW and LSW

We can calculate the number of hours needed by HSW and LSW in a cell to complete the current workload of micro-family i by following equations:

$$h_{HS_i} = X_i * T_i * \alpha_i \quad (1)$$

$$h_{LS_i} = X_i * T_i * (1 - \alpha_i) \quad (2)$$

h_{HS} and h_{LS} are used as benchmarks that allow system to figure out if a cell is able to yield a worker or is in need of a worker by comparing it with the total number of hours remaining, for both HSW and LSW in a cell till the end of the month. Remaining working hours can be calculated by the following equations respectively:

$$xh_i = nh_i * wh * glr \quad (3)$$

$$xl_i = nl_i * wh * glr \quad (4)$$

xh_i and xl_i are the total working hours calculated by adding up the hours that each worker can work from the current moment till the end of the month. If $xh_i > h_{HS_i}$ and/or $xl_i > h_{LS_i}$, the equation 3 and 4 are executed again with one less worker. After second iteration again if $xh_i > h_{HS_i}$ and/or $xl_i > h_{LS_i}$, then the cell yields, respectively, a HSW or LSW that can be used in a cell where $xh_i < h_{HS_i}$ and/or $xl_i < h_{LS_i}$ (provided delay is more than one week, otherwise no action is required).

5 Simulation, Analysis and Results

Simulation is performed for all four control logics, where, monthly throughput is measured for each micro-family. All control logics used same resources and same types of demand patterns. In fact, simulation is performed using real production data and with real system constraints. Summary of findings is shown in table 2 where alternative control logics for adaptive decision-making are compared for their ability to meet monthly demand of each micro-family (calculated as the ratio between average monthly throughput and average monthly demand for each micro-family). It can be seen from the table that without any allocation logic the production system can meet only less than 90% of the monthly demand of micro-families 7 and 8; while with dynamic allocation of flexible workers (DAFW) the production system can meet more than 99% of the overall demand for each micro-family with same resources. Overall, DAFW with basic level multi-tasking yields the highest performance when compared with other control logics. Interestingly, our results show that, with high flexibility (i.e. by high level multitasking) the overall performance is decreased due to worker efficiency losses when performing operations on products other than their own macro-family.

Table 2. Comparative results for different control logics

	DAFW	DAFW (HF)	DAWL	DAWL (HF)	No allocation
Family 1	99.96%	99.95%	97.90%	98.94%	97.41%
Family 2	99.91%	99.36%	97.49%	98.95%	93.52%
Family 3	99.55%	99.94%	98.97%	99.88%	98.97%
Family 4	99.89%	99.94%	99.92%	100.00%	99.92%
Family 5	99.80%	99.91%	99.01%	99.64%	98.76%
Family 6	99.84%	99.86%	98.57%	94.35%	92.69%
Family 7	99.87%	99.78%	99.33%	99.48%	89.60%
Family 8	98.58%	98.58%	94.41%	98.05%	89.67%
Overall	99.68%	99.66%	98.20%	98.66%	95.07%

6 Conclusion

This paper addressed uncertain demand disturbances and the achievement of production responsiveness in an environment made of assembly cells with workers as main resource. In this paper, simulation is used to evaluate alternative control logics for decision-making regarding recurring uncertain disturbances in demand. These control logics include i) dynamic allocation between cells (workload versus workers), ii) different levels of worker flexibility (basic versus high level multitasking). Our simulation study shows that dynamic allocation of flexible workers leads to higher responsiveness to disturbances in demand when compared with dynamic allocation of workload. Furthermore, we found that higher flexibility does not always guarantee higher performance. In fact, it is the right level of flexibility combined with the proper decision-making logic which

leads to higher performance. Therefore, a careful analysis of requisite flexibility and the proper decision logic is important to achieve higher responsiveness. Our results are clearly contingent to type of production environment and the type and nature of disturbance; therefore, in the future it will be interesting to study variants of such type of control logics in different environments subject to different demand patterns.

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