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MTO/MTS policy optimization for sheet metal plate parts in an ATO environment

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Abstract

The management of the production and procurement of the assembled parts in an assembly to order (ATO) environment is a challenging problem. Due to the high variety and high inventory space utilization of the sheet metal plate parts, many companies choose to include in their production the cutting, blending, welding and if necessary, painting processes, reducing the lead time and consequently the stocks levels. The related trade-off between the setup times and the inventory space utilization is clear. This paper aims to propose a bi-objective optimization model to properly set the MTO/MTS policy to adopt. A case study is reported to test the model and to demonstrate the practical implication of this research.

Keywords: Plate parts, Assembly To Order, Make To Order, Make To Stock.

1. Introduction

Following just-in-time (JIT) principles, a growing number of manufacturers are therefore adopting the assembly to order (ATO) paradigm. In this context, the time to market is short and represented by the assembly time. Instead, the parts fabrication and the parts procurement lead times are hidden by the stocks. As consequence, the ATO paradigm typically works with a pull Make To Order (MTO) in the assembly phases, while a push Make To Stock (MTS) policy is adopted before the assembly phase based on forecasts or on re-order points at the warehouses [1]. Between the whole set of the parts used in the assembly process, a particular part typology is interesting: the sheet metal plate parts (Fig. 1). In fact, they:

1. Are used in with different purposes within the product. One of them is the product coverage, that generally happens in the last assembly phases.
2. Have a considerable number of variants (in terms of dimension, shape, colors, etc.) because they are frequently adopted for the product customization.
3. Are large and voluminous.

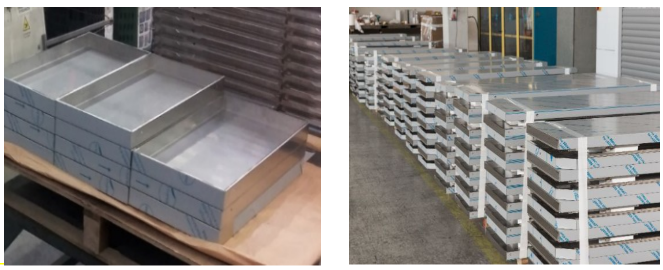

Fig. 1. Example of cut, blended, welded sheet metal plate parts used in the last assembly phase stored using Europallet (EPAL).

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The second two points negatively affect the inventory levels, with a potential huge volume occupied within the warehouse. As consequence, many companies choose to include in their production the cutting, blending, welding and if necessary painting processes, in order to reduce the lead-time (if compared with a procurement process) and consequently the stock levels. Moreover, according the assembly program, it can be possible to apply for this part, a typology not a pure MTS, but a hybrid MTO/MTS policy (Fig. 2).

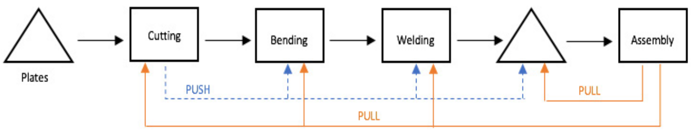

Fig. 2. Example of hybrid MTO/MTS policy applied to a possible production cycle of sheet metal plate parts in an ATO environment.

As reported by different authors [1, 2] in recent years many companies are gradually moving more towards hybrid MTS/MTO production mode. A proper combination of MTO and MTS can exploit the advantages of both lower inventory and short delivery time [3]. This paper aims to explore the possibility to use a flexible production to manage a huge variety of sheet metal plate parts with a hybrid MTO/MTS production. It proposes a bi-objective mathematical model to properly set for each part the MTS or MTO policy in order to minimize both setup time and the inventory used space. The main contribution to the field of this research is to cope with the hybrid MTO/MTS policy definition for internally produced parts in an ATO environment.

The novelty of the research is represented by the proposal of a bi-objective optimization model with a multi-criteria approach considering the inclusion of the agility concept in the hybrid MTO/MTS policy definition. Agility has many definitions in literature [4] but is generally perceived as a combination of speed and flexibility [5]. In this paper the agility metrics proposed by Barbazza et al. [4] are used.

At last, another enforcing element of this research is its applicability to many industrial contexts. The sheet metal plate parts are present in a huge number of assembled products, both for domestic and industrial applications (i.e. ovens refrigerators, washing machines, machines used in the production systems, etc.). The paper reports an industrial application for a washing machines manufacturer.

The remainder of this paper is organized as follows. Section 2 presents the literature review. Section 3 describes the bi-objective optimization model for MTO/MTS policy definition. Section 4 shows the case study, while Section 5 reports the conclusions.

2. Literature review

Shorter market response, customized demand and flexible production are becoming typical challenges to manufacturing enterprises [2]. In this context for each managed item the MTO or MTS policy definition appears a strategic issue.

Although hybrid MTS/MTO production systems have attracted numerous practitioners in practice, only a few research papers have been presented in the literature so far [13]. The first instance of hybrid MTS/MTO was a study by Williams [20]. He assessed one-stage systems in which there were stochastic demands with interactions and capacity constraints using queuing theory. So, this enabled questions to be answered such as which goods should be stocked and the key issue was the inventory management. From that study different other contributions are proposed with different objectives. The basic objectives are:

- MTO/MTS decoupling point, i.e. through the flow of the different production stages, the separation between the upstream MTS to the downstream MTO where the generic products are post-manufactured and customized [7, 8, 11, 17,19].
- Production, planning and scheduling, i.e the possibility to investigate potential production optimization and/or optimize the production planning and scheduling through a proper MTS/MTO definition [6, 9, 10, 12, 13, 15].
- Order acceptance and capacity requirement. i.e. the acceptance/rejection decision over the new arriving orders, considering the constraints in production resources, material supplies and continuous changes in the market force [1, 2, 6, 14].
- Inventory management, i.e. the decision of what and how much semi-finished products to produce with MTS policy. It is also related to the parts standardization and to the product modularity [8, 12, 15, 16].

These different potential objectives in the MTO/MTS policy definition highlight the wideness and the complexity of the problem. Just some authors propose methodologies that try to achieve simultaneously different goals, within the order acceptance problem [6, 12] and inventory management [15].

Different methodological approaches have been proposed. It is possible to find, as single or as a combination of methods, mixed integer programming [2, 6, 12, 15], algorithms [2, 6, 11, 12, 13, 15], decisional processes based on Markov models [9, 10] or based on decisional frameworks [2, 19], even if the best used methods are simulation models [1, 7, 8, 14, 16, 17, 18]. The inclusion of industrial case studies in the research is not often described. In many studies, simple numerical analysis is used to validate the proposed methodology.

The literature review shows how

- Authors focus on one objective a time (even if in the hybrid MTO/MTS policy definition there are more suitable goals).
- Few contributes that use a multi-objective perspective do no propose a robust multi-criteria approach.
- Case studies are frequently not included.

The present paper aims to contribute in the research by proposing a bi-objective optimization model for the hybrid MTO/MTS policy definition in order to minimize both setup time and the inventory used space. It considers two objectives functions in trade-off (setup time and inventory), and selects a best response surface design simultaneously optimizing both criteria using a Pareto Frontier to identify good design candidates [21]. As demonstrated in [21], the Pareto approach shows substantial improvement over the classic desirability function methods. At last this research introduces important metrics to consider in the definition of what parts to manage with a MTO approach: the agility parameter, a combination of speed and flexibility of the production system is calculated with respect to the analyzed part.

3. Bi-objective optimization model for MTO/MTS policy definition in ATO environment

The current section reports the proposed bi-objective optimization model for MTO/MTS policy definition in an ATO environment. The subsection 3.1 reports the nomenclature, while subsection 3.2 describes the parts parameters calculation. Subsection 3.3 reports the two objective functions calculation while subsection 3.4 shows the MTO/MTS policy optimization procedure and the case study.

3.1. Nomencalture

Indices

i = 1,…,I parts
j = 1,…,J production processes
v = management policy (MTO or MTS)

Part Parameters

a_i	agility of part *i* [pieces/h^2]
EPQ_i	Equivalent Pallet Quantity, n° of positionable parts on the pallet of part *i* [pieces/pallet]
$A1_i$	greatest dimension [mm]
$A2_i$	smallest dimension of part *i* [mm]
T_i	thickness of part *i* [mm]
Q_i	total annual required pieces for part *i* [pieces/year]
B_i	Batch dimension for MTS policy for part *i* [pieces/batch] equal to the Economic Order Quantity according [22]
O_i	Number of orders of the part *i* in a pure pull MTO policy [orders/year]
$E_{i,v}$	number of productive event of part *i* for management *v* [productive event/year]
$PR_{i,v}$	number of pallet required for *v* management policy of part *i* [pallet]
EPQ_i	Equivalent Pallet Quantity for part *i*, i.e. n° of storable parts in an EPAL pallet [pieces/pallet]
$EPBQ_i$	Equivalent Pallet Base Quantity for part *i*, i.e. n° of parts storable in the pallet base [pieces/layer]
$EPHQ_i$	Equivalent Pallet Height Quantity for part *i*, i.e. n° of storable levels of $EPBQ_i$ [levels/pallet]
$T_{S_{ij}}$	setup time of part *i* in the process *j* [hours/productive event]
$T_{C_{ij}}$	production time of part *i* in the process *j* [hours /pieces]
T_{STOT_i}	total setup time of part *i* [hours/productive event]
T_{CTOT_i}	Total production time of part *i* [hours /pieces]

3.2. Parts parameters calculation

The basic idea of the research is to define for each part the proper MTO/MTS policy to adopt according two main part parameters easily calculable for each part: the number of maximum storable piece for unit area (the inventory parameter) and the agility (the production parameter). As consequence, for each part *i* are defined two main parameters a_i and EPQ_i that will used in the MTO/MTS policy optimization procedure.

The first one is the agility a_i calculated as:

$$a_i = \frac{1}{T_{STOT_i} * T_{CTOT_i}} \qquad \left[\frac{pieces}{hour^2}\right] \tag{1}$$

Where

$$T_{CTOT_i} = \sum_j T_{C_{ij}} \qquad [hours] \tag{2}$$

$$T_{STOT_i} = \sum_j T_{S_{ij}} \qquad [hours] \tag{3}$$

This agility formulation is derived by Barbazza et al. [4] and represents an acceleration. It measures the capacity of the production system to accelerate in case of production changes. It increases when the total required setup time and the total required production time through the production processes *j* decrease.

The second one is the Equivalent Pallet Quantity EPQ_i, that represents the occupied volume of the part *i* as n° of storable parts in an EPAL pallet (EuroPallet). The Europallet is the most used stock keeping unit and it has a base of 1200mmX800mm, as reported in equation (5). In Fig.1, right side, $EPQ_i = 12$. EPQ_i is calculated as:

$$EPQ_i = EPBQ_i * EPHQ_i \qquad \left[\frac{pieces}{pallet}\right] \tag{4}$$

Where

$EPBQ_i$ is calculated as function of the shape typology of the part (U shape, L shape and I shape for the flat parts), as:

$$EPBQi = \begin{cases} max\begin{cases}\left[\frac{1200}{A2_i+T_i}\right] * \left[\frac{800}{A1_i+T_i}\right] \\ \left[\frac{1200}{A1_i+T_i}\right] * \left[\frac{800}{A2_i+T_i}\right]\end{cases} & \textit{Stacking "U-shape" in pairs} \\ max\begin{cases}\left[\frac{1200}{A2_i+T_i}\right] * \left[\frac{800}{A1_i}\right] \\ \left[\frac{1200}{A1_i}\right] * \left[\frac{800}{A2_i+T_i}\right]\end{cases} & \textit{Stacking "L-shape" in pairs} \\ \left[\frac{1200}{A1_i}\right] * \left[\frac{800}{A2_i}\right] & \textit{Stacking "I-shape" in pairs} \end{cases} \tag{5}$$

3.3. Objective functions calculation

The proposed MTO/MTS policy definition model considers two objectives functions that are calculated as function of the management policy *v* (MTO or MTS) defined for each part *i* within all the production processes *j*.

The two basic objective functions are:

P_{TOT} total number of total EPAL pallet stored [pallet]
TA_{TOT} sum of total setup time [hours/year]

These two functions depend on the MTO/MTS policy assigned to each part *i*. The first represents the total number of EPAL pallets stored, the inventory objective. The latter represents the total setup time for the considered period (year), the production objective.
The calculation of these two functions is as follows:

$$P_{TOT} = \sum_i \sum_v PR_{i,v} \quad [pallet] \tag{6}$$

Where

$$PR_{i,v} = \begin{cases} \frac{B_i/2}{EPQ_i} & if \;\; v = MTS \\ 0 & if \;\; v = MTO \end{cases} \quad [pallet] \tag{7}$$

As highlighted in (7) it is assumed the number of EPAL palled stored is equal to 0 in case of MTO policy. On the other hand in case of MTS policy it is considered the average value in the period represented by the average parts quantity $B_i/2$ according to [22].

$$TA_{TOT} = \sum_i \sum_v (T_{STOT_i} * E_{i,v}) \quad \left[\frac{hours}{year}\right] \tag{8}$$

Where

$$E_{i,v} = \begin{cases} O_i & se\ if = MTO \quad \left[\frac{productive\ events}{year}\right] \\ \frac{Q_i}{B_i} & se\ if = MTS \quad \left[\frac{productive\ events}{year}\right] \end{cases} \tag{9}$$

Generally, because of B_i is the Economic Order Quantity [22] $E_{i,MTO} > E_{i,MTS}$.
The two objective functions (6) and (8) are in trade-off. In fact, when the MTS policy is applied to the greatest set of the parts i, the number of productive event $E_{i,v}$ will decrease, with a positive effect on the sum of total setup time (8) and a negative effect on the total number of total EPAL pallet stored (6). On the other hand, when the MTO policy is applied to the greatest set of the parts i, the number of productive event $E_{i,v}$ will increase, with a negative effect on the sum of total setup time (8) and a positive effect on the total number of total EPAL pallet stored (6). The objective of the proposed model, as described in the following section, is to select the best response surface design simultaneously optimizing both criteria using a Pareto Frontier to identify good design candidates [21].

3.4. MTO/MTS policy optimization procedure

The MTO/MTS bi-objective optimization procedure aims to define for what produced part is better to apply a MTO instead the traditional pure MTS policy. The model aims to minimise both inventory space and setup times. The procedure is based on 4 steps (Fig.3).

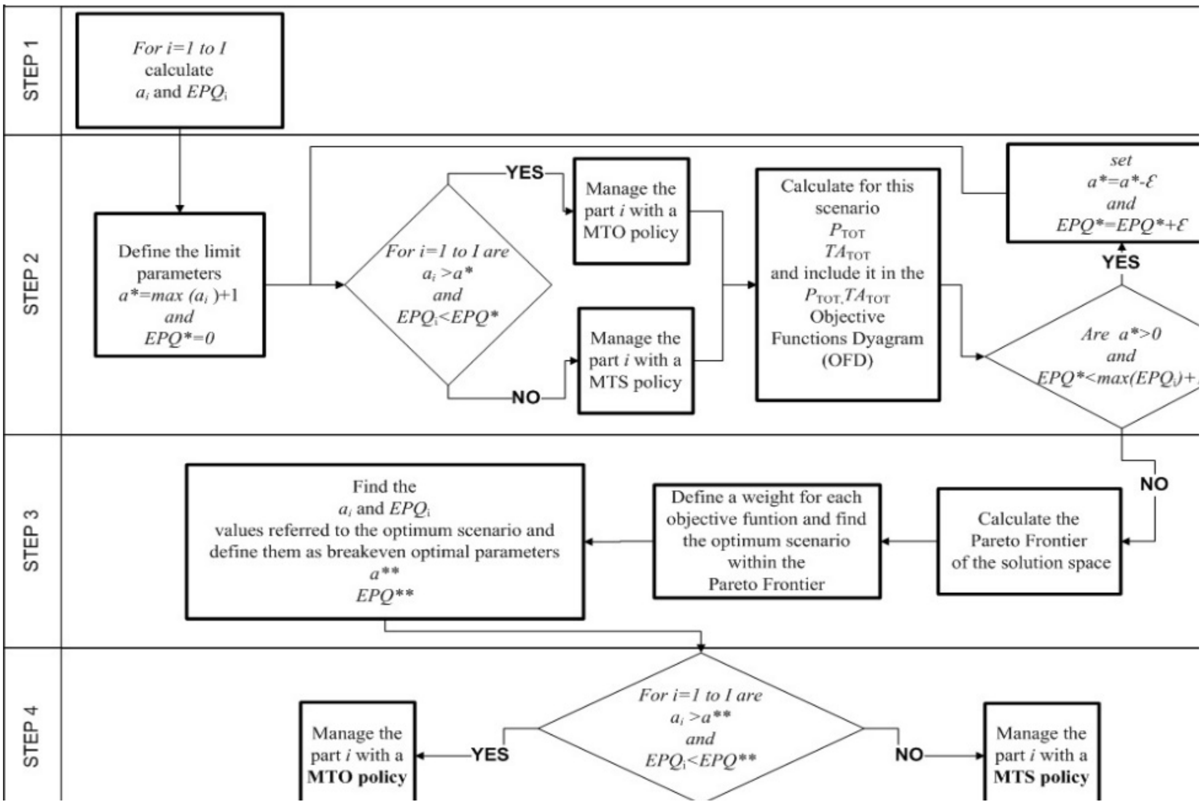

Fig. 3. MTO/MTS bi-objective optimization procedure.

STEP 1. a_i and EPQ_i calculation. For each part i the two part parameters a_i (1) EPQ_i (4) are calculated. In this way, it is possible to graphically define the position of each part according these two parameters. Considering the MTO approach, it will be necessary to consider:

- High values of a_i. It means the ability of the upstream production system to rapidly change the produced part and to speedily produce even a low number of pieces (not an entire productive batch). As consequence, for the considered part *i,* in order to apply a proper MTO policy, it is required a low setup time T_{STOT_i} (2) and a low production time T_{CTOT_i} (3) within the whole production process .
- Low values of EPQ_i. It means that between the different parts i the most critical for a MTS policy are those with high dimensions or critical shapes. As consequence, for the considered part *i,* in order to apply a proper MTO

policy, low values of EPQ_i are required.

STEP 2. Multi-scenario analysis. Considering different limit values of a^* and EPQ^* (Fig. 3), the values of two objective functions P_{TOT} (6) and TA_{TOT} (8) are calculated. The way to generate the different scenarios is detailed in Fig.3 (Step 2) where are present one *FOR* cycle and one *IF* cycle. It is also introduced an ε parameter, that can be chosen small enough to generate a representative number of potential scenarios.

STEP 3. Bi-objective Pareto Frontier and breakeven optimal parameters a^{**} and EPQ^{**} definition. Starting from the Step 2 results, according [21], the dominated and the dominant solutions are found in order to define the Pareto Frontier (the set of solutions where no other solution dominates it). At this stage, it is possible to propose an optimal bi-objective solution that will necessary lie in the Pareto Frontier [21]. The proposed approach considers as an input data a different weight of the two objective functions given as input and find within the Pareto Frontier the point that satisfy this condition.

STEP 4. Final optimal MTO/MTS policy definition according the bi-objective optimal solution. In this stage, according the breakeven optimal values of a** and EPQ** found in STEP 3 is possible to find the related scenario generated in STEP 2, defining as result the final optimal MTO/MTS policy to adopt for each part *i*.

4. Case Study

This section reports a case study from an Italian washing machine manufacturer that applied a pure MTS policy for the internally produced parts. The case study includes the definition of the proper MTO/MTS policy for 425 sheet metal plate parts. involved production technologies are metal cutting, bending and welding.

STEP 1: Fig.4 reports the 425 parts of the case study (blue points) according the a_i (1) EPQ_i (4) parameters.

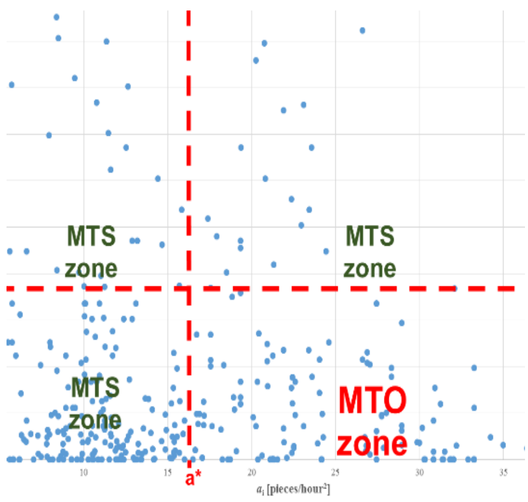

Fig. 4. a_i and EPQ_i calculation and potential MTO zone.

The four quadrants are just an indication on where lies the MTO and MTS policy to adopt according the two parts parameters according Section 3.4 Step 1. The optimisation problem lies on the optimal definition of the MTO zone, i.e. on the optimal definition of the breakeven optimal values of two part parameters a^{**} and EPQ^{**}.

STEP 2: The output is reported in Fig. 5 where for each scenario, two objective functions values are plotted.

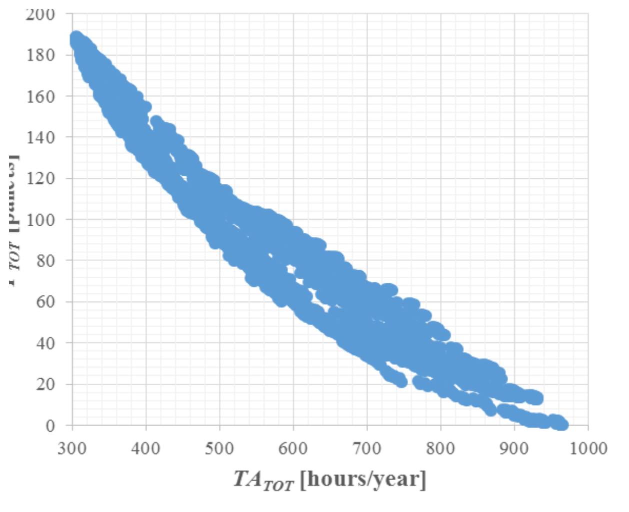

Fig. 5. Objective functions plot for different MTO/MTS scenarios.

From the computational point of view, the problem of calculating the FOR and the IF is trivial. For the case study the scenarios analysis reported in Fig.5 is developed using Matlab SW with an Intel(R) Core i7 generating *2.88e+5* scenarios in *9.89* seconds.

STEP 3: Fig.6 reports the Pareto Frontier for the case study of different scenarios analysed in the Step 2.

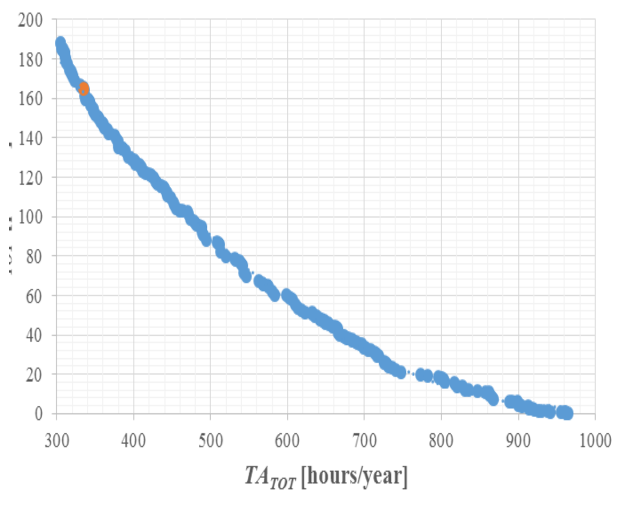

Fig. 6. Pareto Frontier of a bi-objective optimal solution (in red).

Considering the case study conditions, the production objective is more important than the inventory objective. Therefore, according the case company management inputs, a weight equal 2 for TA_{TOT} and equal to 1 for P_{TOT} have been defined. Fig.6 reports in red the point *(335.36; 164.75)* that is the more representative point according the previous weight condition. It represents the optimal bi-objective value. Once defined, it is possible to derive the breakeven optimal values of a^{**} and EPQ^{**} of the related scenario. The case study values related to Fig.6 are $a^{**}=21,75$ pieces/h^2 and $EPQ^{**}=13$ pieces/pallet.

STEP 4: Fig.7 shows the final solution. Each point represents a part. The points belonging to the quadrant in the low-right position will be managed with a MTO policy, while the others with a MTS policy.

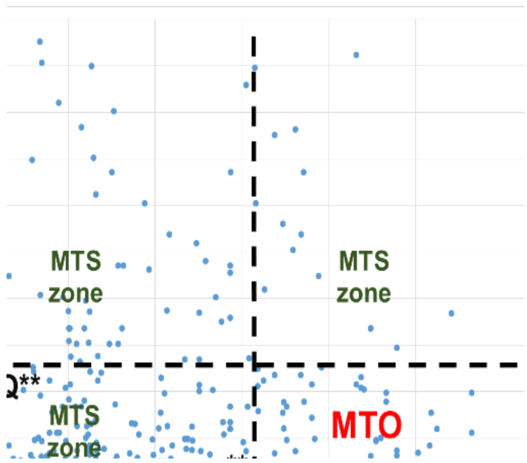

Fig. 7. Final MTO/MTS policy definition.

The application to the case study of the proposed procedure moved 119 parts on 425 from MTS to MTO policy. If compared with the previous pure MTS policy, the total number of stocked pallet decreases about 34%, while the total setup time increases just about 5%. Moreover, the introduction of the agility concept in the proposed model helped to accurately choose the parts to move to MTO policy. Thanks to this, an insignificant impact on the setup time and on the production capacity utilization is observed, permitting a speedily respond to the order requirements/changes.

5. Conclusions

This paper proposes a bi-objective mathematical model, based on a step by step procedure, to properly set the proper MTS or MTO policy in order to minimize both setup time and the inventory used space. The proposed method selects the best response surface design simultaneously optimizing both criteria using a Pareto Frontier to identify good design candidates according the agility and inventory parameters of each part. The application of the method to a real, large dimension problem demonstrate the applicability of the research. The obtained results demonstrate the potential reachable savings, in terms of setup times and inventory space utilization. Future research shall focus on the extension of the proposed model to the supply chain, considering the purchased parts and the related variables and constraints.

References

[1] Lu, Q., Chen, X. Capacity expansion investment of supplier under make-to-order and make-to-stock supply chains. International Journal of Production Economics 2018;198:133-148.
[2] Kalantari, M., Rabbani, M., Ebadian, M. A decision support system for order acceptance/rejection in hybrid MTS/MTO production systems. Applied Mathematical Modelling 2011; 35(3):1363-1377.
[3] M. Yingdong, Design of Hybrid Make-to-Stock (MTS)-Make-to-Order (MTO) Manufacturing System, M.Sc. Thesis, The University of Minnesota, 2001.
[4] Barbazza, L., Faccio, M., Oscari, F., Rosati, G. Agility in assembly systems: A comparison model. Assembly Automation 2017; 37(4):411-421.
[5] Kootbally, Z., Schlenoff, C., Lawler, C., Kramer, T. and Gupta, S. Towards robust assembly with knowledge representation for the planning domain definition language (pddl)", Robotics and Computer-Integrated Manufacturing 2015; 33:42-55.
[6]Wang, Z., Qi, Y., Cui, H., Zhang, J. A hybrid algorithm for order acceptance and scheduling problem in make-to-stock/make-to-order industries. Computers and Industrial Engineering, 2018; In press
[7] Beemsterboer, B., Land, M., Teunter, R., Bokhorst, J. Integrating make-to-order and make-to-stock in job shop control. International Journal of Production Economics 2017, 185:1-10.
[8] Jia, Y., Weng, W., Fujimura, S. A hybrid MTS-MTO production model with a dynamic decoupling point for flexible flow shops. Proceedings - 16th IEEE/ACIS International Conference on Computer and Information Science 2017; ICIS 7960102, 803-807.
[9] Wilson, S. Mix flexibility optimisation in hybrid MTS/MTO environments in process industries. Cogent Engineering 2018; 5(1): 1-17.
[10]Beemsterboer, B., Land, M., Teunter, R., Hybrid MTO-MTS production planning:An explorative study. European Journal of Operational Research 2016; 248:453–461.
[11]Tadeuz, Maruf, A. Scheduling Method for MTS/MTO Production System. IOP Conference Series: Materials Science and Engineering 2016; 114(1),012061.
[12]Almehdawe, E., Jewkes, E. Performance analysis and optimization of hybrid manufacturing systems under a batch ordering policy. International Journal of Production Economics 2013;144(1): 200-208.
[13]Rafiei, H., Rabbani, M., Alimardani, M. Novel bi-level hierarchical production planning in hybrid MTS/MTO production contexts. International Journal of Production Research 2013; 51(5):1331-1346.
[14]Rafiei, H., Rabbani, M. Capacity coordination in hybrid make-to-stock/make-to-order production environments. International Journal of Production Research 2012; 50(3): 773-789.
[15]Zhang, T., Zhang, Y., Bai, X., Jin, D. Research on the MTO-MTS production management of steel-iron factories. Proceedings of the 2011 Chinese Control and Decision Conference, 2011 5968848:3610-3615.
[16]Persona, A., Battini, D., Manzini, R., Pareschi, A. Optimal safety stock levels of subassemblies and manufacturing components. International Journal of Production Economics 2007; 110(1-2):147-159.
[17]Soman, C., A. Make to Order and Make To Stock in food processing industries. Ridderprint B.V. Ridderkerk 2005.
[18]Chang, S.-H., Pai, P.-F., Yuan, K.-J., Wang, B.-C., Li, R.-K. Heuristic PAC model for hybrid MTO and MTS production environment. International Journal of Production Economics 2003; 85(3): 347-358.
[19]Van Donk, D., V., Make to stock or make to order: The decoupling point in the food processing industries. Int. J. Production Economics 2001, 69: 297-306.
[20]Williams, T.M., Special products and uncertainty in production/inventory systems. European Journal of Operational Research 1984; 15 (1): 46–54.
[21]Lu, L., Anderson-Cook, C.M., Robinson, T.J. A case study to demonstrate a Pareto Frontier for selecting a best response surface design while simultaneously optimizing multiple criteria. Applied Stochastic Models in Business and Industry 2012; 28(3):206-221.
[22]Hax, AC; Candea, D., Production and Operations Management, Englewood Cliffs, NJ: Prentice-Hall 1984.