Production Rescheduling for Contract Manufacturing Industry based on Delivery Risks

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Abstract: Contract Manufacturers (CM) usually schedule production considering each customer’s needs and constraints. One drawback of this strategy is the difficulty of evaluating its general production scheduling, mainly when urgent production rescheduling is needed. The lack of integration and synchronization between CMs and customers imposes that production rescheduling be based on planners experiences. This paper proposes a new conceptual model for contract manufacturing production rescheduling based on the evaluation of delivery risks to customers, including integration between the production scheduling with the customer delivery commitment. The model was implemented and tested by means of a simulation-based procedure using real capacity information.

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Keywords: Production Rescheduling, Contract Manufacturer (CM), Contract Manufacturing Service (CMS), Simulation, Conceptual Model.

1. INTRODUCTION

Contract Manufacturer (CM) industry does not have their own brand for final consumers, which are contracted to manufacture parts (printed circuit boards, subassemblies and others) or even the complete product of the company that owns the brand. It is agreed in the contract that CM goods will be supplied according to changeable demand (Hahn et al., 2016). This kind of organization has a small profit margin compared with finish goods industries, thus it is important to have good Production Planning Control (PCP).

Planning is the enterprise area which guides all the other organization areas in order to achieve the commitment agreed with the customer. It is responsible for demand management, Master Production Schedule (MPS) and schedule execution. One of the most important decision-making processes in the industries is the scheduling process (Li and Ierapetritou, 2008). The real time schedule execution tracking is invaluable in order to guarantee the delivery commitment (on time and product quantities). Whenever production disturbances occur, actions must be taken to realign production schedule and delivery plan, avoiding or mitigating any annoyance in the customer.

Currently the companies are interested in creating value for the customers, especially in terms of improvements in lead time, delivery services, product availability and reliability (Witkowski, 2017). For CMs it is usual to have specific production schedule for each customer and, some medium or big companies have dedicated teams and resources for each customer (workcells). One common drawback of this kind of organization structure is the difficult of evaluating general plant capacity, mainly when urgent production rescheduling due to unexpected production downtimes is necessary.

In the industry 4.0, products and services are connected by network applications which are automated and self-optimized including delivery without human interventions, hence system elements make autonomous decisions (Hofmann and Rüsch, 2017). Literature review about production scheduling under industry 4.0 perspective aims at opportunities in rescheduling strategies, integration of supply chain data into scheduling and dispatching decisions, among other factors (Waschneck et al., 2016). Reference models are required for smart systems to understand the clear description of concepts linking real-time data availability and automated monitoring control (Thoben et al., 2017) and dynamic environments and perturbations can be represented by simulation (Frazzon et al., 2015; 2016; 2017).

Following the trend of Industry 4.0, this research wants integrating production running information into CM and inventory consumption into customers to evaluate the risks that changes to the CM schedule may cause at the customer. Hence, an assertive rescheduling can occur automatically (without planner intervention) whenever there is a threat in the deliveries agreed with the customer, and the two companies receive the information concomitantly.

This paper proposes a new conceptual model to suggest production rescheduling based on delivery risks evaluation to customers. The main contribution of this model is taking the customer information to decide about the needed of
production reschedule in the CM industry, integrating both channels, the factory and the customers. This process should be flexibly connected, allowing automation and self-optimization without human intervention, in order to have autonomous decisions made by the system. The conceptual model was developed based on the authors’ experience in CM organization, and then the model was implemented and tested by means of a simulation-based procedure using real capacity information.

2. THEORETICAL FRAME

2.1 Production Rescheduling

Production rescheduling concepts are already presented in some studies:

“Rescheduling is the process of updating an existing production schedule in response to disruption or other changes.” (Vieira et al., 2003).

“Rescheduling is the procedure to repair a production plan affected by unexpected disruptions. [...] Rescheduling is a process of generating a new executable schedule upon the occurrence of an unforeseen disruption.” (Dong and Jang, 2012).

Significant operation changes trigger Production Rescheduling, they are not previously planned but are needed due to unavoidable circumstances, which can be uncertainty caused by external business or internal production environments. (Jain and Elmaraghy, 1997; Li, 1999; Li et al., 2000; Chan and Zeng, 2005; Rao and Janardhana, 2014).

Manufacturing systems are dynamic, thus production rescheduling occurrences are common, because, usually, manufacturing operations are not perfect. The main factors that can cause production disturbances are: machine breakdowns, increased order priority, rush orders arrival, order cancellation, order modification, quality problems, products reworks, processing time delay, operator unavailability and unavailable materials. (Jain and Elmaraghy, 1997; Li, 1999; Vieira et al., 2003; Dong and Jang, 2012; Rao and Janardhana, 2014; Salido et al., 2017).

In contract manufacturing service companies, schedules are typically created specifically for each customer. In addition, some more structured factories have workcells with dedicated planners. In this way, it is very complex to assess where the greatest risks and capacity opportunities are, considering all lines and all customers. When production rescheduling is needed, the Planner, based on its experience (with customers, in-process models and line configurations), negotiates changes in delivery plans and determines changes in the running day's schedule. It is necessary to develop systems that can synchronize and integrate information between customers (inventory consumption) and CMs (production execution) in order to get the better production rescheduling to meet the goals for both enterprises.

Methods of approaching a scheduling problem have been studied for a long time and many categories have been used to classify them: conventional, knowledge-based, distributed solving, right-shift rescheduling, heuristic-based, multi-agents, active scheduling, fuzzy logic, case-based reasoning, constraint-based scheduling, artificial intelligence techniques, stochastic scheduling, robust optimization method, sensitivity analysis, parametric programming method, analytic, simulation and meta-heuristics. (Suresh and Chaudhuri, 1993; Raheja and Subramaniam, 2002; Lee, 2008; Li and Ierapetritou, 2008; Ouelhadj and Petrovic, 2009).

Most scheduling problems are complex, large-scale, non-linear and uncertain, belonging to the class of NP-hard optimization problems. Consequently, optimal solutions often cannot be computed or only in long computational times when modelled analytically (Ku and Beck, 2016). In order to minimize these problems, Sobaszek et al. (2017) proposed an intelligent scheduling system that utilizes data feedback to create a robust schedule (schedule generation method, according to Vieira et al. (2003) framework), reducing the likeliness of the need for rescheduling. However, robust schedule may to consider more resources to avoid losses with little downtimes.

Based on the rescheduling framework proposed by Vieira et al. (2003), this research will address production rescheduling problems with the following characteristics: Environment: Dynamic; Strategy: Predictive-reactive (general and update); Policy: Hybrid (periodic and event-driven); Method: Schedule repair.

2.2 Simulation Approach

Simulation is a tool for the evaluation and analysis of stochastic and complex systems, such as manufacturing systems (Lin and Chen, 2015). Complex systems can be evaluated or developed using simulation-based techniques, in this way simulation models can predict the effect of changes in an existing system or can predict the operational performance of a new system (Kück et al., 2016).

Modeling and simulation is one of the most proper ways to deal solutions based experience in the real-world complex systems (Longo, 2010). One way to justify and determine the attractive configuration of the system is the use of simulation as a strong decision-making and risk analysis tool (Dehghanimohammadabadi and Keyser, 2014), since sufficient justification is needed to convince the managers to adopt improvements in organizations (Bamakan and Dehghanimohammadabadi, 2015).

Simulation softwares can model most of the real-world systems behaviours, but when it is necessary to model refined human decision-making, the simulation packages have limitations. So, computational support tools integrated with the simulation should be used to make the simulation model more efficient and robust (Dehghanimohammadabadi and Keyser, 2017). Frantzén et al. (2011) presented a novel scheduling and real-time rescheduling system that integrates a simulation-based optimization model with the shop floor database that utilizes data from the system's current state.
The rescheduling process proposed in this research is based on professional experience of two authors. It is difficult to convince the industry staff about a new process architecture without a simulation model that can predict the operational performance of a new system. So, the conceptual model of production rescheduling proposed in this research will be validated in a simulation model. It is expected to have an automation and self-optimization process without human intervention (autonomous decisions made by the system), however, due to the limitations of simulation software it is necessary to use a computational support tool to optimize the complete proposed solution.

3. CONCEPTUAL MODEL

The process of production rescheduling based on delivery risks to customers is conceptualized in Fig. 1.

3.1 Contract Manufacturer: schedule information and production execution

In contract manufacturer industry, it is common to have independent schedule for each customer. This conceptual model proposes to have a unique schedule for all customers, which will distribute the schedule for all lines according to priorities and capacity constraints. The schedule execution must be monitored in real time, forecasting the production results at the end of the day. The output of this block must inform the balance between production schedule and production executed for each line.

3.2 Customers: delivery information and inventory consumption

On the customer side, the inventory consumption will suggest acceptable delivery plans adjustments to be considered by rescheduling proposal, just in case it is needed. It should be taken into account the contractual tolerances for delivery quantities and delays. The committed delivery plan must also be informed.

3.3 Production Rescheduling Process

This is the core of the conceptual model. The production execution information will be compared with committed delivery plan. If there are no delivery risks, then production schedule will be kept. In contrast, if there is any disturbance in production with potential risks of delivery delays or even delivery cancels, an autonomous production rescheduling will be suggested based on the capacity recorded in the system by CM factory side and the acceptable adjustments for delivery plans informed by customer side. If the proposed changes suggested in rescheduling infringes contractual agreements or does not eliminate the delivery risks completely (just mitigate the quantities or delays), the CM production planner must be involved to negotiate changes in delivery plan with the customer. If there is an agreement, the acceptable adjustments in delivery plan are updated by the customer and the flow is followed again, if not the production schedule is kept and contract manufacturer industry will assume the liability.
4. TEST CASE

4.1 System Description

In order to validate the conceptual model, data were collected from a multinational industry (called CM Factory from this point) that has part of its production dedicated to contract manufacturing services. This organization designs, engineers and manufactures audio products for automotive companies, they market for more than twenty brands around the world. Lean culture is followed; tools like heijunka, single minute exchange of die (SMED) among others are known and applied by them. As a way to facilitate the modeling, this scenario considered just three “final” lines, three customers and two models for each customer. The lines have the same configuration and capacity shared; they can be used to manufacture any product for any customer used in this scenario. As shown in Fig. 2, the car audio production process has four assembly stations, two test stations (Automated Functional Test – AFT, and Manual Functional Test - MFT) and packing; if any operator detects some non-conformity, the product goes to a repair technician.

![Fig. 2. Car audio production process flowchart.](image)

4.2 Data Applied in Simulation Model

The data applied to validate this model were collected or adapted/estimated as informed in the Table 1.

| Data Parameter       | Data Source                                      |
|----------------------|--------------------------------------------------|
| Production schedule  | Real data from CM Factory.                      |
| Run rate             | Real data from CM Factory (85% full capacity).   |
| Delivery Plan        | Adapted: schedule date was moved a day further into the future every day. |
| Cycle times          | Real data from CM Factory (85% full capacity). For test workstations were considered full capacity. |
| Setup                | Real data from CM Factory: Target: 10 min (above the target, it is downtime) |
| First Pass Yield (FPY)| Real data: Target 97.00%, Actual 98.80%          |
| Failure Rate         | Real data: True Failure 1.18%, False Failure 0.02% |
| Scrap                | Real data: Target 0.50%, Actual 0.33%            |
| Downtime             | Real data from CM Factory.                      |
| Repair time          | Estimated: 30 minutes                           |

4.3 Simulation Model

The car audio production process (Fig. 2) was modelled in Simio simulation software considering the data informed in Table 1. In order to facilitate the simulation modeling some assumptions were established: (1) The initial schedule is provided by the planner; (2) Production is executed according to the schedule, and everything that is produced is delivered the next day (before lunch time), not being higher than delivery plan; (3) There are no raw material constraints; (4) Cycle times for test workstation are informed as 100% of capacity, due to the main tasks being executed by equipment; (5) Preventive Maintenance times are not considered; (6) Minimum Order Quantity (MOQ) and Order Increment (OI) quantity are not considered in the Delivery Plan and (7) If a product changeover happens in the beginning of the first shift, the setup time is not considered. In this study, computational tools to support the optimization were not used. The comparison between “production execution information” and “committed delivery plan & acceptable adjustments” and analysis to check “delivery risks” were performed in an excel spreadsheet. In order to suggest changes in deliveries, an empirical logic to adjust delivery quantity was applied to improve the simulation results, as shown in Fig. 3. Since the deliveries occur the day following the production day, in case of incomplete quantity, the initial production of the delivery day is used to complete the batch.

![Fig. 3. Empirical logic to adjust delivery quantities.](image)

4.4 Results and Analysis

The real data applied interfered in the outcome. The positive side was validating that the CM Factory’s lean culture does not allow any significant divergence between produced and scheduled quantities. The negative side was the lack of significant production disturbances to simulate the production rescheduling process. These impacts (positive and negative) confirm that in the real industries, robust schedules (schedule generation method, see Vieira et al. (2003)) are applied to avoid schedule repairs in case of production downtime, however some reschedules can occur in a low frequency. The proposed conceptual model is designed for a schedule repair method (see Vieira et al. (2003)), the real data was used to simulate production execution and the main aspect analyzed was the comparison between delivery plan and original delivery quantity, suggesting delivery adjustments. The Fig. 4 illustrates the original delivery quantity (shipping the total produced quantity in the previous day) compared with the
delivery plan. Note the shipment for customer Alpha without delivery plan on Jan/18th.

![Graph showing delivery plan vs. delivered quantity]

**Fig. 4. Delivery Plan vs Delivered Quantity Adjusted.**

Based on simulation results and following the empirical logic shown in Fig. 3 in order to eliminate or mitigate lost delivery quantities and, when feasible, adjust these deficits in the next shipment, some changes were suggested, as illustrated in Fig. 5. Note that the second shipment to customer Alpha occurred on Jan/19th, as requested in the delivery plan.

![Graph showing delivery plan vs. delivered quantity]

**Fig. 5. Delivery Plan vs Delivered Quantity Adjusted.**

The Table 2 shows the results summary (quantities): schedule and delivery plan (same products quantities), produced and shipped (same quantity), and balance. The total production was shipped, although 70 products were missed in relation on the schedule, due to 66 scrapped and 4 awaiting technical repairs. In addition, the quantity of deliveries occurrences with missing quantities and the days in delay (days occurred until settle the shipment deficit) are also presented (Table 3).

**Table 2. Results summary (quantities).**

| Customer | Product | Schedule & Deliv. Plan | Production & Delivered | Balance |
|----------|---------|------------------------|------------------------|---------|
| Alpha    | CMA1    | 0                      | 0                      | 0       |
| Alpha    | CMA2    | 1,253                  | 1,250                  | -3      |
| Beta     | CMB1    | 1,085                  | 1,081                  | -4      |
| Beta     | CMB2    | 7,130                  | 7,164                  | -26     |
| Gamma    | CMG1    | 3,535                  | 3,521                  | -14     |
| Gamma    | CMG2    | 9,192                  | 9,169                  | -23     |
| **Total**|         | **22,195**             | **22,125**             | **-70** |

**Table 3. Results Summary (delivery occurrences).**

| Customer | Product | Alpha | Beta | Gamma | Total |
|----------|---------|-------|------|-------|-------|
|          |         | CMA1  | CMA2 | CMB1  | CMB2  | CMG1  | CMG2  | **Total** |
| Delivery Occurrences | 0 | 3 | 5 | 17 | 7 | 20 | 52 |
| Incomplete Qty Occurrences (original) | 0 | 2 | 2 | 11 | 4 | 10 | 29 |
| Incomplete Qty Occurrences (after adjustments) | 0 | 2 | 2 | 5 | 3 | 3 | 15 |
| Days to adjust delivery qty until last delivery (original) | 0 | 16 | 9 | 34 | 28 | 23 | 110 |
| Days to adjust delivery qty until last delivery (after adjustments) | 0 | 17 | 7 | 19 | 22 | 10 | 75 |

The quantity of deliveries occurrences with missing quantities was decreased from 29 to 15 after delivery adjustment (see delivery procedure in Fig. 3), special attention to the models with high volume (CMB2 and CMG2) with up to 50% of improvement. After delivery adjustments, the days occurred until settle the delivery quantity deficit were reduced from 110 to 75 days. Note that in the original delivery, model CMA2 had one shipment in advance (not planned with customer) which gives the false sensation of a better result. In order to improve the delivery results, it should be considered 0.05% (scrap target) of additional products in the first days of the schedule. However, this percentage should be decreased in the last days of schedule. In this way, the tolerance balance should be visible just at the end of the month.

**5. CONCLUSIONS**

A new conceptual model for contract manufacturing production rescheduling based on the evaluation of delivery risks to customers was presented in this study. A relevant part of the conceptual model is the integration of production execution information (on CM side) and inventory consumption information (on customers side). This proposal allows autonomous decisions made by the system. The test case application, using real data, showed a good alignment between scheduled and executed production due to the company’s lean culture. However, opportunities were identified in the delivery execution. Recommendations for future research includes the use of computational tools to support the optimization of this model (specially production...
rescheduling process block), testing autonomous decision and integration with data feedback systems.

REFERENCES

Bamakan, S. M. H., & Dehghanimohammadabadi, M. (2015). A Weighted monte carlo simulation approach to risk assessment of information security management system. *International Journal of Enterprise Information Systems (IJEIS)*, 11(4), 63-78.

Chan, W. T., & Zeng, Z. (2005). Rescheduling precast production with multiobjective optimization. In *Computing in Civil Engineering* (pp. 1-10).

Dehghanimohammadabadi, M., & Keyser, T. (2014, January). Does the Iranian national productivity and excellence award get leadership buy-in. In *IIE Annual Conference. Proceedings* (p. 2656). Institute of Industrial and Systems Engineers (IISE).

Dehghanimohammadabadi, M., & Keyser, T. K. (2017). Intelligent simulation: Integration of SIMIO and MATLAB to deploy decision support systems to simulation environment. *Simulation Modelling Practice and Theory*, 71, 45-60.

Dong, Y. H., & Jiang, J. (2012). Production rescheduling for machine breakdown at a job shop. *International Journal of Production Research*, 50(10), 2681-2691.

Frantzén, M., Ng, A. H., & Moore, P. (2011). A simulation-based scheduling system for real-time optimization and decision making support. *Robotics and Computer-Integrated Manufacturing*, 27(4), 696-705.

Frazzon, E. M., Albrecht, A., Hurtado, P. A., de Souza Silva, L., & Pannek, J. (2015). Hybrid modelling approach for the scheduling and control of integrated production and logistic processes along export supply chains. IFAC-PapersOnLine, 48(3), 1521-1526.

Frazzon, E. M., Albrecht, A., & Hurtado, P. A. (2016). Simulation-based optimization for the integrated scheduling of production and logistic systems. *IFAC-PapersOnLine*, 49(12), 1050-1055.

Frazzon, E. M., Albrecht, A., Pires, M., Israel, E., Kück, M., & Freitag, M. (2017). Hybrid approach for the integrated scheduling of production and transport processes along supply chains. *International Journal of Production Research*, 1-17.

Hahn, G. J., Sens, T., Decouttere, C., & Vandaele, N. J. (2016). A multi-criteria approach to robust outsourcing-decision-making in stochastic manufacturing systems. *Computers & Industrial Engineering*, 98, 275-288.

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, 89, 23-34.

Jain, A. K., & Elmaraghy, H. A. (1997). Production scheduling/rescheduling in flexible manufacturing. *International Journal of Production Research*, 35(1).

Ku, W. Y., & Beck, J. C. (2016). Mixed Integer Programming models for job shop scheduling: a computational analysis. *Computers & Operations Research*, 73, 165-173.

Kück, M., Ehm, J., Hildebrandt, T., Freitag, M., & Frazzon, E. M. (2016, December). Potential of data-driven simulation-based optimization for adaptive scheduling and control of dynamic manufacturing systems. In *Proceedings of the 2016 Winter Simulation Conference* (pp. 2820-2831). IEEE Press.

Lee, K. K. (2008). Fuzzy rule generation for adaptive scheduling in a dynamic manufacturing environment. *Applied Soft Computing*, 8(4), 1295-1304.

Li, H., Li, Z., Li, L. X., & Hu, B. (2000). A production rescheduling expert simulation system. *European Journal of Operational Research*, 124(2), 283-293.

Li, L. X. (1999). Proposing an architectural framework of a hybrid knowledge-based system for production rescheduling. *Expert Systems*, 16(4), 273-279.

Li, Z., & Ierapetritou, M. (2008). Process scheduling under uncertainty: Review and challenges. *Computers & Chemical Engineering*, 32(4), 715-727.

Lin, J. T., & Chen, C. M. (2015). Simulation optimization approach for hybrid flow shop scheduling problem in semiconductor back-end manufacturing. *Simulation Modelling Practice and Theory*, 51, 100-114.

Longo, F. (2010). Emergency simulation: state of the art and future research guidelines. *SCS M&S Magazine*, 1(4).

Ouelhadj, D., & Petrovic, S. (2009). A survey of dynamic scheduling in manufacturing systems. *Journal of Scheduling*, 12(4), 417.

Raheja, A. S., & Subramaniam, V. (2002). Reactive recovery of job shop schedules—a review. The International Journal of Advanced Manufacturing Technology, 19(10).

Rao, K. V., & Janardhana, G. R. (2014). The Effect of Rescheduling on Operating Performance of the Supply Chain under Disruption—A Literature Review. *Applied Mechanics & Materials*, 592-594, 2704-2710.

Salido, M. A., Escamilla, J., Barber, F., & Giret, A. (2017). Rescheduling in job-shop problems for sustainable manufacturing systems. *Journal of Cleaner Production*.

Sobaszek, Ł., Gola, A., & Świąc, A. (2017, September). Predictive Scheduling as a Part of Intelligent Job Scheduling System. In *International Conference on Intelligent Systems in Production Engineering and Maintenance* (pp. 358-367). Springer, Cham.

Suresh, V., & Chaudhuri, D. (1993). Dynamic scheduling—a survey of research. *International Journal of Production Economics*, 32(1), 53-63.

Thoben, K. D., Wiesner, S., & Wuest, T. (2017). “Industrie 4.0” and Smart Manufacturing—A Review of Research Issues and Application Examples. *Int. J. of Automation Technology*, Vol, 11(1).

Vieira, G. E., Herrmann, J. W., & Lin, E. (2003). Rescheduling manufacturing systems: a framework of strategies, policies, and methods. *Journal of scheduling*.

Waschneck, B., Altenmüller, T., Bauernhansl, T., & Kyek, A. (2016). Production Scheduling in Complex Job Shops from an Industry 4.0 Perspective: A Review and Challenges in the Semiconductor Industry. *In SAM40 workshop at i-KNOW*.

Witkowski, K. (2017). Internet of Things, Big Data, Industry 4.0—Innovative Solutions in Logistics and Supply Chains Management. *Procedia Engineering*, 182, 763-769.