Potential Benefits of Reverse Blending in the Fertilizer Industry

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Abstract. Delayed differentiation, one of the key techniques of mass customization, has proven to be a high-performance strategy in the discrete industry. In the process industry, however, it remains poorly explored, especially when differentiation relates to product composition rather than form. Reverse Blending is a new OR blending problem based on a quadratic formulation, where output requirements are similar to those of classical blending, but here inputs are not pre-existing and must be defined simultaneously with their use in the blending process while exactly meeting output requirements. These may then be used to obtain a wide variety of custom fertilizers (outputs) from a small number of Canonical Basis Inputs that can be blended outside the chemical plant, close to the end-users. This would avoid production of a wide variety of small batches of final products through a small number of large batches of intermediate products, resulting in valuable logistical streamlining and substantial cost savings. Accordingly, our paper investigates the potential benefits of implementing Reverse Blending in the fertilizer industry.

Keywords: Reverse Blending, Delayed Differentiation, Fertilizer Industry.

1 Introduction

Increasing global food production by maximizing crop yields while preserving soil fertility is critical to sustaining food security and keep pace with population growth. To this end, soil nutrient concentration must be optimal to ensure high nutrient use efficiency [1]. This requires using customized fertilizers complying with specifically adapted formulas whose nutrients and proportions differ according to the pedological characteristics and the crops. In addition to the principal nutrients (nitrogen N, phosphorus P, potassium K), such fertilizers can be supplemented by several secondary nutrients (such as sulfur), resulting in hundreds or even thousands of formulas to match the actual needs for these different nutrients. For a fertilizer manufacturer, this means producing a large number of batches of different customized fertilizers on continuous production lines, and a major challenge in managing the production, storage and distribution of a wide variety of continuous flow products. However, such very wide variety, especially in the context of continuous production, should be avoided since production and delivery performance are undermined by a greater product variety that increases direct labour and material costs, manufacturing overheads, delivery lead time and inventory levels [2]. Concerning discrete production, extensive literature reviews are available as to which industrial organization is most suitable to handle a wide product variety. For example, through their review of 60 papers (80% of which concern discrete production and 20% of which deal with the service sector), Reis et al. [3] identified seven strategies capable of mitigating the negative effects of product variety. The most recurring strategy consists in using common components [3]. According to Johnson and Kirchain [4] this turns out to be the most effective way of reducing costs. This strategy, also known as standardization, is commonly associated with Delayed Differentiation (DD), the objective of which is to delay the differentiation processes, where the combination of common products occurs as late as possible so as to achieve supply chain cost-effectiveness [5]. In discrete production, DD refers to the successive production of different products obtained by combining alternative components in an assembly line allowing for thousands of product combinations with a high level of reactivity (e.g. automotive industry). To our knowledge, no research was ever conducted on the management of very high diversity in continuous production, save where this diversity derives from customized shapes (e.g. packaging in the coffee industry [6] or product shape/cutting in the steel industry [7]). We hold the view that in the process industry, Reverse Blending (RB) (an extension of classical blending where the inputs are to be defined), can be a disruptive approach to implementing effective delayed differentiation by adding to mere packaging a dimension concerning actual product internal composition [8]. By showing a major impact on Supply Chain (SC) organization, our paper discusses the potential benefits of RB for those fertilizer producers who are prepared to redesign their supply chain.

Following this brief introduction, our paper is structured as follows: section 2 describes RB fundamentals before discussing; in section 3, the potential benefits of a RB-based organization; section 4 presents the main findings of our case study and to conclude, section 5 highlights important guidelines for future research.

2 Reverse Blending Fundamentals

To achieve a wide variety of customized fertilizers, RB seeks the optimal chemical specifications of the smallest set, called “canonical base (CB)”, of blending inputs, called “Canonical Basis Inputs (CBIs)”, whose blend combinations form a bill of materials (BOM) used to produce any quantity of any output belonging to the variety of fertilizers under consideration [8]. Other additional fertilizer formulae may be obtained from these CBIs by a classical blending linear problem aiming at minimizing deviations from the specifications of these formulae. In terms of OR, RB is a new one-stage blending problem where input characteristics are decision variables as opposed to classical blending where input specifications are parameters. Our literature review, set forth in [8], proves the originality of our approach versus the blending problems as dealt with in various industries (the agri-food, mining, petroleum, and chemical sectors) and the fertilizer industry in particular. [8] points the differences between the modeling of RB and classical blending.

As non-pre-existing, some of the CBIs are composite materials that may have to be created from scratch, and laboratory experiments may, therefore, be required to obtain chemically stable reactions for the development of the new target formulas. An alternative is to produce the CBIs by blending pre-existing composites available on the market. This approach amounts to a two-stage blending problem where existing composites are blended to obtain the CBIs (first stage) and where the CBIs are blended to obtain the customized fertilizers (second stage). This method, called Adapted Pooling Problem (APP), differs from the Pooling Problem (PP), which also refers to multistage blending problems [10]. The reasons for this difference are set forth in [8]. They include the fact that chemical specification of existing composites may preclude the simultaneous use of some of them in producing a CBI, thereby preventing the free combination of all CBIs in producing a fertilizer (the differences between the APP and the PP models are outlined in [8]). Due to these chemical constraints, it is most likely that a number of composites in the set we studied is not suitable to produce a CB capable of satisfying all needs for fertilizers. We accordingly opted for an extended version of RB consisting in producing a subset of CBIs by mixing existing composites through APP while completing the manufacture of the remaining subset through RB.

Regardless of how CBIs are created, this approach allows for massive flow concentration since it can reduce the flows to be managed from 100% down to only 1% as shown by the results of our case study reported in [8] where 700 fertilizer solutions could be delivered with no more than 10 CBIs.

3 Reverse Blending Potential benefits

An extensive literature review assesses the best production policy of Make-To-Order (MTO), Make-To-Stock (MTS), and hybrid MTS/MTO. Overall, MTS is used when production can be based on forecasted demand [7, 11] which usually involves few, low-cost, standard products. While this approach induces streamlined production costs, reduces customer lead-time, increases production capacity and reduces changeover costs, few systems fully use MTS. This results from the fact that to remain competitive, industries must now fulfill customer expectations [7]. In fertilizer industry, these refer to customized fertilizers to maximize crop yields. MTO policy, where production is launched following customer orders, on the other hand, while delivering a large variety of products, induces longer customer lead times and higher changeover costs [12]. An alternative is to combine these two approaches in a hybrid MTS/MTO, involving a hierarchical approach (e.g., priority to MTO, and using MTS for remaining capacity) [13], or storing semi-finished products in intermediate warehousing (MTS) and assembling pursuant to customer orders (MTO) [11, 12, 14]. The choice of the optimal production strategy is influenced by several factors depending on products, processes, and market characteristics [6] (e.g., discrete/process industry, product variety, product expiry/ contamination, market competitiveness, supply chain structure, flexible/rigid processes…). Yet, as many researchers argue [11, 12, 15, 16], where the industrial context is conducive, the most effective policy is hybrid MTS/MTO as it delivers customized products with lower customer order fulfillment lead time [16]. The idea is to develop lean approaches based on efficiency, waste elimination, cost-saving in the upstream phases of SC, and design agile processes that enable quick response to real-time changes in demand in downstream phases [17]. To do so, many researchers see DD as the best option [6, 11, 12, 16]. However, if DD has proven to be very relevant to the discrete industry (e.g., Hewlett Packard reported double-digit savings on supply chain costs by applying DD [6]), in the process industry, it is more challenging, as it is difficult to decouple processes at an intermediate stage [6].

The difficulty lies in finding commonalities between different product varieties to be able to design a common platform to which specific bricks can be added to obtain customizable products for specific segments [18]. Also, in the process industry, when customization affects a product's inner composition and is not a mere packaging/labeling issue, it becomes tough to postpone the Product Differentiation Point (PDP) to the SC downstream stages, which limits flexibility and responsiveness to customer demand [8]. In the fertilizer industry, RB is a solution that overcomes these difficulties as: *i*) it provides a robust common platform which can serve an extensive base of customized fertilizers; *ii*) it ensures an effective and efficient DD since differentiation may be performed close to farmers, rather than at production sites, in small blending units that can produce, at similar costs (through a common blending process), any required fertilizer using the relevant CBI formula. RB can thus become a key lever for the successful implementation of a hybrid MTS/MTO system in the process industry. With an RB-based configuration, at the chemical plant level, production is MTS and involves very few CBIs. In addition to harnessing MTO's main strength, through high responsiveness and sales loss prevention, such RB transformation offers several benefits. It simplifies the production system as it enables a continuous flow with no (or very few) production line changeovers. Indeed, as changeover operations can result in significant burdens in chemical plants (e.g. product and time losses, additional water, and energy use, creation of wastewater, chemical use for cleaning purposes… [19]), improving changeover times is very crucial to meeting customer demand as well as productivity targets [9, 19-21]. A continuous flow production of few CBIs (one/two CBIs per production line) would thus significantly enhance the performance of production lines compared to a pull production involving small quantities of a broad diversity of products (e.g., Grundermann *et al*. assessed the impact of converting from batch to continuous production and concluded that this conversion might reduce the use of detergent and water by up to 95% [22]). Eliminating shutdowns due to changeovers would also increase production capacity and avoid losing market share to competitors.

Moreover, it is admitted that MTS production leads to high storage costs and entails risks that forecasted orders will not materialize [13, 23]. RB almost eliminates such risks since the few CBIs to be stored correspond to a universal common platform for any custom-made fertilizer, ensuring strong demand for these CBIs. RB would also simplify storage shed management (one or two inputs per shed) thus doing away with the storage issues arising from increased diversity (vacant space due to small production batches, contaminated fertilizers due to poor product segregation, production shutdown due to stock saturation, etc.). At shipment level, RB-related standardization would simplify routing operations by facilitating flow segregation (as the same CBIs are used for all customers), reduce conveyor line cleaning process costs, as well as delivery costs and all issues to do with loading fertilizers onto the ships, to name but a few. From a commercial standpoint, RB ensures high flexibility and responsiveness to individual customer demand as differentiation is implemented: *i)* close to the farmers and *ii)* through a straightforward mixing process in mostly pre-existing blending units. Note that remote blending is indeed already performed though not with very good results: it is limited to mixing a few existing fertilizers that hardly meet the full range of nutrient requirements. In short, RB will greatly improve customer satisfaction and increase the customer base, especially as such customization will be more cost-effective than MTO-based customization. In addition to these economic benefits, RB would preserve soil fertility in the long term, thus ensuring sustainable agriculture and global food security.

4 Case study

4.1 Case description

OCP Group, one of the world leaders in the fertilizer sector, is seeking to increase its share of the world fertilizer market and to win over new customers by offering them customized fertilizer solutions. Increasing the diversity of its product portfolio is a strategy that OCP Group has been pursuing for many years. Indeed, since 2000, OCP Group has expanded the variety of its fertilizers to 50 different fertilizers.

This growing diversity improves agility and flexibility, and comforts the Group's leadership. However, in an MTO-dominated approach, the greater the diversity, the more difficult it is to manage production, storage, and distribution. The aim of our case study, therefore, was to show that OCP's production diversity-related issues could be solved by RB through a shift from MTO to MTS production. To this end, we started from OCP's daily 2019 production program, and reviewed the list of relevant CBIs as discussed below.

In 2019, OCP's order book included 28 fertilizers whose overall production on 7 production lines is provided in the Annual_Production.xlsx file included in the Mendeley link (http://dx.doi.org/10.17632/zfp6nzy87w.1) used to store our large tables so as to keep the text within the prescribed format. We applied the RB model to this annual dataset before analyzing its results on a monthly mesh. OCP's monthly fertilizer production is shown in the Monthly_Production.xlsx file.

4.2 Findings

Applying RB to the 28 different fertilizers revealed that all can be produced using a mere 8 CBIs. Table 1 describes the chemical composition of each CBI in terms of N, P, K, B_2O_3, Zn, and *filler* (a neutral component added for chemical stabilization purposes having no impact on the nutritional structure).

Table 1. The optimal composition of RB CBIs

	Canonical Basis Inputs (CBIs)								
	CBI 1	CBI 2	CBI 3	CBI 4	CBI 5	CBI 6	CBI 7	CBI 8	*filler*
%N	46.00%	11.86%	12.70%	19.00%	0.00%	2.34%	2.14%	0.00%	0.00%
%P	0.00%	56.08%	16.11%	38.00%	0.00%	56.00%	56.00%	51.24%	0.00%
%K	0.00%	0.00%	16.11%	0.00%	63.60%	0.00%	0.00%	0.00%	0.00%
%S	0.00%	0.00%	0.00%	7.00%	25.27%	11.78%	7.06%	19.67%	0.00%
%B_2O_3	0.00%	0.00%	0.00%	0.00%	6.13%	3.15%	0.00%	0.00%	0.00%
%Zn	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	7.79%	0.00%
filler	54.00%	32.06%	55.07%	36.00%	5.00%	26.72%	34.81%	21.30%	100.00%

In addition to identifying the CBIs, RB shows the quantities of each CBI required to produce the exact volume needed for each fertilizer and to match their precise chemical composition (see details for this solution in the RB_Annual_Results.xlsx file). Please remember that the filler must be used in combination with the CBIs to obtain the desired quantities.

Annualized results.

Finer study of RB results showed that OCP's annual production volume of 4,440,150 tons comprising at least 28 fertilizers (see corresponding % share in the left box of Fig. 1) can be fully obtained by producing just 4,290,687 tons broken down into 8 CBIs (see % share in the right-hand box of Fig. 1) the first four of which account for more than 96% of total production.

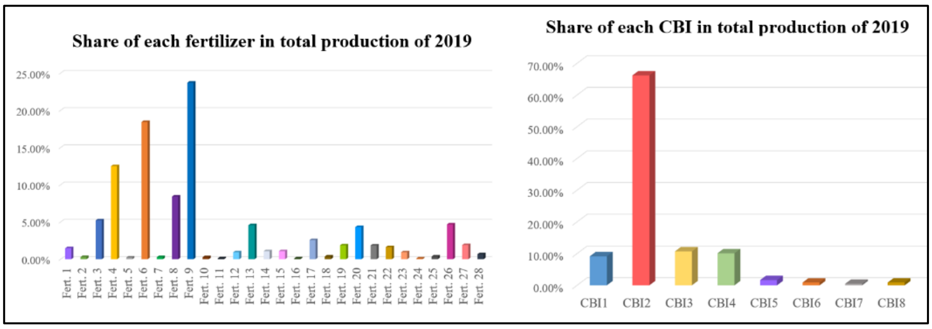

Fig. 1. Current OCP production vs. CBI-based production

The above flow consolidation would have been even more significant had we dealt with a greater variety than just 28 fertilizers. Note for example in [8], that RB matched the requirements for more than 480 NPK formulas with no more than ten CBIs. To meet growing trends towards precision agriculture, particularly in Africa, we believe that OCP will need to increase its portfolio diversity in the next few years, so significantly strengthening the value of RB-based production.

Monthly results

The value of RB is even clearer on the basis of monthly results. Indeed, using the current production system (see Fig. 2), we observe that product diversity and output volumes vary from month to month and that volumes correspond to small batches (the production system being driven by actual orders (MTO)).

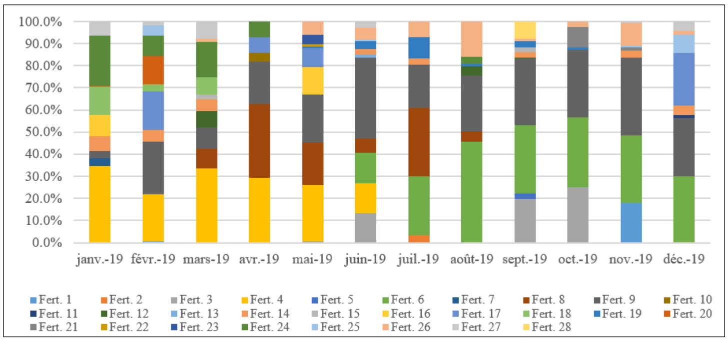

Fig. 2. Fertilizer share of OCP aggregate monthly production

The different colors (for each different fertilizer reference) in each stick (overall monthly production) illustrate the diversity and provide an indication as to the number of production line changeovers that had to be carried out in 2019. Considering the daily production schedule, the total number of changeovers for all 7 production lines amounted to 175. As launch time depends on the nature of the "previous reference/following reference" couple, and knowing that the shortest launch time is of nearly two hours, then production had to be stopped for at least 350 hours (175*2). Furthermore, OCP has two types of production lines (lines 107 and 07 with production rates of 108.3 tons/hour and 80.82 tons/hour, respectively). In terms of production capacity, on lines 107, where production shutdown amounted to 200 hours, lost production capacity reached 2,1660 (108.3*200) tons and on lines 07, where production was stopped for at least 150 hours, lost production capacity was 12,123 (80.82*150) tons. Moreover, OCP experiences arduous inventory management in its 9 storage sheds, due, among other reasons, to its production system which is based on the irregular launch of small batches.

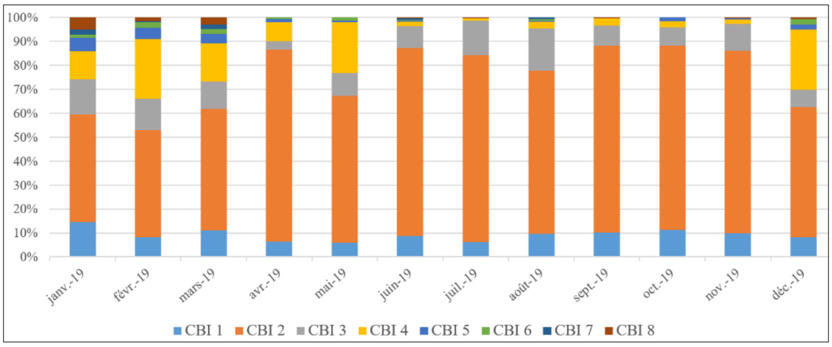

Fig. 3. Share of CBIs in aggregate monthly production

In contrast, as we examine RB impact on the production system of the chemical plant, the producer's concern is the volume of CBIs to be produced within its production site and not how these will be used further down the supply chain in the blending units. That said, Fig. 3 shows how production would have been obtained month by month if CBIs had been used. A comparison of Figs. 2 and 3 shows how this transformation dramatically simplifies production management since the same formulas are maintained each month, and given that the first 4 CBIs, especially the 2nd one, account for more than 90% of monthly production.

The above flow consolidation points to the opportunity of designing a new production system based on MTS. Using seven production lines, three of which have an annual throughput of about 897, 000 tons, and four an annual throughput of about 669,000 tons, managing the production of 8 CBIs is quite straightforward. Indeed, considering the respective shares of CBIs (cf. Fig. 1) and taking into account the throughputs of OCP's production lines, we recommend allocating CBIs to dedicated production lines to ensure continuous production to the fullest possible extent (one CBI per production line) and so reap the benefit of streamlined, cost-saving production. Moreover, since CBI2 accounts for more than 66% of the annual production volume, we recommend dedicating three full production lines to it. CBIs 1, 3 and 4, each accounting for about 10%, we recommend allocation of a production line to each one of them. Finally, with the remaining CBIs accounting for less than 4% of the total production, we recommend the allocation of a single production line.

By producing continuously, mono-product lines would eliminate launch time stoppages, so boosting production capacity. Turning to the only remaining multi-product line, it could retain an order-point production rationale (production starts when a given stock level is reached) to produce CBI 5 that accounts for almost 2% of annual production. Concerning CBIs 6, 7 and 8 (each representing less than 1% of annual production), production could be triggered when inventory drops below the safety stock and stopped when the storage capacity is fully used.

OCP's current product portfolio covers a limited set of fertilizers with 5 references accounting for more than 60% of sales. With this in mind, RB's contribution does not appear to be crucial. Nevertheless, we are not looking to replace the production of 28 fertilizers by that of 8 CBIs, but rather to demonstrate the impact on production and storage of a CB enabling hundreds of fertilizer formulas to be manufactured on demand. The case for our solution becomes highly compelling if OCP implements its strategy of conquering emerging markets by offering them customized fertilizers, as it will then have to dramatically increase product diversity (to the tune of hundreds of fertilizers): in these circumstances, RB's contribution becomes obvious.

5 Conclusion

Through delayed differentiation (a MTS/MTO hybrid), Reverse Blending, a technique that can be used in industries operating in blending contexts, offers the advantages of both MTS (i.e., facilitate production, storage and distribution management, increase production capacity and reduce customer lead-times) and MTO (i.e., offer customized products and retain competitive edge), while doing away with their main disadvantages namely high storage costs and long delivery lead times respectively. Our case study shows that significant savings can be made at production system level alone while the impact at inventory and shipment levels has yet to be studied. Note that this approach may require thorough reengineering of the production and distribution processes, since industries looking to implement RB may have to change their decoupling points. Indeed, while several RB potential benefits are explored in this paper, the next step of this research should be to consider the challenges facing producers on the road to implementing RB.

6 References

1. Incrocci, L., D. Massa, and A. Pardossi, *New trends in the fertigation management of irrigated vegetable crops.* Horticulturae, 2017. **3**(2): p. 37.
2. Salvador, F., C. Forza, and M. Rungtusanatham, *Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions.* Journal of operations management, 2002. **20**(5): p. 549-575.
3. Da Cunha Reis, A., L.F. Scavarda, and B.M. Pancieri, *Product variety management: A synthesis of existing research.* African Journal of Business Management, 2013. **7**(1): p. 39.

4. Johnson, M.D. and R.E. Kirchain, *Quantifying the effects of product family decisions on material selection: A process-based costing approach.* International Journal of Production Economics, 2009. **120**(2): p. 653-668.
5. Boone, C.A., C.W. Craighead, and J.B. Hanna, *Postponement: an evolving supply chain concept.* International Journal of Physical Distribution & Logistics Management, 2007.
6. Van Hoek, R.I., *The rediscovery of postponement a literature review and directions for research.* Journal of operations management, 2001. **19**(2): p. 161-184.
7. Kerkkänen, A., *Determining semi-finished products to be stocked when changing the MTS-MTO policy: Case of a steel mill.* International Journal of Production Economics, 2007. **108**(1-2): p. 111-118.
8. Benhamou, L., Giard, V., Khouloud, M., Fenies, P., & Fontane, F. (2019). Reverse Blending : An economically efficient approach to the challenge of fertilizer mass customization. International Journal of Production Economics, 107603.
9. Karam, A.-A., Liviu, M., Cristina, V., & Radu, H. (2018). The contribution of lean manufacturing tools to changeover time decrease in the pharmaceutical industry. A SMED project. Procedia Manufacturing, 22, 886 892.
10. Chang, J. C., Graves, S. C., Kirchain, R. E., & Olivetti, E. A. (2019). Integrated planning for design and production in two-stage recycling operations. European Journal of Operational Research, 273(2), 535 547.
11. Sharda, B. and N. Akiya, *Selecting make-to-stock and postponement policies for different products in a chemical plant: A case study using discrete event simulation.* International Journal of Production Economics, 2012. **136**(1): p. 161-171.
12. Gupta, D. and S. Benjaafar, *Make-to-order, make-to-stock, or delay product differentiation? A common framework for modeling and analysis.* IIE transactions, 2004. **36**(6): p. 529-546.
13. Agra, A., M. Poss, and M. Santos, *Optimizing make-to-stock policies through a robust lot-sizing model.* International Journal of Production Economics, 2018. **200**: p. 302-310.
14. Morikawa, K., K. Takahashi, and D. Hirotani, *Make-to-stock policies for a multistage serial system under a make-to-order production environment.* International Journal of Production Economics, 2014. **147**: p. 30-37.
15. Soman, C.A., D.P. Van Donk, and G. Gaalman, *Combined make-to-order and make-to-stock in a food production system.* International Journal of Production Economics, 2004. **90**(2): p. 223-235.
16. Jewkes, E.M. and A.S. Alfa, *A queueing model of delayed product differentiation.* European Journal of Operational Research, 2009. **199**(3): p. 734-743.
17. Fornasiero, R., L. Macchion, and A. Vinelli, *Supply chain configuration towards customization: a comparison between small and large series production.* IFAC-PapersOnLine, 2015. **48**(3): p. 1428-1433.
18. Tyagi, S., *Optimization of a platform configuration with generational changes.* International Journal of Production Economics, 2015. **169**: p. 299-309.
19. Gungor, Z.E. and S. Evans, *Understanding the hidden cost and identifying the root causes of changeover impacts.* Journal of Cleaner Production, 2017. **167**: p. 1138-1147.
20. Ferradás, P.G. and K. Salonitis, *Improving changeover time: a tailored SMED approach for welding cells.* Procedia CIRP, 2013. **7**: p. 598-603.
21. Meixell, M.J., *The impact of setup costs, commonality, and capacity on schedule stability: An exploratory study.* International Journal of Production Economics, 2005. **95**(1): p. 95-107.
22. Grundemann, L., Gonschorowski, V., Fischer, N., & Scholl, S. (2012). Cleaning waste minimization for multiproduct plants : Transferring macro batch to micro conti manufacturing. Journal of Cleaner Production, 24, 92 101.
23. Karasu, M. K., Cakmakci, M., Cakiroglu, M. B., Ayva, E., & Demirel-Ortabas, N. (2014). Improvement of changeover times via Taguchi empowered SMED/case study on injection molding production. Measurement, 47, 741 748.