Performance improvement of manual assembly lines in a context characterized by complexity

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Abstract: The researchers’ difficulty at transferring the scientific knowledge to practitioners and the existence of a gap among the methods developed in literature and the real life problem are issues recognized by literature and seems that they have not been solved yet. The aim of the present work is to outline a methodology that is successfully applicable to the industrial context, i.e. that is able to both take in account of the difficulty of managing a high number of different components and materials and assure the correct line balancing to gain performance improvement of the assembly lines as well as the maintain of such better performance over time. Among the techniques presented by literature, the “kaizen assembly” is exploited to perform the line balancing and to be transferred to practitioners. As the methodology addresses a typical industrial issue, it is outlined through its application to the case of an Italian plant of a chocolatier and confectionery company, leader in the market of premium quality chocolate. In order to get such a difficult result, firstly, a methodology to reduce the complexity is proposed and applied to the case study, by identifying groups of components distinct based on commonalities in the job elements and cycle times, rather than on part-IDs. Secondly “kaizen assembly” are performed and lean manufacturing techniques are applied in order to enhance the assembly lines performance and reach a set target. This allowed the company to achieve the performance objective and to maintain changes steady over time, confirming the validity of the approach.

Keywords: Assembly line; Lean manufacturing; Kaizen; Case study.

1. Introduction

The assembly activities are considered as very critical within the manufacturing process, due to the high impact on the production times and costs (Rashid et al., 2012). Therefore, the research works related to the optimization of these activities are considered as strongly useful to enhance the efficiency of the manufacturing process stages. Notwithstanding the existence of broad research on assembly optimization and, in particular, considering the line balancing problem (LBP), a gap still exists among the methods developed in literature and the real life problems (Battaïa, & Dolgui, 2013). According to Boysen et al. (2007), gap among practical applications and academic studies emerges. In addition, companies do not use the mathematical approaches developed in literature to configure the assembly lines. This lack shows the researchers’ difficulty at transferring the scientific knowledge to practitioners (Boysen et al., 2007). Moreover, considering the fact that the application context changes (i.e. input data given to mathematical approaches are not constant), it is often not easy to assure the retention of the results provided by such approaches over time. Furthermore, the industrial context is characterized by a high number of products assembled by the same line to be balanced. Then, a high number of different components and materials to be managed to complete the assembly process has to be considered.

The present work aims at filling the gap between academic literature and practical applications developing a methodology that has a twofold objective: allow the correct management of such a high number of different components and materials that can cause complexity; assure the correct line balancing to gain performance improvement of the assembly lines as well as the maintain of such better performance over time. As the methodology addresses a typical industrial issue, it is outlined through its application to the case of an Italian plant of a chocolatier and confectionery company.

The paper is structured as follows: in section 2, the review of literature related to LBP is performed; in section 3 the case study is introduced; then, in section 4 the methodology is described and applied to the case study; and finally, in section 5, the main conclusions of the study are presented.

2. Literature review

The assembly optimization studies are related to the product development and production stages. This study is focused on this second stage: the optimization of the production. It includes the design of the assembly lines, which aims at improving the effective utilization of the company’s facilities (Sivasankaran & Shahabudeen, 2014). The assembly lines represent a set of work stations positioned according to a definite order and connected by
transport mechanisms as, for instance, conveyors (Saif, 2014). A flow of work pieces passes through the work stations, where several different tasks are performed (Baybars, 1986). And these tasks are performed following specific precedence relationships, in order to assemble a final product. The precedence relationships, together with the task times and the number of work stations, represent a constraint to take into account during the design of the assembly lines, (Sivasankaran & Shahabudeen, 2014).

The assembly lines design represents a long-term decision that requires high investments (Becker and Sholl, 2006). Thus, one of the most critical issue is related to the line balancing problem (LBP), which consists in efficiently allocating the resources to the workstations involved (Battaïa, & Dolgui, 2013). The main objective of the LBP is to optimize the distribution of the workloads according to specific objectives such as the minimization of workstations’ idle times (Saif, 2014).

According to Battaïa, & Dolgui (2013) the solutions methods related to the LBP can be divided in two main categories: (i) Exact methods, and (ii) Approximate methods. Exact methods (i.e. mixed integer programs, branch and bound, dynamic programming, etc.) are particularly effective with small-scale applications, which imply a restricted number of tasks (Baybars, 1986). Indeed, since LBPs represent complex combinatorial problems, classified as NP-hard, the more the instances considered, the higher the computational time required to solve exact methods (Battaïa, & Dolgui, 2013). In particular, the optimality assessment of a solution obtained is extremely time consuming (Baybars, 1986).

Thus, approximate methods (i.e. bounded exact methods, simple heuristic, metaheuristics, etc.) are often employed to solve LBPs. Even if this class of methods do not assure optimality, it is able to provide feasible results in adequate time (Sivasankaran & Shahabudeen, 2014). Battaïa, & Dolgui (2013) recognized as one of the main criticalities in the LBPs solution, the fact that a gap still exists among the methods developed in literature and the real life problems. Regarding the data perturbation characterizing the practical problems, some study addressed this problem, trying to develop robust solutions with respect to input data perturbations, but still additional studies are needed (Battaïa, & Dolgui, 2013).

A different approach to improve assembly line performance and to maintain this improvement over time is proposed by Ortiz (2006). He introduced the “kaizen assembly”, namely a method to design and manage the assembly lines through the application of a lean manufacturing approach and based on a continuous improvement philosophy. Thus, the company should follow a process-oriented kaizen philosophy, focused on continuous improvement and standardization, in order to build a solid foundation to change, maintaining high performance over time and a culture oriented to incremental progresses (Prashar, 2004; Ortiz, 2006). Therefore, kaizen strategy is focused on the total enterprise involvement in order to reach continuous improvement by working together (Solter and Waldrip, 2002). Ortiz (2009) defined that the kaizen benefits are both measurable and non-measurable: on one hand, kaizen allows the company to better apply lean manufacturing, reaching good results in terms of performance and customer satisfaction; on the other hand, there is also another straightforward improvement, that is the diffusion of a solid continuous improvement culture among the organization, based on teamwork and time targets. Thus, kaizen events can generate positive changes both “in business results and human resources outcomes” (Glover et al. 2011).

For the reasons explained above, this work proposes to reach the performance enhancement through lean manufacturing practices and techniques, by organizing the improvement activity as a kaizen event.

3. Case study

The methodology is outlined through its application to the case of a world leader chocolatier and confectionary company that realizes a large selection of premium products and provides excellence and innovation as main competitive priorities. The production process, in the considered plant, is characterized by assembly lines that are mostly manual, and over years they represented a critical issue since the cost performances have not reached the company targets. Due to these emerged criticalities, the managerial trouble rises. Moreover, the managerial concern is about the high number of products, components, and materials to be managed in order to complete the assembly process, amounting the context to be a complex one. Accordingly, the company manifested the need to optimize the confectionery process, in order to reach the targets and be able to maintain the internal control of these core activities.

4. Methodology

The here proposed methodology aims at improving the performance of assembly and packing lines in a context characterized by complexity, that, in this work, is represented by a high number of products, components or materials to be managed to complete the process. Though performance improvements need activities and resources, there is a lack of a supporting improvement infrastructure within the organizations (Ishikawa 1985; Glover et al. 2011). In particular, the methodology is first applied to the Autumn/Winter (A/W) season boxed chocolate family, which involves more than 400 part-IDs. Then, the need to focus on a restrict group of products, components or materials emerges. To reach such a challenging result, the methodology is structured in two macro-phases: the first is aimed at reducing the size of the problem derived by the proliferation of products and parts variants sometimes targeted to customers, or markets; the second one deals with assembly and packing line performance improvement, intended to enhance line activities by means of lean manufacturing techniques and reach the performance target.

4.1 Complexity reduction

The complexity reduction macro-phase deals with three subsequent steps: (i) clustering of parts; (ii) macro-cycles
definition; (iii) product representatives’ selection; presented in the following.

According to literature, clustering is a common methodology applied order to reduce complexity without loss of generality (Xu and Wunsch, 2005).

The ‘clustering of parts’ step addresses the problem of identifying subsets of parts/components starting from sets of parts/components grouped by functional characteristics. In such sets parts are identified by part-IDs and distinguish one from another mainly due to morphological characteristics (such as size, shape or colour) and performance (such as capacity or strength). In some cases, different part IDs involve diverse assembly tasks and cycle times. In other cases, components with different morphological characteristics or performance require comparable assembly tasks and cycle times. Then, from an assembly point of view, such distinction between components/parts is not effective. Then, we propose a more effective parts distinction based on job elements and cycle times, rather than on part-IDs. Accordingly, the identification of clusters as subsets of the functional sets in which parts are usually organized, and the identification of the components/parts that can be grouped in the same cluster is suggested. As detail on the relation between job elements, cycle times and parts is usually neither formalized nor recorded in databases, the complexity reduction step is carried out involving a team composed by the Operations Manager, supervising the whole project, the Assembly Lines Manager, contributing with practical knowledge of the assembly activities involved by the parts to be assembled by the lines, and one person from the Industrialization Function, who contributes with knowledge of the end-items managed by the plant, their BOMs and related confectionery performance and codification of part-IDs. In detail, given list of part-IDs, obtained by the bill of materials (BOMs) of all end-products assembled and packed by the lines under study, the Assembly Lines Manager defines whether each part (‘i’) in the BOMs requires activities comparable in both job elements and time to a previously analysed part. If ‘i’ is similar to one or more parts, it belongs to an already defined cluster (C); otherwise, a new cluster is defined. At the end of the step, the team analyses 52 BOMs and defines 40 parts clusters.

To the complexity reduction purpose, a ‘macro-cycle’ is here defined as a sequence of ordered cluster numbers identifying a corresponding sequence of assembly job elements, obtained substituting the part-IDs in the BOMs with the corresponding cluster number. Due to the amount of end-item and components characterizing the A/W season boxed chocolate family and the future possibility to extend the analysis to Spring/Summer and Easter boxed chocolate families and chocolate eggs, a Visual Basic tool is developed to help the team work. With the help of the tool, the team automatically obtains 33 ‘macro-cycles’ representing different sets of activities and times needed to obtain all end-items belonging to the A/W season. As expected, the number of different ‘macro-cycles’ is smaller than the number of end-items assembled and packed, as many involve similar activities and time to be completed.

The last step of the complexity-reduction macro-phase deals with the identification of the most representative ‘macro-cycles’ sample to be studied for lines performances improvement. Identification is based on a modification of the Product Quantity Analysis (PQ Analysis), a classical approach for product mix segmentation (Braglia et al. 2006). According to literature, the underlying logic of PQ Analysis is that high volume products are responsible for the largest part of non-value-added costs. Then, the same logic is proposed in case of the assembly and packing lines, with the aim of boosting the overall performances of the line improving high-volume ‘macro-cycles’. In this case, the team considers the planned working hours (given by the sum of the planned working hours of every end-item characterized by the same ‘macro-cycle’) instead of quantity, as big differences in time consumption of the assembly and packing lines by end-items are pointed by the team. This method proposes to display the ‘macro-cycle’ mix in the form of a Pareto chart, sorting the products in order of decreasing assembly and packing planned hours. As the number of ‘macro-cycles’ is small, the class A, upper grade, about 20% of the ‘macro-cycles’ assembled and packed by the lines seize them for less the 80% of its planned production time. Accordingly, class A is identified as a set of representative ‘macro-cycles’ samples, that are worth the improvement activities performed in the second macro-phase of the approach.

4.2 Performance improvement

Reduced the size of the problem, the lines performance improvement macro-phase is conducted through a series of focused Kaizen events, each one involving one representative ‘macro-cycle’. The objective of each Kaizen event (i.e. the enhancement of line throughput, while maintaining quality standards and benefits from involvement and teamwork) is pursued through two steps: standardization and line balancing. All line operators participate to the event.

We here describe the Kaizen event focusing on the ‘Luxury chocolate bags box’ end-item (the name is disguised for privacy reasons). Eight clusters of parts constitute the end-item. The manual assembly and packing line is characterized by a straight layout and assembly work in process is moved by means of a conveyor belt. A printer for lot and batch numbers is used before the assembled box is packed, and a case sealer machine helps the packing activities. Ten people work on the line on as many workstations that perform: (i) bag bend; (ii) handle application; (iii) bag bend and handle application; (iv, v) bag fill with chocolate; (vi) bag closure; (vii) seal application; (viii) case construction and fill; (ix, x) palletisation and strap. Two more people work in a feeder line to prepare the box base and trays, distant from the line, as hot glue is required. Due to this reason they are not considered when performing the line improvement activities. One more person is devoted to line service, i.e. feeds materials and takes the finished product out of the line area.
Before implementing any change to the line, the stabilization of performance at operator work process level through activities standardization is needed. Then, the Kaizen event should first address the problem of throughput variability, one of the causes affecting manufacturing systems performance (Hopp and Spearman, 2008) and, among the numerous practices and tools that minimize process time variability (Saha and Ward, 2007), the definition of standard work procedures specifying work to smallest detail, addressing less variability in cycle time, is applied during the Kaizen events. In particular, the standardization step involves the concepts of job element sheet (JES), standard work document giving details on a specific work element, and standard operating sheet (SOS), a sequence of more JESs, distinguishing in value-added activities (that are described by the JESs) and non value-added activities (such as movements and search, that are not included in JESs, Ortiz, 2006), describing the job content of the workstation on the line. JESs and SOSs are composed with the help of assembly and packing line operators, who have knowledge on the detail of the work elements and that, while composing them, share knowledge on the best way to perform the discussed activities, obtaining a first performance improvement through its formalization.

Figure 1 depicts the output of the standardization step: the representation of the content of work of each workstation, according to the SOS, and the time required to accomplish it. Representing on a board the job elements and the non value-added time of each workstation helps for improvement activities, highlights which activities requires more than one operator to be completed on time, and whether the contents of work of the workstations are not balanced. For activities performed by workstations 8-10 (case preparation, palletisation and strap) the content of work is expressed for one bag, so that it is easier to compare with the calculated takt-time (i.e. the cycle time of each workstation necessary to meet the demand, given by the ratio between the production net time available and the customer demand) and to see on the board.

![Diagram](image_url)

**Figure 1: The standardization step output: content of work, time and operators for each workstation**

The Kaizen event, then, addresses the problem of reducing the difference between the workstation cycle time and the target takt-time the line should maintain. Previous than the Kaizen event the line performance does not satisfy the throughput of 10 box/hour required. Each box contains 60 bags (12 bags per level, 5 levels), then, the target takt-time regarding the single bags is 6 seconds. According to the four rules described by Ortiz (2006), at this step the 'balance by time', 'balance by work content' and 'balance by material' are applied. The first rule ('remove non value-added activities'), in fact, is implicitly applied when performing standardization activities. While searching for the best (i.e. shortest in time, while maintaining the desired quality level) way to perform an activity, a reduction of time wastes is pursued. Before the Kaizen the workstations 1-2 involve the content of work related to the bag bend and handle application, i.e. 20 seconds. Notwithstanding 3 operators perform these activities before the Kaizen event, compared to the takt-time, the pace of such a feeder line is not sufficient. Looking at the board representation (Figure 1) it is easy to see that the line feeding activity, a non value added one, requires 2.5 seconds to be performed. In particular, the operator has to place the work in process on the conveyor belt respecting a feeding rate to maintain the stability of the amount of time to complete the work. Then, the proposed solution is to move the activity out of workstations 1-2, so as to ensure the respect of the takt-time by the feeder line, that pass from 20 to 17.5 seconds (the latter can be respected, as 17.5 seconds/3 workstation < 6 seconds/workstation). For a better performance the decision is to dedicate one operator to workstation 1 (bag bend activity) and two operators to workstation 2 (handle application) to parallelize their work. Notwithstanding feeding the line is a non value added activity, no immediate solutions to avoid the work by an operator emerged from the discussion. On the other hand, ensuring a stable feeding rate is important to respect the takt-time. Then, an operator is dedicated to such activity as long as an automated solution is available. This solution does not increase the number of operators working on the assembly and packing line, as the board shows that the standardized bag fill activity, composed by bag control and fill, can be completed in less then 6 seconds. Then, one workstation is sufficient. Regarding workstations 4-7, the content of work is compatible with the takt-time, then, one workstation is sufficient to respect the desired pace. With reference to workstation 8, the number of operators dedicated to palletisation and strap activities is sufficient to respect the desired pace. Figure 2 depicts the line organization after the balancing step.

![Diagram](image_url)

**Figure 2: The standardization step output: content of work, time and operators for each workstation**
It is worth underlying that as soon as an automated line feeder is available the operator can be no longer dedicated to feeding activities, then the possibility of a new balancing of activities among workstations and line reorganization emerges. Due to the ease of the kaizen activities, such new balancing could then be performed autonomously by the line managers.

With reference to the cost sustained by the company for the line balancing improvement activity, it counts only one day time of the line manager that, while the line operators work, gathers data needed. The JES and SOS development, in fact, needs the involvement of the line operators only for few minutes.

5. Conclusions

The present work outlines an approach based on complexity reduction and lean manufacturing techniques which is applied to a context characterized by a high number of products, components and materials to be managed to complete the process. In particular, to improve assembly performance and to gain the opportunity to maintain such improvement over time, the kaizen events methodology is suggested. According to the presented case study, the kaizen approach performed after an effective complexity reduction, provided several benefits, both quantitative (target throughput reach) and qualitative (line balancing methodology transferred to practitioners) to the assembly and packing lines. Main critical issues have been identified (such as unbalancing of content of work among workstations or non-constant line feeding). They have been demonstrated to provide a negative effect on the lines in terms of process efficiency, enhancing the overall costs and times. These issues could be solved directly during the events providing temporary solutions (e.g. a dedicated feeding workstation) and suggesting future further improvements, in order to enhance performance.

In particular, standard methods were proposed, in order to define specific procedure and best practices in terms of movements and cycle times. Then, the assembly and packing lines were balanced and reorganized in terms of resources and layout, minimizing wastes and exploiting as much as possible all the resources available. Even ergonomics aspects have been taken into account in order to improve the work place, reducing the efforts and simplifying the movements required to perform the operations needed. Finally, eventual design problems were discovered during the kaizen events, i.e. choices related to the product design, taken during the previous product development phase, that were demonstrated to not be suitable for the assembly or packing operations.

In conclusion, according to the positive results emerged by the application of the proposed approach, the kaizen event methodology used to perform line balancing seems to provide numerous benefits. The approach application to other industries could represent a future research step and a possibility to improve and generalize it.

References


