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Complexity reduction and kaizen events to balance manual assembly lines: an application in the field

Cannas, V., Pero, M., Pozzi, R., Rossi, T. (2018)

Notwithstanding the existence of a broad research base on assembly line balancing (ALB), companies do not use the mathematical approaches developed in the literature to configure assembly lines. This article aims to fill the gap between research and application by presenting and testing in a real industrial context a methodology based on complexity reduction and kaizen events. First, the methodology supports reducing the complexity that affects real-life assembly systems in terms of the variety of, e.g., finished products, materials and parts. Next, the methodology proposes the conduction of kaizen events by using lean manufacturing tools, such as process analysis, time observation, waste identification, workstation standard documents, and yamazumi charts. The methodology is successfully applied to a case study that describes its use in the confectionery process for a major chocolatier company along with the results of the application. The main contribution of this paper consists in presenting a method to manage the line balancing activity within everyday industrial realities, helping practitioners to improve and maintain the performance over time.

Keywords: assembly line balancing; lean manufacturing; kaizen; yamazumi chart; standardization

1. Introduction

An assembly line is a set of workstations positioned in a definite order and connected by transport mechanisms (e.g., conveyors) (Saif, 2014). Materials pass through workstations where different tasks are performed, following specific precedence relationships to assemble the final product (Baybars, 1986).

Assembly line design and balancing strongly affect manufacturing process times and costs (Rashid et al., 2012). Assembly line design encompasses decisions about the number of workstations and type of task to perform in each station. Assembly line balancing (ALB) aims to assign the tasks to the workstations so that workloads are as equal as possible (Bentaha et al., 2015), thus minimising workstation idle time (Saif, 2014) and buffers among them and improving effective utilisation of facilities (Sivasankaran and Shahabudeen, 2014).

Notwithstanding the existence of a broad research base on ALB (Battaïa and Dolgui, 2013), companies do not use mathematical approaches developed in the literature to configure assembly lines (Boysen et al. 2007) for several reasons:

- The methods developed in the literature still cannot capture all complexities of real-life problems in terms of products, components, materials, and operations variety (Battaïa and Dolgui, 2013);
- Researchers struggle at transferring the scientific knowledge to practitioners (Boysen et al., 2007). So far, few attempts have been made to provide help to managers in determining which model to use in their special assembly system (Boysen et al., 2008);
- The application context changes subject to both internalities, e.g., operation times, resource availabilities (Hazir and Dolgui, 2013), and externalities, e.g., market demands, product variety. Therefore, it is often not easy to assure the retention of results over time provided by mathematical approaches;
- The articles dealing with ALB are mainly concerned with the mathematical modelling of the problem and less concerned with how to apply the model in the real world. Boysen et al. (2008) noted that only 5% of articles found in the reviews by Scholl and Becker (2006), Becker and Scholl (2006), and Boysen et al. (2007), explicitly address line balancing of real assembly systems.

Kaizen Assembly might help to overcome this gap. Ortiz (2006) proposed solving the ALB problem by performing kaizen events directly on the assembly lines. Kaizen events are structured projects in which dedicated cross-functional teams apply lean manufacturing tools (e.g. process analysis, time observation, waste identification, workstations standard documents, yamazumi charts, etc.) to a specific area, focusing on a continuous improvement (i.e., kaizen) mind-set (Cannas et al., 2016). Lean manufacturing (LM) has been widely discussed in the literature and applied in companies (Jasti and Kodali, 2015). However, to our knowledge, few examples of applications of LM tools to balance assembly lines may be found in the literature. Talip et al. (2011) propose a method that combines yamazumi and King's algorithm to redesign the layout of a fishery factory and balance the workload on the newly defined manufacturing cells. Despite the relevance of yamazumi charts in improving assembly processes and the importance of clustering algorithms, the proposed methods do not seem sustainable in high variety contexts, such as actual ones where both the number of products to be assembled and the rate of new product introduction are high. In fact, performing kaizen events for every product and redesigning the layout of the manufacturing plant every time a new product is launched would require too much time and too many investments. Therefore, the following research question emerges: “How can companies perform ALB in high variety contexts in an efficient and effective way that can support maintaining the performance over time?”.

The present work aims to answer this question by filling the gap between academic literature and practical applications. To this end, we propose a two-step methodology for ALB. The first step is aimed at reducing the real-life complexity in terms of the variety of finished products, materials and components, which must be handled by the assembly line. The second step allows to perform the balancing of the assembly line. It does not apply mathematical balancing models but organisational tools based on the kaizen event concept. This since, on the one hand, as previously mentioned and more deeply discussed in the literature review, ALB mathematical models are not so used in real-life contexts and, on the other hand, the use of kaizen-based organisational tools lets practitioners involved in the process better understand and more independently adapt the line balancing over time. The methodology has been successfully applied in the Italian plant of a chocolatier and confectionery company.

The paper is structured as follows: in section 2, a review of literature related to ALB is performed; in section 3, the methodology is introduced; then, in section 4, the application to the case study is presented; in section 5, the obtained results are discussed; finally, in section 6, the main conclusions of the study are presented.

2. Literature review

2.1 Assembly line balancing

A recent study performed by Battaïa, and Dolgui, (2013) reviewed and analysed the recent literature related to the ALB problems (ALBPs), classifying the main solving methods and underling the current gaps and recent trends in the literature. They defined the ALBP as complex combinatorial problems, classified as NP-hard. For this reason, the solution methods mostly applied in the literature, according to Battaïa, and Dolgui (2013), consist in the application of the mathematical models mainly used for the combinatorial optimisation: (i) the exact methods, which are suitable to search for the optimal solution, among a set of finite possible solutions, when the complexity of the problem is not too high and the time to generate the solution is feasible with respect to the time available; (ii) the approximate methods, which are often better for solving large-scale ALBPs: they do not assure optimality such as exact methods do, but they can provide feasible results in adequate time.

In the following subsections, the characteristics and the main problems in the application of these methods to real complex industrial realities are analysed in-depth.

2.1.1 Exact methods

Exact methods include different models such as mixed integer programs, general solvers useful for describing and understanding different assembly lines, and branch and bound and dynamic programming, which are original dedicated methods helpful in dividing the optimisation problem into sub-problems. These methods are particularly effective only with small-scale applications related to a restricted number of tasks (Battaïa, and Dolgui, 2013). Given the extremely high computational complexity for problems of significant size, such as real-world problems, an optimal solution requires extremely long solving times with a consequent low practical relevance (Pachghare and Dalu, 2014).

Scholl and Boysen (2009), for example, developed a branch and bound procedure (i.e., Absalom) for solving ALBPs. They assessed the method through a computational experiment based on a data-set proposed in the literature: it showed good results and optimality if applied to small- and medium-sized problems; however, for larger problems, the deviation from optimality might become high. Additionally, Kellegöz and Toklu (2012) applied a branch and bound procedure (i.e., Jumper) to solve ALBPs and evaluated it by means of an experimental study based on a benchmark problem proposed in the literature for simple ALBPs; the results revealed that even if this exact method is better than previous methods in terms of solving time, it does not perform well in finding feasible solutions when applied to large problems. Recently, Roshani and Giglio (2016) proposed a mixed integer mathematical program to solve ALBPs, stating, that since ALBPs are NP-hard, these methods can find an optimal solution in reasonable time only with small-sized problems. Therefore, they additionally proposed two approximate methods to address larger ALBPs.

2.1.2 Approximate methods

Approximate methods are classified as heuristic and metaheuristic. According to Pachghare and Dalu (2014) and Battaïa, and Dolgui (2013), heuristic methods are based on assigning tasks through the application of the greedy approach or priority rules (e.g., maximum task time, minimum earliest, etc.). These methods consist of performing random iterations to provide solutions, the best of which is retained. The number of iterations defines the time and optimality of the solution: single-pass heuristics (i.e., one iteration) provide quick results even with large-scale problems, whereas multi-pass heuristics allow the analysts to find different and optimal results at each step, and they continue to iterate until the solutions become stable. The heuristic methods are useful for improving exact method solutions or for providing a local optimum of intermediate solutions, which needs to be included in metaheuristic methods. Metaheuristic methods try to cope with the heuristic limitations, providing an initial solution and then moving to an improved neighbour solution without stopping when a worse solution is found to avoid a premature end of the iterations (Pachghare and Dalu, 2014).

Among the approximate methods, genetic algorithms (GAs), simulated annealing (SA) and ant colony optimisation (ACO) are applied most often (Sivasankaran and Shahabudeen, 2014). Even if these methods are faster than exact methods in solving large ALBPs, most studies in the literature, according to Battaïa, and Dolgui (2013), addressed simplified ALBPs based on the following assumptions: a single serial assembly line is related to one homogeneous product, characterised by fixed cycle times and deterministic operation times and composed of equally set workstations (Scholl and Becker, 2006). In addition, specific literature reviews related to approximate methods recognised the scarcity of applications to real-world ALBPs. For example, Tasan and Tunali (2008) in their review of GAs applied to ALBPs, stated that GAs still have not been shown to effectively solve complex problems. They found a lack of studies in this field addressed to real-world ALBPs and an absence of tests to demonstrate the performance of GAs to practitioners with realistic results. Additionally, Rashid et al. (2012) in their review of soft computing approaches such as GA and ACO, found a gap in the literature concerning the application of these methods to complex ALBPs. Moreover, they expressed a need for making the application of these methods closer to the real world but also emphasised that this increases the complexity and computational costs.

Accordingly, recent studies are providing innovative methods, which consider as much as possible the real-life conditions (i.e., complexity and variability). Nevertheless, few authors have applied their innovative approximate methods to real case studies as, for example, Polat et al. (2016). They developed a metaheuristic methodology based on a variable neighbourhood search that considers the real-world variability of task times depending on worker skills. The authors applied the developed methodology to a real case study to test it in an industrial context, showing that their algorithm helps in improving performance when they depend also on worker skills. However, the authors recognised that the algorithm still does not consider other important real-world variants such as job rotation, collaboration between workers, etc. that should be included in future studies.

Most studies still test their innovative approximate methods with ALBP samples taken from the literature. For example, the study developed by Roshani and Giglio (2016) proposed two innovative metaheuristic approaches, based on SA, to solve ALBPs characterised by parallel working places in each workstation. They first proposed a mathematical solution to this type of ALBP, applying SA to more realistic and complex ALBPs; however, they did not assess the method with a real case study but tested it on a set of problems taken from the literature. In addition, Delice et al. (2016), developed a new GA approach that considers conditions characterising real-world ALBPs such as the stochastic task time; however, they also tested the method with a sample taken from the literature without considering a real case study.

In conclusion, efforts are still needed to reduce the gap in the literature between the practical and theoretical world of ALBPs, to improve the applicability of mathematical models to large and complex ALBPs in real industrial cases and to make it possible to maintain improvements over time.

2.2 Kaizen assembly

The concept of "kaizen", i.e. continuous improvement, was introduced by Imai (1986) to define a business strategy that "involves everyone in an organisation working together to make improvements without large capital investments". Later, Harmon and Peterson (1990) described the continuous improvement as the key to become a world class manufacturer. Moreover, kaizen events can generate positive changes "in business results and human resource outcomes" (Glover et al. 2011). For this reasons, the kaizen concept and its empirical applications have been have been analysed in the literature.

Hyer and Wemmerlov (2002) defined continuous improvement as fundamental for manufacturing philosophies to increase performance of a specific variable without negatively affecting the others important ones. They emphasised the concept of "kaizen blitzes", i.e. intense improvement activities based on teamwork, which affect the employees' motivations and job satisfaction thanks to the increasing interaction and mutual dependency with the group. The kaizen blitzes make possible to effectively find problems, search for solutions, apply them and control the results over time. They explained how to build an improvement culture within the company by prescribing actions such as making improvement an expectation, creating improvement teams and being open to new ideas that come from the workforce involved in the process. This work provides good insights related to the kaizen application and useful guidelines, but does not provide in-depth analysis related to empirical applications.

Hamel (2010) defined kaizen events as drivers for applying LM tools and reduce wastes. His work provided guidelines to practitioners on how to apply kaizen within a company and how to conduct kaizen events. The main key factors identified were the good definition of the standard work approach, the identification of the strategy and value-stream driving the events, the presence of an effective lean transformation leader and, finally, the application of an employee-driven approach. Unfortunately, no applications of the techniques and practices well outlined by the author to real industrial cases are provided.

Regarding the application of the kaizen to the ALBPs, an approach was proposed by Ortiz (2006). He introduced the "kaizen assembly": a methodology to design and balance the assembly lines performing kaizen events directly on the assembly lines. Ortiz (2006) described in detail an industrial application of kaizen assembly to a manual-assembly line, the Electric Bike line, and highlighted the best methods to design and balance the assembly lines by means of kaizen events. According to this study, in solving ALBPs, the following steps are needed: (i) performance of a rigorous time and motion study, (ii) definition of volume requirements and effective hours of the line, and consequently, (iii) calculation of takt-time, namely, the line pace to consider for balancing workstations. Studying time and motion helps to identify and eliminate non-value added activities, improving the line flow. Takt-time definition permits balancing work and making the cycle times of each workstation equally distributed and aligned to the line pace so that the operators do not wait excessively or reach overcapacity. In addition, work contents can be well distributed with the help of operators and the kaizen team, defining how to split work contents according to the takt-time without decreasing product quality. Finally, considering the type of materials moving along the line and the takt-time, the line can be redesigned to define the right number and position of workstations within the assembly line. In conclusion, Ortiz (2006) demonstrated the effectiveness of kaizen events for solving ALBPs, identifying the low implementation costs and exploitation of the value and talent of the existing workforce as one of the main benefits of kaizen events.

In 2009, an additional work was developed by Ortiz to define guidelines to implement kaizen and kaizen events in a company, based on his empirical experience. He, first, defined the steps needed for the application of LM tools such as 5S and standard work during kaizen events. The study suggests to first compute the effective times and the volume requirements, to well define the required takt-time to respect for satisfying the customer requirements. Then, the process analysis is suggested, by means of LM tools, such as time and motions study. Finally, the assembly balancing can be reached considering time, work contents, and inventory. Ortiz (2009) described also a specific case study where kaizen events have been successfully applied in a company mainly manual-assembly based. He demonstrated that the main benefits from kaizen events application are both measurable and non-measurable: on the one hand, a better application of LM, reaching good results in terms of performance and customer satisfaction; and on the other hand, spread of a solid kaizen concept within the organisation. Nevertheless, the case study application was mostly related to 5S kaizen events, while the standard work kaizen events to reach a good line balancing have not been considered in this application.

Recent studies have further developed the concept. However, despite showing the ability of kaizen assembly to solve ALBPs, in literature only few works present real applications of the method and provide the supporting tools for a correct implementation, such as examples of standard work sheets. For example, Álvarez et al. (2009) defined a methodology to redesign and balance assembly lines based on the kaizen concept and applied it to a real case study, focusing their study on a specific products family, an injection valve. Their work demonstrated how this approach can quickly reach good and durable results in real industrial case studies. The main results reached with the application of the kaizen concept to assembly lines were: elimination of non-value-added times, improvement of material flow, cycle time reduction, inventory reduction along the line, and an increase of flexibility.

Then, Prashar (2014) addressed the application of kaizen events to redesign the assembly line of a company. He stated that application of LM tools could lose effectiveness unless supported by kaizen concept. Thus, he conducted qualitative-interpretative research to study how an Indian company improved the assembly process of the Column Type Electric Power Steering by applying kaizen events. This study reached several tangible results such as the reduction of inventory levels, required storage space, the distance travelled by material, and the defection rate; intangible results were also reached such as the improvement of the kaizen team's ability to implement the kaizen concept, maintaining improvements over time and quickly replicating them in other assembly lines.

Ham and Park (2014) proposed a framework (i.e. a five-level decomposition model) for the application of continuous improvement to a manned assembly line. They stated that this approach is based mainly on two activities: the "assembly work process improvement", related to the efficiency of the workers and workstations along the line, and the "improvement of line balancing efficiency", related to the workloads optimisation. This work is mainly focused on the process design looking at both macro (i.e. system) and micro (i.e. motion) aspects, by analysing both the workstation and the line. The framework was also successfully applied to a real industrial case study, providing performance improvement and minimising inefficiencies, but no details about the considered product/line are given.

In conclusion, the effectiveness of kaizen events applied to ALBPs has been proven in the literature. Nevertheless, theoretical and empirical work is still needed to explore the "kaizen assembly". The lack of studies related to the kaizen concept has been underlined by the in-depth literature review by Suárez-Barraza et al. (2011). They found out that the definition of kaizen and its application within companies is quite confused and inconsistent in the literature. The ambiguity makes complex for practitioners to implement kaizen approaches in the real world. For this reason, there is a need for studies that analyse the main key factors for kaizen successful application in companies with different size (big, medium, and small) and in different areas (manufacturing and service). Finally, as shown in the above literature review about kaizen assembly, this concept has been few covered in the literature and more empirical research is needed to define effective methodologies and tools for applying the kaizen concept, solving real ALBPs, and maintaining good results in the long term. Moreover, it is worth underlying that none of the revised studies has applied kaizen in cases dealing with numerous different products, overlooking such an issue.

3. Research objective and methodology

The present work proposes a methodology with a twofold objective: (i) ease the ALB dealing with a large number of parts; and (ii) allow practitioners to sustain assembly line performance improvement over time.

The methodology is structured in two phases: (i) complexity reduction to reduce the problem size derived by the proliferation of product and part variants by means of clustering and the definition of macro-cycles, i.e., the set of tasks and the estimated assembly time required by one or more end-items; and (ii) kaizen events, for assembly line balance and performance improvement and enhancing assembly activities by means of LM tools. Kaizen events, in fact, are proven to increase manufacturing performance and overcome the limitations of other methodologies, such as the difficulties in transferring knowledge to practitioners. They assure the retention of line balancing results over time, and address real assembly systems balancing issues. Figure 1 depicts the methodology outline that will be discussed in the following. The complexity reduction phase is preparatory to kaizen events to bound the number of kaizen events to be performed for an efficient enhancement of assembly line performance. In fact, considering macro-cycles allows for the simultaneous improvement of assembly performance for all end-items assigned to the same cluster through standardisation and line balancing of only one end-item assigned to that macro-cycle. In addition, in case of new end-items, the identification of the corresponding macro-cycle leads to immediate identification of an efficient and effective line configuration. 3.1 Complexity reduction

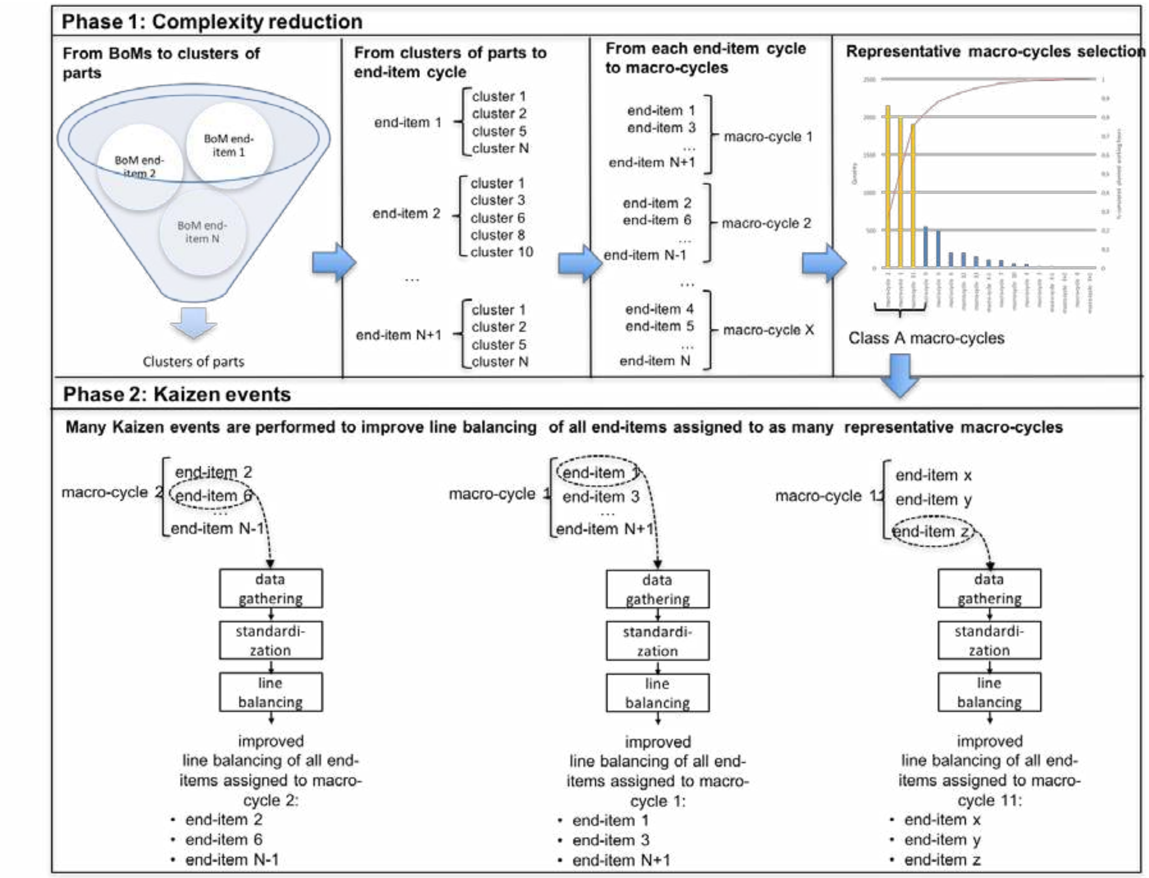


Figure 1

3.1.1 Background

The here-proposed methodology aims to improve assembly line performance in a context characterised by complexity. Saeed and Young (1998) define complexity as the "systemic effect that numerous products, customers, markets, processes, parts, and organisational entities have on activities, overhead structures, and information flows". Several methodologies support the analysis of complexity in manufacturing (Efthymiou et al. 2016).

Complexity can be managed and reduced by applying different strategies both at the product level, i.e., component commonality, product modularity, platforms, component configurations and product variations, and at the process level, i.e., component families/cell manufacturing, process modularity, process commonality and delayed differentiation (Bednar and Modrak, 2014; Brun and Pero, 2012).

Clustering is one of the common methods used to reduce complexity by grouping elements that present some similarities, thus reducing the number of problem elements, and it is applied in many strategies to reduce or manage complexity. Clustering is at the basis of the application of group technology and, therefore, cell manufacturing. Bhaskar and Narendran (1996) apply group technology to group printed circuit boards and components based on an ad hoc measure of similarity. Gonçalves and Resende (2004) combine a local search heuristic with a genetic algorithm to group product families and machines into cells. Al-Araidah et al. (2007) propose a clustering step to reduce the complexity of the block layout problem. They partition work centres into clusters based on flow intensity. In contrast, Agrawal et al. (2011) apply the ant colony optimisation approach to parts and machines, grouping problems taken from the literature.

3.1.2 Complexity reduction phase description

The complexity reduction phase presented in the following section contains three consecutive steps: (i) clustering of parts; (ii) macro-cycles definition; and (iii) representative products selection.

Clustering of parts

The 'clustering of parts' addresses the problem of partitioning parts starting from sets of parts. From an assembly perspective, the distinction/equivalence between parts should be based on tasks to be performed and their cycle time. As details on the tasks and cycle times involved in the assembly of parts is usually neither formalised nor recorded in databases, a clustering algorithm should be performed involving a team with practical knowledge of the assembly activities involved with the parts, end-items managed by the plant, their bill of materials (BoMs) and the related assembly performance. Figure 2 outlines how to conduct the 'clustering of parts' step. Given the end-items assembled by the line and the set of parts (i) needed for their assembly (Figure 2a), the tasks they require (Figure 2b) and the cycle time they involve are compared to each other (Figure 2c). Each part requires one task. Whether a part ($i \in I$) in the BoMs requires a task equivalent (both task and cycle time) to a previously analysed part ($j \neq i$, $j \in I$), i belongs to an already defined cluster ($c_i = c_j \in C$, $C = C_1, \ldots, C_N$); otherwise, a new cluster is defined (Figure 2c). A cluster of parts is characterised by the combination of a task and the corresponding cycle times (Figure 2d). As all parts assembled by the line are analysed and belong to a cluster, the macro-cycles can be defined (Figure 2e).

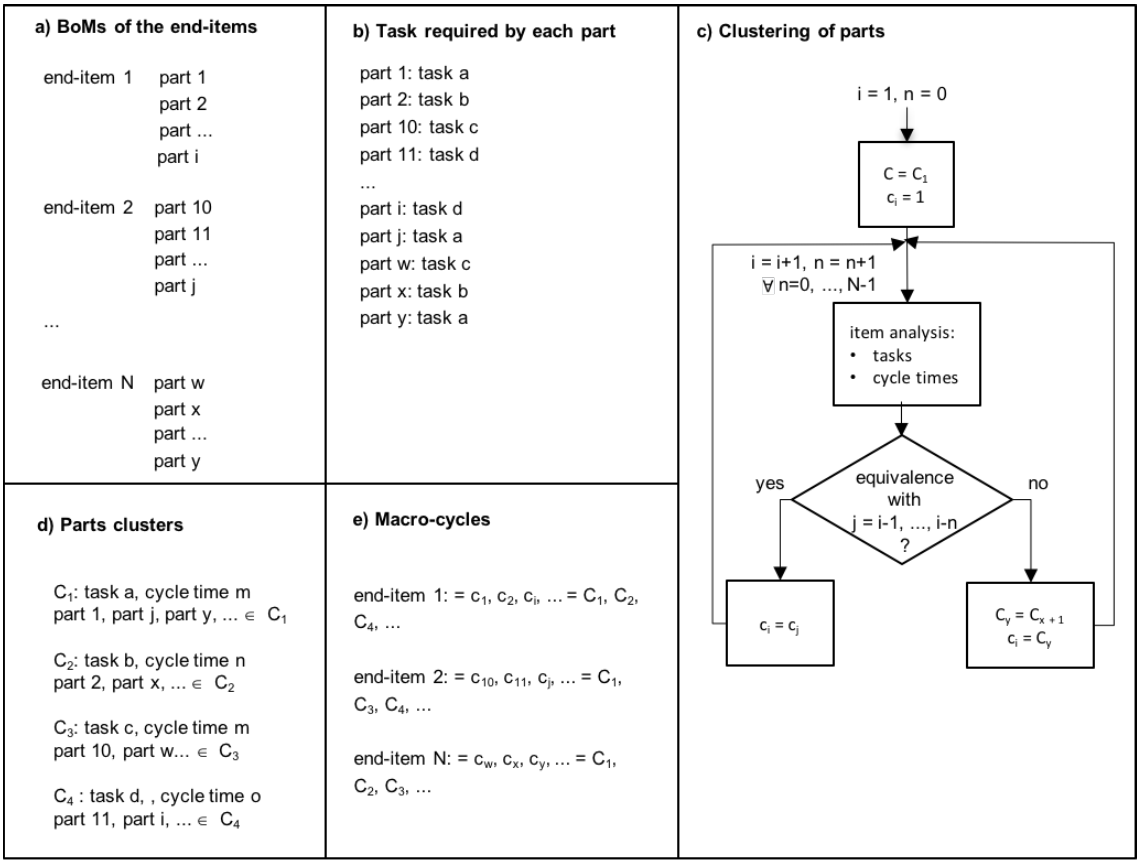


Figure 2

Macro-cycle definition

A ‘macro-cycle’ identifies the set of tasks and the estimated assembly time required by one or more end-items. It is represented by a sequence of cluster numbers (ascending order) assigned to the parts listed in the BoM of the considered end-items. For any end-item assembled by the line, the sequence is obtained through the substitution of every part-ID in the BoM with the corresponding cluster number. As the same tasks and time (i.e., cluster numbers) are involved by more end-items, the same ‘macro-cycle’ is assigned to more end-items.

Representative products selection

The last step of the complexity-reduction phase concerns the identification of the most representative ‘macro-cycles’ sample to be studied for line performance improvement. Identification is based on a modification of the product quantity analysis (PQA), a classical approach for product mix segmentation (Braglia et al. 2006). According to the literature, the underlying logic of PQA is that high volume products are responsible for most non-value-added costs. The same logic is proposed for assembly lines to boost overall performance of the line, improving high-volume ‘macro-cycles’. The methodology considers the planned working hours (given by the sum of the planned working hours of every assembled end-item that is assigned the same ‘macro-cycle’) instead of the quantity, as big differences in time consumption of the assembly line availability by end-items could occur. This method proposes to display the ‘macro-cycle’ mix in the form of a Pareto chart, sorting the products in order of decreasing planned assembly hours. Accordingly, class A is identified as a set of representative ‘macro-cycle’ samples that are worth the improvement activities performed in the second macro-phase of the approach.

3.2 Kaizen events

Line performance improvement should be conducted through a series of focused kaizen events. Each event involves one representative end-item belonging to class A. Kaizen events should address the problem of unfulfilled target performance and throughput variability, one of the causes affecting manufacturing system performance (Hopp and Spearman, 2008). The objective of each kaizen event (i.e., enhancement of line balancing and throughput, maintaining quality standards and benefits from involvement and teamwork) is pursued through three consecutive steps: (i) data gathering, (ii) work standardisation and (iii) line balancing. Kaizen events should be organised during a work shift so that operators take part in the entire procedure. To get effective results, before starting improvement activities, lean principles (5S and standard work) and the objective of the event (effective line balancing to improve assembly performance) should be shared with participants.

Data gathering

Data gathering aims to collect data needed to perform standardisation and balancing. While the assembly line is working, the assembly line manager gathers data about the end-item and the assembly process: number of operators, number of workstations, takt-time, line output required, and production net time available for the product. The takt-time of the assembly line must be calculated; the takt-time is obtained by computing the ratio between the production net time available, that, is the period devoted to a production campaign and the amount to be produced. Then, the current layout of the line is drawn, depicting workstations, machines positions, the existence of feeder lines and conveyor belts.

Standardisation

Standard work is one of the main principles of the Toyota Production System (Hopp and Spearman, 2008), it is a fundamental tool aimed at explicitly defining and communicating the current best practice for an activity (Hamel, 2010). Moreover, standardisation, identifying which tasks are currently assigned to each workstation, allows to calculate the cycle time currently needed to perform the tasks for each workstation.

Among the numerous practices and tools that minimise process time variability (Shah and Ward, 2007), the definition of standard operating procedures specifying work to the smallest detail and addressing less variability in cycle time is performed during the kaizen event. In particular, the standardisation step involves the concept of the workstation standard document, i.e. the job element sheet (JES) and the standard operating sheet (SOS). JES is a document giving details on how to conduct a specific task to obtain desired time and quality performance. SOS is a sequence of JESs, distinguishing between value-added activity times (gathered and formalised by the JESs) and non-value added activity times (such as movements and search), describing the job content of the line workstations. JESs and SOSs must be composed with the help of assembly line operators, who have knowledge of the detail of the work elements and their reasons. Working together on JESs and SOSs leads to knowledge sharing among operators on the best way to perform the discussed activities, a first step towards performance improvement (Pozzi et al. 2015). According to the line balancing rules described by Ortiz (2006), at this step, the first one ('remove non-value added activities') is implicitly applied: while searching for the best way to perform tasks, a reduction of time waste is pursued. Standardisation ends with drawing on a whiteboard (placed in the assembly line area) a representation of the content of work of each workstation, according to the SOSs, and the time required to perform them. Representing job elements and the non-value added time of each workstation (highlighting the difference through different colours) eases the identification of aspects that should be improved (e.g., layout or parts feeding), which requires more than one operator to be completed on time and whether the work contents of the workstations are not balanced.

Line balancing

The kaizen event, then, addresses the problem of line balancing to satisfy planning requirements. The assembly line manager is mainly involved in performing this step, but the participation of the operators is still required. According to Pakdil and Leonard (2017), the line balancing step addresses the problem of reducing the difference between the workstation cycle times and the target takt-time through the application of Yamazumi. Accordingly, the line balancing rules described by Ortiz (2009), 'balance by time', 'balance by work content', and 'balance by material', are applied. Value added and non-value-added times drawn on the Yamazumi board should be progressively assigned to workstations so that the cycle time of each workstation is close to (but never over) the takt-time. It is important not to assign workstations several tasks so that the cycle time is higher than the takt-time, as the target throughput would not be reached; at the same time, it is important not to allocate too little time, as the operator assigned to such a workstation would often be waiting. Breaking down the work content eases the time balancing among workstations. To correctly assign tasks to different workstations, the involvement of operators is needed to correctly evaluate precedence relationships and test the feasibility of the proposed change. Last, in case some task greatly exceeds takt-time, the task addresses designing the workstation to accommodate two units at the same time or with creating parallel workstations. Due to the whiteboard representation, the line balancing step can be autonomously performed by assembly line operators and the line manager.

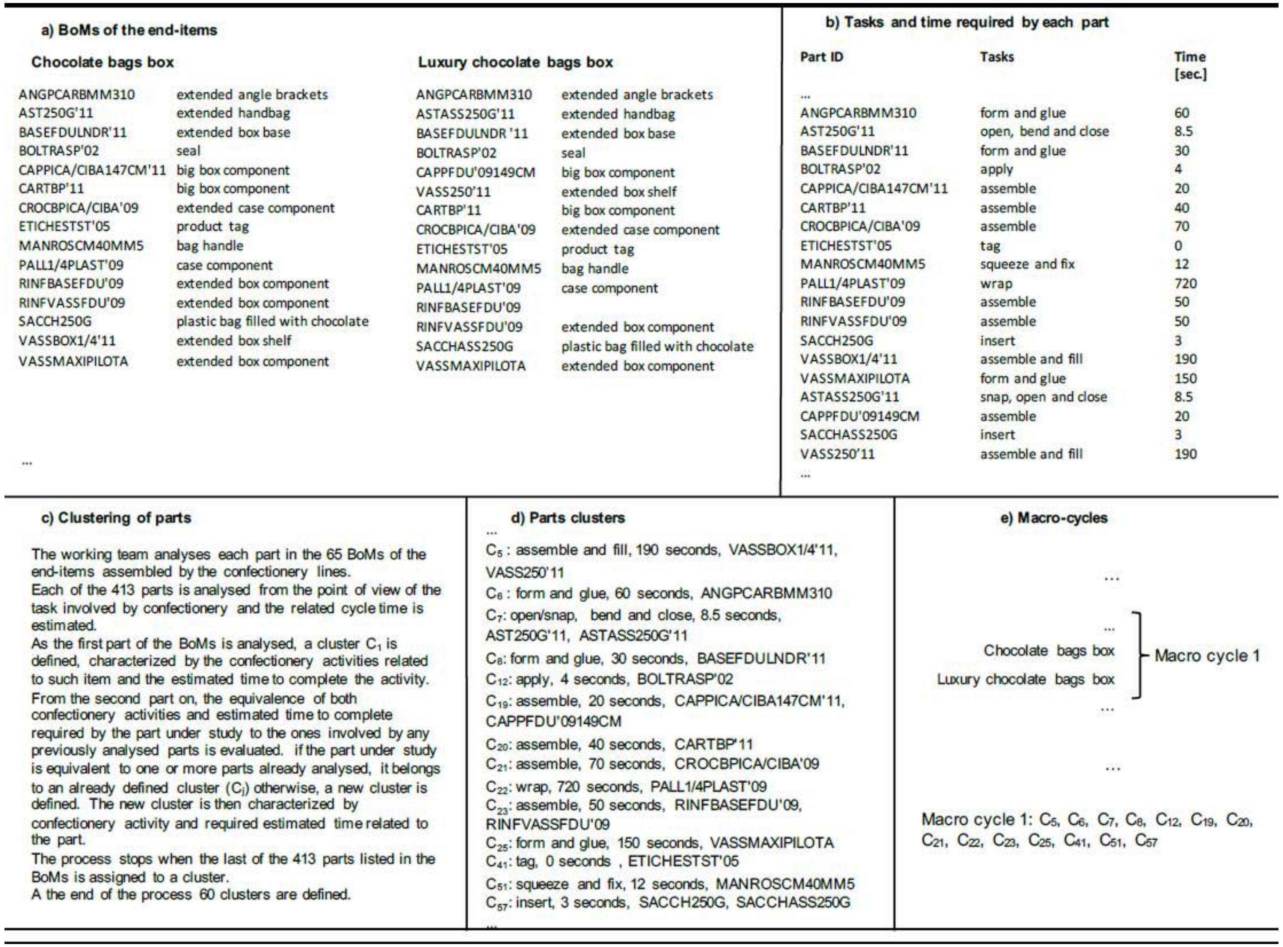
4. Case study

4.1 Background of the case study

As the methodology addresses a typical industrial issue, it is applied to the case of the Italian plant of a world leader chocolatier and confectionary company. The company, whose critical success factors are excellence and innovation, produces a large selection of premium products for which the package is a key factor of product preciousness. In the considered plant, the packaging process is performed on three manual assembly lines that are assigned the packaging of a large variety of products. The context is characterised by complexity, due to the number of end-items packaged (65) and parts to be managed to complete the assembly process (413). Once the packaging of one end-item is concluded the line is set up for the packaging of the next end-item. For this purpose, the layout of the line changes in the number of workstations and operators involved in the package assembly. Because of the large number of different packages to be assembled to cover the end-item and the variety of the assembling activities, the efficiency performance of the package assembly process has deteriorated over the years, not being able to reach the company efficiency targets, and the package assembly process of several end-items has been subcontracted. Despite the cost reduction associated with the outsourcing, the quality obtained by the subcontractor does not satisfy the company premium quality standards. Therefore, the company manifested the need to optimise the manual package assembly lines, to reach the efficiency targets while maintaining the premium quality standards and the internal control of these core activities. The methodology is applied to the autumn/winter (A/W) season boxed chocolate family and the outcomes are presented in the following. The working team consists of the operations manager, supervising the entire application of the methodology, the package assembly line managers, contributing with practical knowledge of the package assembly activities involved in the parts to be assembled by the lines, and one person from the industrialisation function, who contributes with knowledge about the BoMs, codification of part-IDs and target performance of the end-items managed by the package assembly lines.

4.2 Complexity reduction application

The complexity reduction phase is applied to all end-items whose packages are assembled by the three lines under study. The list of part-IDs is obtained by the 65 end-item package BoMs, and it is organised by functional characteristics. Different part-IDs are characterised by different morphological characteristics (e.g., size, shape, or colour) or performance features (e.g., capacity or strength). Figure 3 aims at showing the application of the steps and, due to space constraints, it presents an extraction of the complexity reduction application, focusing on the packages of two representative end-items, ‘Chocolate bags box’ and ‘Luxury chocolate bags box’ (the names of the end-items and part-IDs are disguised for privacy reasons). The BoMs of the two representative end-items are depicted in Figure 3a. For each part in the BoMs the task/tasks required for its package assembly is/are listed (Figure 3b). Given the list, the working team, with help from the package assembly lines manager, analyses each part in the BOMs from the perspective of the tasks involved for package assembly, and estimates the amount of time required to execute this assembly activity. According to the procedure depicted by Figure 2c, if the analysed part involves package assembly tasks and an amount of time equal to the ones involved by one or more parts already analysed, the part belongs to an already defined cluster (C_j); otherwise, a new cluster is defined. The cluster is then characterised by the package assembly activity/activities and estimated times for completion of the part (Figure 3c). At the end of the step, the working team analyses 65 BoMs, 413 part-IDs and defines 60 part clusters (C). With reference to the herein considered BoMs ('Chocolate bags box' and 'Luxury chocolate bags box' packages BoMs), the list of clusters identified and the package assembly activities and estimated times for each of them as well as the parts belonging to that cluster are presented (Figure 3d). Last, according to the BoMs and the list of clusters, the macro-cycles associated with the herein considered end-items are defined and found to be the same (Figure 3e).



a) BoMs of the end-items

Chocolate bags box

ANGPCARBMM310	extended angle brackets
AST250G'11	extended handbag
BASEFDULNDR'11	extended box base
BOLTRASP'02	seal
CAPPICA/CIBA147CM'11	big box component
CARTBP'11	big box component
CROCBPICA/CIBA'09	extended case component
ETICHESTST'05	product tag
MANROSCM40MM5	bag handle
PALL1/4PLAST'09	case component
RINFBASEFDU'09	extended box component
RINFVASSFDU'09	extended box component
SACCH250G	plastic bag filled with chocolate
VASSBOX1/4'11	extended box shelf
VASSMAXIPILOTA	extended box component

...

Luxury chocolate bags box

ANGPCARBMM310	extended angle brackets
ASTASS250G'11	extended handbag
BASEFDULNDR '11	extended box base
BOLTRASP'02	seal
CAPPFDU'09149CM	big box component
VASS250'11	extended box shelf
CARTBP'11	big box component
CROCBPICA/CIBA'09	extended case component
ETICHESTST'05	product tag
MANROSCM40MM5	bag handle
PALL1/4PLAST'09	case component
RINFBASEFDU'09	
RINFVASSFDU'09	extended box component
SACCHASS250G	plastic bag filled with chocolate
VASSMAXIPILOTA	extended box component

b) Tasks and time required by each part

Part ID	Tasks	Time [sec.]
...		
ANGPCARBMM310	form and glue	60
AST250G'11	open, bend and close	8.5
BASEFDULNDR'11	form and glue	30
BOLTRASP'02	apply	4
CAPPICA/CIBA147CM'11	assemble	20
CARTBP'11	assemble	40
CROCBPICA/CIBA'09	assemble	70
ETICHESTST'05	tag	0
MANROSCM40MM5	squeeze and fix	12
PALL1/4PLAST'09	wrap	720
RINFBASEFDU'09	assemble	50
RINFVASSFDU'09	assemble	50
SACCH250G	insert	3
VASSBOX1/4'11	assemble and fill	190
VASSMAXIPILOTA	form and glue	150
ASTASS250G'11	snap, open and close	8.5
CAPPFDU'09149CM	assemble	20
SACCHASS250G	insert	3
VASS250'11	assemble and fill	190
...		

c) Clustering of parts

The working team analyses each part in the 65 BoMs of the end-items assembled by the confectionery lines.

Each of the 413 parts is analysed from the point of view of the task involved by confectionery and the related cycle time is estimated.

As the first part of the BoMs is analysed, a cluster C_1 is defined, characterized by the confectionery activities related to such item and the estimated time to complete the activity.

From the second part on, the equivalence of both confectionery activities and estimated time to complete required by the part under study to the ones involved by any previously analysed parts is evaluated. if the part under study is equivalent to one or more parts already analysed, it belongs to an already defined cluster (C_j) otherwise, a new cluster is defined. The new cluster is then characterized by confectionery activity and required estimated time related to the part.

The process stops when the last of the 413 parts listed in the BoMs is assigned to a cluster.

A the end of the process 60 clusters are defined.

d) Parts clusters

...

C_5 : assemble and fill, 190 seconds, VASSBOX1/4'11, VASS250'11

C_6 : form and glue, 60 seconds, ANGPCARBMM310

C_7: open/snap, bend and close, 8.5 seconds, AST250G'11, ASTASS250G'11

C_8: form and glue, 30 seconds, BASEFDULNDR'11

C_{12}: apply, 4 seconds, BOLTRASP'02

C_{19}: assemble, 20 seconds, CAPPICA/CIBA147CM'11, CAPPFDU'09149CM

C_{20}: assemble, 40 seconds, CARTBP'11

C_{21}: assemble, 70 seconds, CROCBPICA/CIBA'09

C_{22}: wrap, 720 seconds, PALL1/4PLAST'09

C_{23}: assemble, 50 seconds, RINFBASEFDU'09, RINFVASSFDU'09

C_{25}: form and glue, 150 seconds, VASSMAXIPILOTA

C_{41}: tag, 0 seconds , ETICHESTST'05

C_{51}: squeeze and fix, 12 seconds, MANROSCM40MM5

C_{57}: insert, 3 seconds, SACCH250G, SACCHASS250G

...

e) Macro-cycles

...

...

Chocolate bags box

Luxury chocolate bags box

...

Macro cycle 1

...

Macro cycle 1: C_5, C_6, C_7, C_8, C_{12}, C_{19}, C_{20}, C_{21}, C_{22}, C_{23}, C_{25}, C_{41}, C_{51}, C_{57}

Figure 3

Due to the number of end-items and parts characterising 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 tool is developed by means of visual basic application (VBA) to help the team work. With the help of the VBA tool, the team obtains 44 'macro-cycles' representing different sets of activities and times needed to complete the packaging of 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 the same activities and amount of time to be completed.

To identify the representative 'macro-cycles', the team considers the planned working hours (given by the sum of the planned working hours of every end-item characterised by the same 'macro-cycle') instead of quantity, as the team finds big differences in the time of consumption of the assembly and packing lines by end-items belonging to different clusters. This method proposes to display the 'macro-cycle' mix in the form of a Pareto chart, sorting the products in order of decreasing package assembly planned hours. Approximately 20% of the 'macro-cycles' (class A) assembled by the package assembly lines consume their capacity for approximately 80% of the planned production time. Accordingly, class A is identified as a set of representative 'macro-cycles' to be involved in the second phase of the approach with the aim of efficiently improving line performances.

4.3 Kaizen event conduction

We here describe the kaizen phase performed on one end-item that is the representative of the 'macro-cycle' presented above: the 'Chocolate bags box' (Figure 4). According to Figure 3, 14 clusters of parts compose the end-item package: C_5, C_6, C_7, C_8, C_{12}, C_{19}, C_{20}, C_{21}, C_{22}, C_{23}, C_{25}, C_{41}, C_{51}, C_{57}. Before the kaizen event, the package assembly performance does not satisfy the target throughput of 10 boxes/hour (takt-time per box: 360 seconds). As each box is made of 60 bags (12 bags per level, 5 levels), the takt-time can be effectively expressed per single confectioned bag (6 seconds).

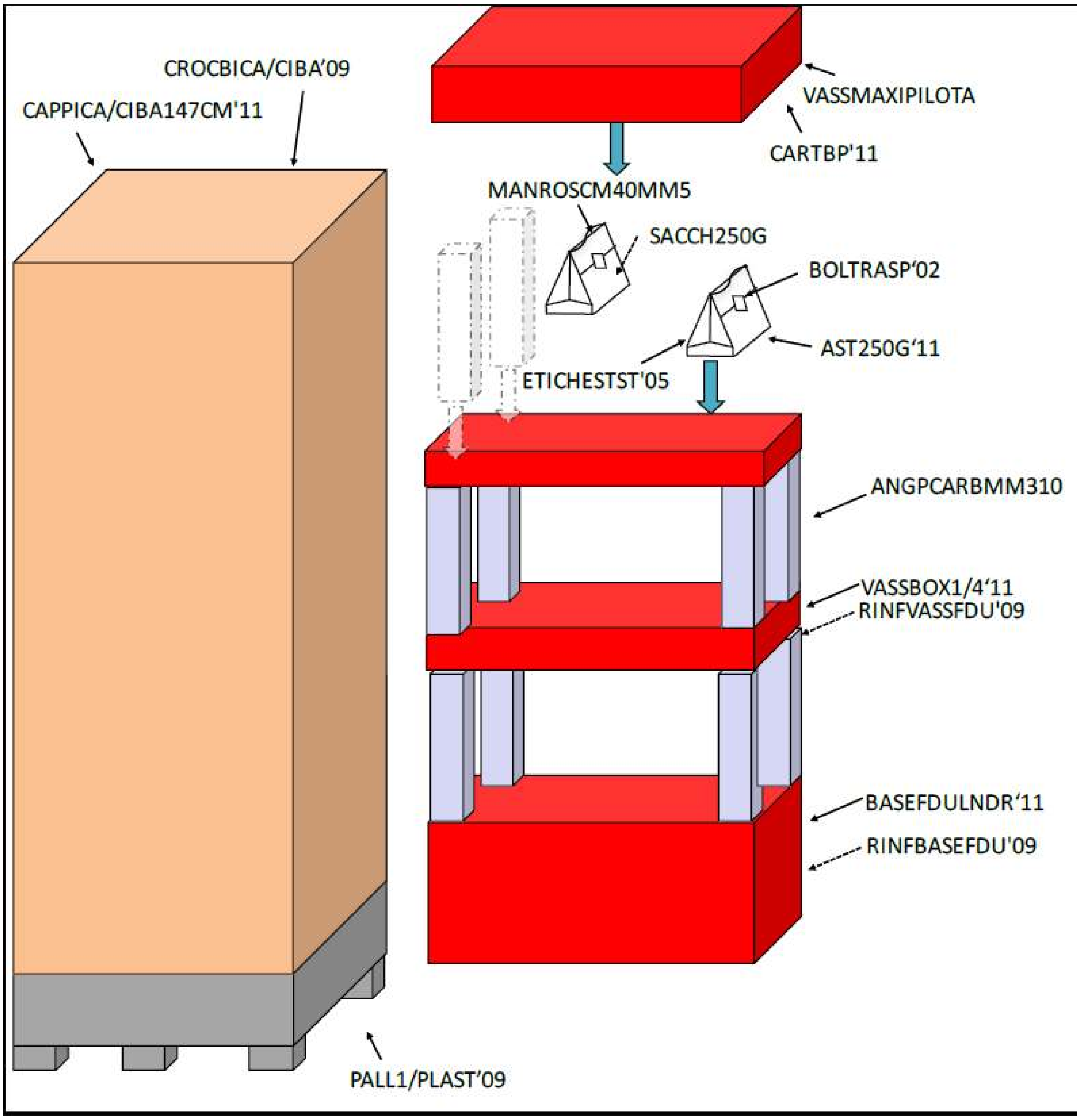


Figure 4

The manual assembly line is characterised by a straight layout and package assembly work in process is moved by a conveyor belt (Figure 5). A printer prints lot and batch numbers on a tag (C_{41}) on each bag before the assembled box is packed and a case sealer machine helps the packing activities. Ten operators work on the line in 6 different workstations:

- Workstation (WS1): three operators work in this workstation, opening and bending the extended handbag (C_7, without closing, duration: 5 seconds out of 8.5 seconds), squeezing and fixing the handle of the handbag (C_{51}), and feeding the line (non-value added task, duration: 2.5 seconds);

- Workstation (WS2): two operators work in this workstation, performing the inspection of the chocolate plastic bag (non-value added task, duration: 2.8 seconds) and inserting the chocolate plastic bag to fill the handbag (C_{57});
- Workstation (WS3): one operator works in this workstation, performing the closure of the handbag (C_7, without opening and bending, duration: 3 seconds out of 8.5 seconds), preparatory to the application of the seal;
- Workstation (WS4): one operator works in this workstation, applying a seal for handbag closure (C_{12});
- Workstation (WS5): one operator works in this workstation, assembling the big box component, i.e., part RINFBASEFDU’09, (C_{23}), assembling and filling the extended box shelf, i.e., part VASSBOX1/4’11, (C_5), and assembling the extended box shelf, i.e., part CROCBICA/CIBA’09, (C_{21});
- Workstation (WS6): two operators work in this workstation, wrapping the box (C_{22}), i.e., PALL1/4PLAST'09, to cover the end item.

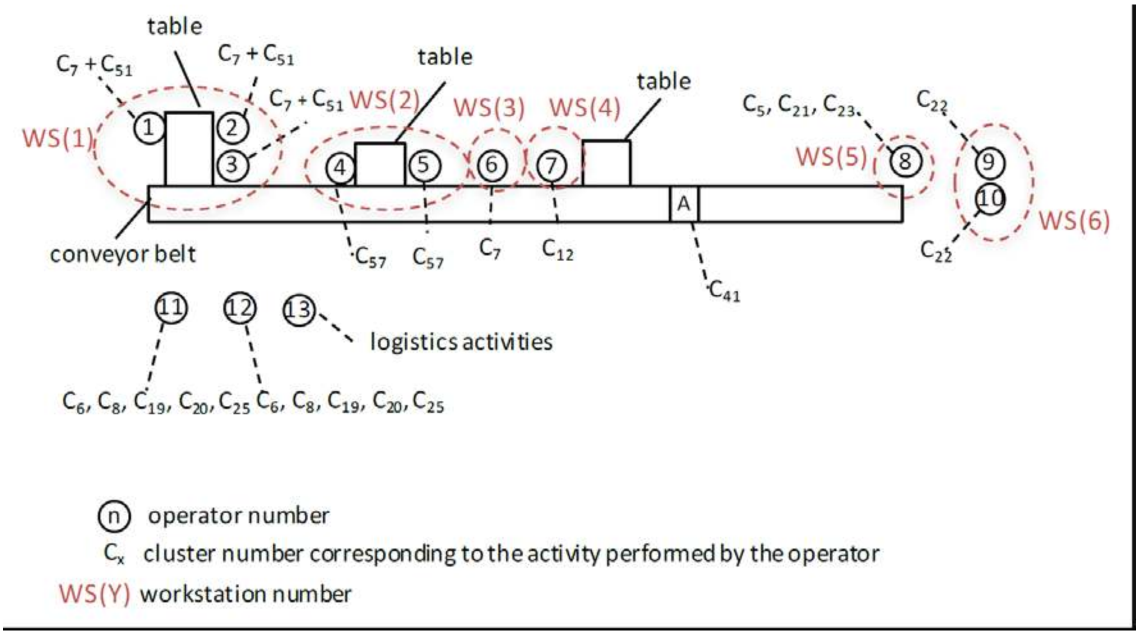


Figure 5

Two operators work in a feeder line to prepare the box base and trays, distant from the assembly line as hot glue is required (C_6, C_8, C_{19}, C_{20}, C_{25}). They start working before the line activities start, making a buffer of box bases and trays (based on the expected total production) to feed the line according to the takt-time. One operator performs line logistics activities, i.e., feeds materials and takes the finished product out of the line area. These three operators work outside the assembly line workstations to support the line activities. Thus, they are not considered when performing the line improvement activities.

Figure 6 shows one of the JES developed in the standardisation phase. In particular, it represents the confectionery activity performed by workstation 1 (bag bend).

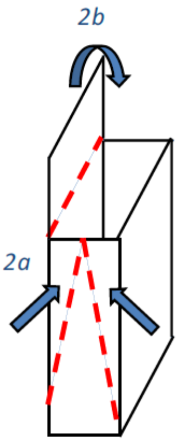
Task: *handbag open and bend*				JES number: *1*
n°	task	how	why	drawing
1	*handbag open*	*gently pressing together the short sides of the handbag with open palms until the shape of the bag is built*	*the gentleness is required by the opening snap*	
2	*handbag bend*	*- fold one short side of the handbag with both thumbs, following the die-cutting, then fold the other side (see drawing 2.a)* *- fold the cover in the die-cutting (see drawing 2.b)*	*to ease the handbag closure after filling it with the chocolate*	

Figure 6

Figure 7 shows the output of the standardisation step drawn on the Yamazumi board. For activities performed by all workstations the content of work is expressed for one chocolate bag, which is easy to compare with the calculated takt-time and easy to see on the Yamazumi board. From the standardisation step emerges the execution of non-value added activities (in Figure 7, coloured red) such as line feeding and work in progress inspection performed before filling the bag with chocolate.

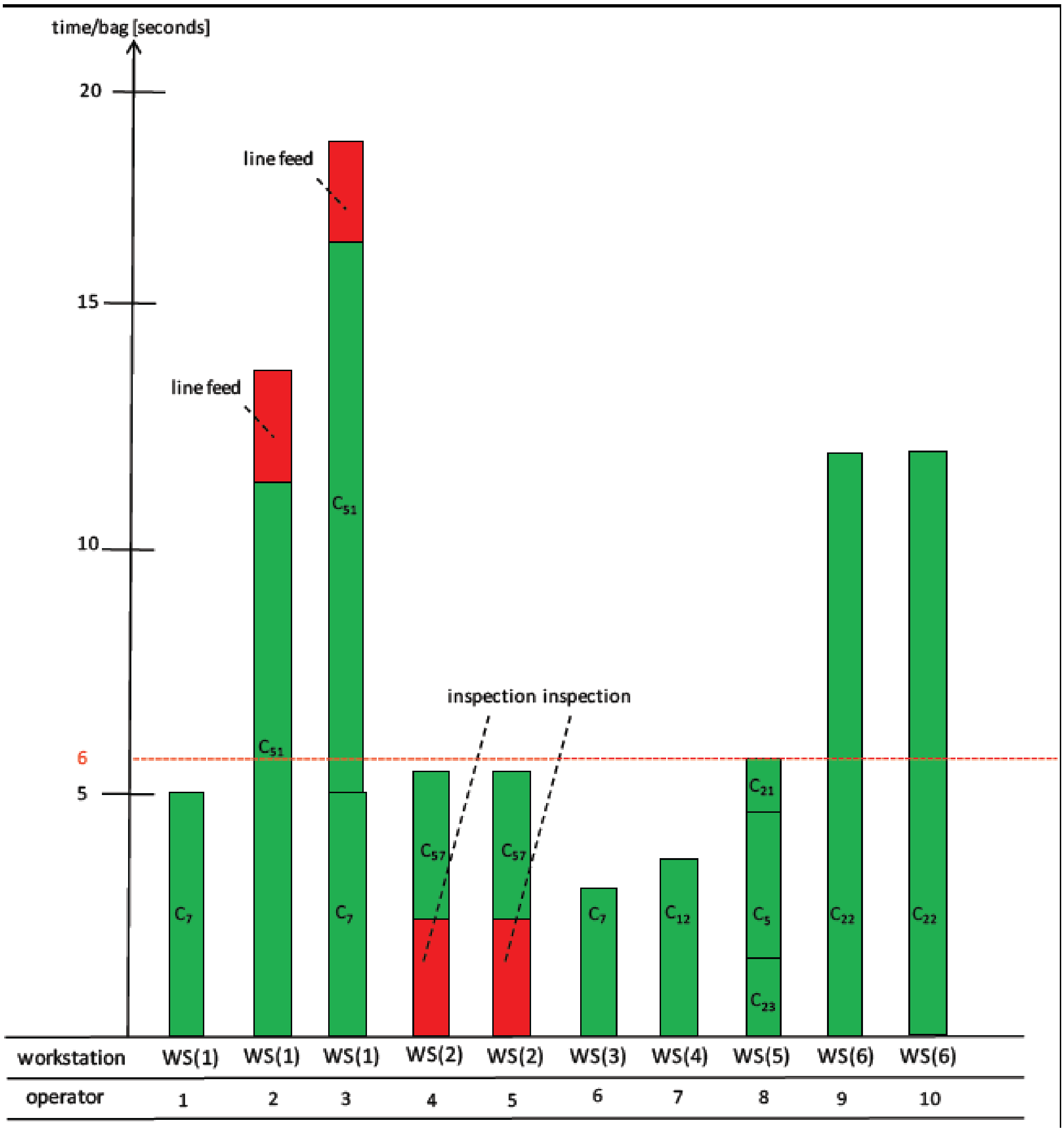


Figure 7

Before the kaizen, workstation (1) involved the work content related to activities related to clusters C_7 and C_{51}, summing up to 17 seconds. Although 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 7) it is apparent that the line feeding task, 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 task out of workstation (1), to ensure the respect of the takt-time by the feeder line, that pass from 19.5 to 17 seconds (the latter can be respected, as 17 seconds/3 workstations < 6 seconds/workstation). For a better performance, the decision is to divide workstation 1 into two new workstations, dedicating one operator to workstation (1.a) (bag open and bend) and two operators to workstation (1.b) (squeeze and fix the handle with the bag) to parallelize their work. Although feeding the line is a non-value added task, 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 for respecting the takt-time. Then, an operator is dedicated to this task as long as an automated solution is available (workstation 1.c). This solution does not increase the number of operators working on the assembly and packing line, as the board shows that the standardised activity of inserting chocolate into the handbag performed at workstation (2), composed of bag control and fill (C57), can be completed within 6 seconds. Then, one operator is sufficient to complete the task without exceeding the takt-time. Regarding workstations (3) and (4), the content of work is comparable with the takt-time, then, one operator for each activity is sufficient to respect the takt-time. With reference to the activities performed in workstation (5), the amount of time required for execution per bag is equal to the calculated takt-time, then one operator can complete them respecting the takt-time. With reference to the final activity needed to wrap one box (C22) in workstation (6), the amount of time required to perform this needs the involvement of two operators (i.e., operators 9 and 10). Figure 8 shows how many workstations are in the line and which activities are assigned to workstations after the balancing step.

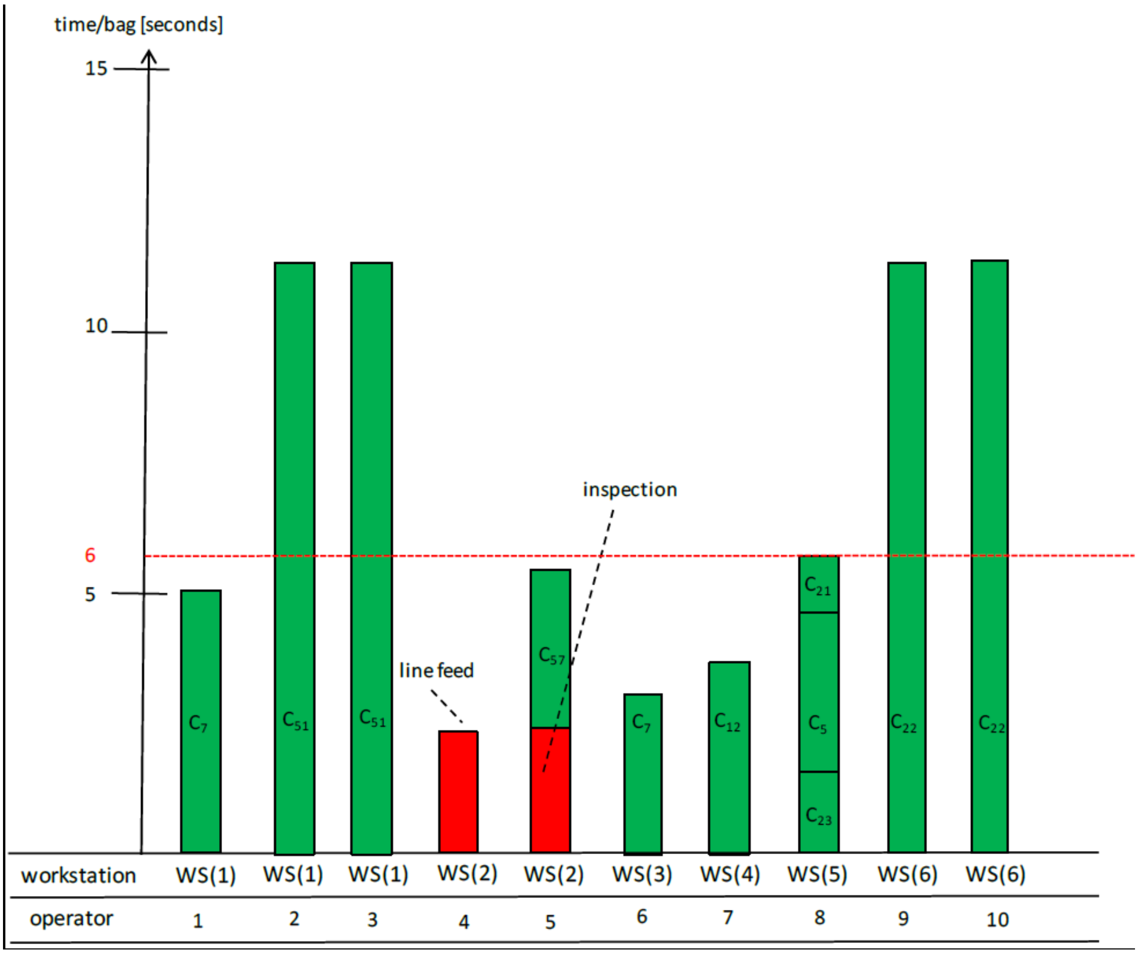


Figure 8

A one-shift test confirms that the line respects the throughput objective. Then, the so-balanced line configuration is maintained until the end of the production campaign, due to the benefits in terms of time and the quality of the performance. As soon as an automated line feeder is available the operator can no longer be dedicated to feeding activities, and the possibility of a new balancing of activities among workstations and the line reorganisation emerges. Due to the simplicity of the improvement activities conducted during a kaizen event, this new balancing could be performed autonomously by the line managers.

5. Discussion and implications

The application to the real case study described in the previous section allowed the researchers to identify the main contributions and implications of the proposed methodology and to compare them with the ones of the alternative traditional approaches.

As outlined in Section 2, the approaches traditionally applied by practitioners in real-life contexts are mainly related to approximate methods and kaizen assembly methods. The approximate methods are defined in the literature as mathematical approaches able to reach feasible results in an adequate amount of time. Nevertheless, when applied to real cases they have proven to be complex and time consuming. Moreover, the approximate methods do not consider the line activities improvement and they are not able to easily support companies in maintaining results over time. Meanwhile, the kaizen assembly methods demonstrated to quickly reach effective results, both tangible (i.e., performance enhancement and assembly activities improvement) and intangible (i.e., ability to sustain the improvements over time). Nevertheless, previous works have provided applications of the kaizen assembly limited to one single product family, overlooking the issue of a variety of assembled end-items to be balanced, which could lead to a reduction of the benefits offered by kaizen assembly. Indeed, kaizen assembly does not handle the complexity of the high variety and high innovation context because it considers each end-item to be independent of the others. This means that specific line balancing activities are required for each end-item included within the company's product portfolio, and new line balancing activities are needed each time a new end-item is launched into the market. Therefore, the total time required to balance the manual assembly lines would be equal, in this case, to the total number of end-items in the product portfolio multiplied by the duration of each assembly line balancing activity. Thus, kaizen assembly alone appears not suitable in high variety and rapidly innovative contexts, such as business to consumer industries.

The new approach is, instead, able to limit the total time needed to perform the line balancing activities thanks to the complexity reduction phase performed before the kaizen events. Due to the clustering, one kaizen event allows the optimisation of the manual assembly line for all the end-items belonging to the same cluster. Thus, the total time required to balance the manual assembly lines is, in this case, equal to the total number of kaizen events (i.e., one for each cluster identified, always lower or equal than the number of end-items) multiplied by the total duration of each kaizen event. Moreover, the clustering process allows the company, when doable, to include the new products launched within already existent clusters. This makes it possible to quickly identify the optimal line configuration for the new products. Therefore, the main contribution of the new method proposed in this study consists in the combination of the clustering reduction together with the kaizen assembly, and its application to a real case study in a high variety and innovation context. The empirical application of the method allowed the researchers to test the new method and shows its effectiveness in a context characterised by complexity.

In addition, the application of the approach to a real case study demonstrated that the tools proposed and applied in work standardisation activities (i.e. JES and SOS) effectively accomplish job element standardisation in the kaizen events, allowing the company to reach not only the optimal line balancing but also the line activities improvement. Moreover, the possibility of involving everyone working on the line, including the line manager, during the kaizen events generates a positive change in the company's culture and makes replicating the activities and maintaining improvements over time possible.

In Table 1 a comparison between results obtained with the traditional methods and the new approach is show.

Table 1. Traditional methods vs. proposed new method: results comparison

Results	**Traditional approximate methods**	**Traditional kaizen assembly method**	**New method: Complexity reduction + kaizen events**
Time to perform ALB for all assembled products	*High*	*Low (for one product, it increases linearly when variety increases)*	*Very low (also in high variety contexts)*
New product introduction lead time	*High*	*Low*	*Very low*
Possibility of assembly activities improvement	*No*	*Yes*	*Yes*

6. Conclusions

The present study contributes to fill the gap between literature and real-life application of ALB methods by proposing a two-phase methodology that can be applied in a high variety context. The methodology supports the reduction of real-life complexity in terms of finished products, materials, and parts variety, helping the application of balancing models, assuring correct line balancing to gain performance improvement, and helping practitioners maintain this performance over time.

To this end, the present work proposes a new clustering methodology based on a tasks and cycle times equivalence, which is part of a complexity reduction phase aimed at defining macro-cycles, i.e., a set of defined tasks to be performed in assembling one or more end-items. Then, a kaizen phase aimed at performance improvement, allows practitioners to autonomously address line balancing, avoiding involvement of optimisation algorithms and the need for external help. Interestingly, the method is also convenient in a highly innovative context because it allows for easily performing ALB for new products: when a new product can be assigned an already existing macro-cycle, the ALB problem for that product has already been solved.

As the methodology addresses a typical industrial issue, it is tested through an application to the Italian plant of a world leader chocolatier and confectionery company that produces a large selection of premium, excellent and innovative products. The application to a real case demonstrates the capability of the proposed methodology to deal with the issue of ALB in a real and complex context, filling the gap found in the literature. Evidence of success is pursued by considering the A/W season boxed chocolate family. With a team of practitioners, the macro-cycles with the greatest performance improvement priority were identified, and kaizen events were successfully conducted. Afterward, the practitioners' team could autonomously apply the two-phases methodology to the spring/summer season boxed chocolate family, demonstrating that the methodology allows practitioners to autonomously sustain the assembly line performance improvement over time. Moreover, a successful application to an actual case demonstrates the positive impact of kaizen concept and LM tools in real contexts.

In addition, the proposed methodology provides two additional advantages. With reference to the 'complexity reduction' phase in particular, the clusters identification allows the exploitation of the output of the standardisation activity performed during the kaizen for all end-items constituted by parts belonging to the same clusters of the ones analysed. Moreover, the proposed methodology also enhances plant performance from a production planning perspective. The macro-cycles definition highlights which end-items require the same tasks and times to be assembled as well as the same line setting. The subsequent assembly of end-items belonging to the same macro-cycle reduces the effort in line setup for the confectionery of the next end-item.

Therefore, this work provides managers with a methodology that they can easily apply to balance assembly lines, without the need to rely on complex mathematical models, and add to the body of literature insights regarding ALB and kaizen assembly, providing the scientific community also with a case study of a real application.

While this research provides several benefits, the present work suffers from limitations which should be addressed in future research. First, the proposed methodology is applied to a unique case study. Future research will need to test the proposed methodology considering a larger number of cases, specifically from a cross sector perspective, to evaluate the performance of the methodology in case of companies dealing with different products (e.g. in size and weight) or involving more and different resources, needed to complete the assembly tasks and/or handling activities. Considering different resources involved in the ALB issue, future research could deal with the application of the proposed approach to assembly lines in which collaborative robots working together with humans are being introduced with the aim to test possible different details in standard work definition.

Second, this work is limited because the data collected and evidence presented deal with one campaign, the A/W, and insights are given about the successful application of the proposed methodology to the spring/summer campaign. Future longitudinal studies could also follow the proposed methodology adoption over campaigns, when new finished products, materials and parts are introduced. The aim is to quantitatively evaluate benefits provided by the ‘complexity reduction’ phase.

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