PRODUCTION LOGISTICS FOR MIXED-MODEL LINES: EMBEDDING MASS CUSTOMIZATION INTO DEMAND FLOW MANUFACTURING

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Abstract: *Production logistics include many aspects of materials management in a production process. Production process in Mass Customization Industries deals with mixed-model production lines, including assembly and fabrication lines. Great amount of various materials need to be organized by abiding economies of scope. Flow manufacturing is used in demand driven supply chain networks and Mass Customization seeks answers to such models. This paper represents effective material handling methods, such as Kanban Systems. Especially, eleven rules for Flow Mixed-model Manufacturing Implementation are described and analyzed on first sight. Appropriate production methods, algorithms and tools are described for Mass Customization Implementation. Designing, estimating, regulating, sequencing and sheculing problems are addressed from Mass Customization point of view. Approaches for solving these problems are also proposed.*

Key Words: ***Mass Customization, Demand Flow Manufacturing, Mixed-model lines, Production logistics***

1. INTRODUCTION

A mixed-model line provides production flexibility by producing several end products during a shift. Several products bring on productivity fluctuations and the solution is to level the production loading. Load Leveling does not use large batches of one product, rather than several products following customer's demand. This necessitates demand-driven production system. If such a system could quickly adjust to the demand differentiation by an economical way, Mass Customization could be achieved. Machines and operators should decrease the setup times less than a single-digit minute in order to achieve Load Leveling in production scheduling. Small setup times signify an efficient production system that manufactures different products in one shift. Every workstation has its own setup times and they usually differ to each other. This craves for a flexible scheduling by conducting production factors such as setup times, cycle times, takt time, resources reallocation, production planning and different logistic sequences with accurate capacity [1]. This work investigates subjects around production logistics that could help into Mass Customization implementation.

We introduce 11 steps that should be completed in order to achieve Mass Customization for Production:

1) Capture demand fluctuations and transform them into load-leveling production.
2) Define Key Value customizable Attributes and check production cost proliferation.
3) Define common components according with the economies of scope and subject the rest under special conditions.
4) Squeeze setup times into single-digit minutes and eliminate non-value adding time.
5) Induct JIT methods and consolidate the exact size of containers (Kanban System) for semi-finished components.
6) Reduce inventory levels of semi-finished products or components (Work-In-Process) and find suitable decoupling points (one decoupling point is more efficient).
7) Build a First In - First Out Supermarket in the decoupling point and flush costs backwards.
8) Reengineer the production scheduling and solve the makespan problem for mixed-model flow line.
9) Connect production sequence with replenishment sequence of materials.
10) Connect production sequence with supply chain sequence.
11) Provide exactly the right amount of end products, at the right time, every day.

2. SET OF PROBLEMS

This is not the perfection of Mass Customization, because perfection conceptually implies one of a kind product for every Takt time. To give an example, if the demand rate is very high, Takt time will be just a few minutes. The production flow line should be able to manufacture and/or assemble one of a kind product in every few minutes. The manufacturing technology that is spread around was based on Mass Production System. Economies of scale are implemented on every workstation, but what about the whole production system and the asynchronous workstations? When productivity in each workstation is high, productivity of the whole production line does not considered to be also high. Economies of scale in asynchronous workstations cannot pay back. How can you build and deliver different products to many customers in such a system?

Kanban Systems are used in Just in Time (JIT), namely that production rate should follow the demand rate. The market expresses the required quantities of a specific daily product mix in decoupling points and production lines. Models that use algorithms in order to formulate the quantities of the Kanban containers, from optimization point of view, assist mostly on theoretical and experimental issues [2].

A logic model was developed in order to link all the production parameters that affect Kanban quantities and sequencing issues of production logistics systems [3]. Constraints of the model express stock-out situations in decoupling points which are used to outcome a daily production sequence of different products. Simulation test examine this model, concerning four parameters that influence the final results, which are Kanban quantities, number of Kanban containers, process time and setup times.

Supply chain systems can easily be expressed by mathematical models. The concept of the mixed-model production batch is analyzed by mathematical optimization procedures. A mixed-integer nonlinear programming (MINLP) problem is set on a supply chain including many assembly plants. Small size MINLP problems are optimally solved by branch and bound (B&B) methods. Moreover, heuristics are developed to decompose real life large size MINLP problems into several small problems. Logistics scheduling and production control issues are solved by Kanban systems [4]. The same problem exists in production logistics, translating assembly plants into production lines or unbalanced workstations of a production line. The accuracy to the real life is the main objective. What if the business policy looks for mixed-model flow manufacturing and not for batch manufacturing?

"Mixed model" production lines are often used in manufacturing systems based on just-in-time techniques (i.e. Kanban and sequenced Kanban Cards [5-14]. In these production lines, different product types are manufactured simultaneously by processing very small batches and sometimes batches are transformed into one single piece.

3. MASS CUSTOMIZATION IN PRODUCTION LOGISTICS

3.1 Capture demand fluctuations and transform them into load-leveling production.

Every industry has its own production rate. This rate depends on market characteristics and a business strategy that industry follows. In such a way, the rate is theoretical. The rate could change from time to time due to unexpected reasons. Production defaults, maintenance absence, abnormal planning - scheduling, forecasting failure, unskilled workers, mixed up logistics, unstable tax system and many other factors. The real-life production is full of fluctuations. Daily declinations on stable productivity targets may exist.

Technical and human nature reasons can be overcome because they are inner-industry problems. On the contrary, outer problems call for solutions which push the exogenous factors to change its business culture. The opposite approach constitutes to adopt and bring the outer environment into the production line, namely inside the shop floor. The fluctuations should be leveled and smoothness on production rate could be established, see below Figure 1.

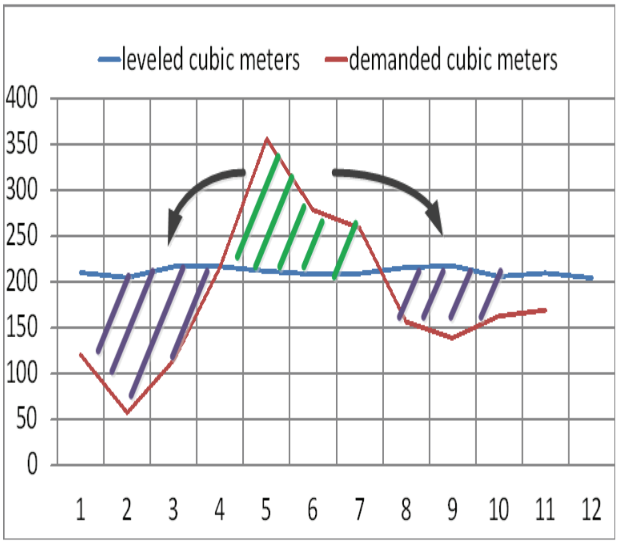

Fig. 1. *Production leveling*

Let's assume that the red line is a normal demand curve and the blue line is a leveled production rate. It is mandatory to level the sales and pursue smoothness for completing orders. The success of this procedure depends on special attributes of each market. If customers are willing to purchase products by a leveled rate, production could be leveled as well. The target is also to redraw the red line as the blue one, namely to level the sales as good as the production rate. By a glimpse, the green sketched area should be moved into the blue sketched area, respectively.

3.2 Define Key Value customizable Attributes (KVAs) and check production cost proliferation.

The attributes of a customized product are critical for the whole value stream. In which degree is the customer involved in product design and production process is determined by how many attributes and how much are they customized [15]. By defining the number of customized attributes, can be specified the number of decoupling points (one or more) in production stream. Decoupling points declare the production operations in which customers are involved and advanced directions need to be given.

These KVAs define also the competencies that are required in order to achieve Mass Customization [16].

Moreover, KVAs are distinguished into five types, concerning dimensional fitting, product's functions, aesthetics, materials' quality and packaging. Customers choose among many options for each KVA. These options are also correlated to each other. Every option may influence the others indirectly.

The economic point of view asks for economies of scope and two main concepts are assigned:

a) The matching of functional requirements to demanded specific attributes for every customer.
b) The sequence of attributes according to importance.

When the number of attributes increases, cost proliferates. As the number and the range of attributes increases, the returns decrease. It is suggested Pareto-type analysis to stall the law of diminishing returns [17].

3.3 Define common components according to economies of scope and subject the rest under special conditions.

Commonality in components derives from feature standardization. Feature standardization refers to standard geometric design that is created by standard machine tools. Machine tools create geometrical characteristics in a specific range of variability. Machine tools must be standard in order to create standard part features. Standard part features create common parts or parts with low diversification to each other. Many factors are correlated to each other for commonality issues.

The commonality reduces material handling cost, enhances product quality, lower setup times, gives flexibility in manufacturing and higher responsiveness to customers. The variety of end products should be produced by common parts and standard processes in order to achieve cost effectiveness [18].

A design approach for Mass Customization (DFMC) was proposed and a Mass Customization oriented Product Family Architecture (PFA) is needed to be built for every industry in order to achieve cost effectiveness [19]. This formulation deals with commonality or reusability clustering methods in product design or process selection from product family perspectives.

This rule refers to designing phase of customized products and highlights the critical point of common parts. The higher commonality degree does exist, the greatest cost effectiveness is achieved. To reduce the parts dispersity in a known market, Pareto-type analysis for design parameters is proposed. For future and unknown situations, approaches such as clustering design parameters are efficient. A hybrid strategy of clustering design parameters and a feedback control or assessment tool for each design parameter on functional requirements is also proposed, see below Figure 2.

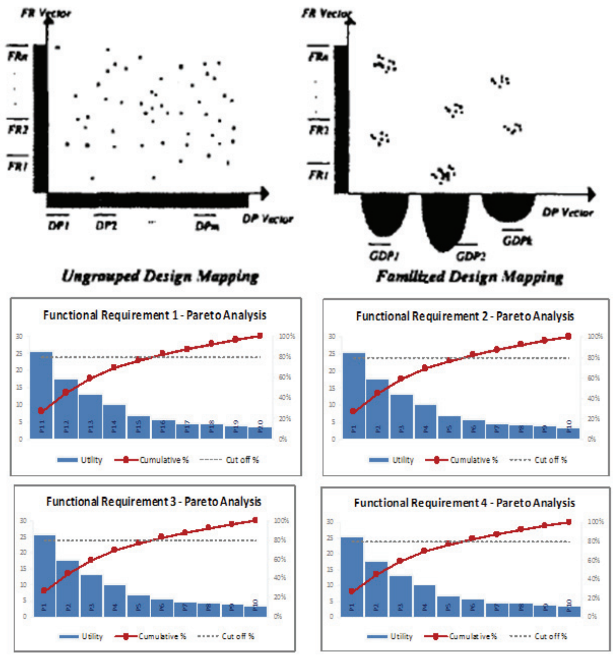

Fig. 2. *Hybrid strategy for parts commonality (clustering product spectrum and Pareto-type analysis (for every Functional Requirement)*

3.4 Squeeze setup times into single-digit minutes and eliminate non-value adding time.

Single Minute Exchange of Die (SMED) is a known method in manufacturing that radically decreases set up times, they should be no more than 10 minutes [20]. In Mixed-Model Production Lines, set up procedures occur many times during a shift, such as die casting or manufacturing systems reprogramming. This creates long downtime and therefore production rate decreases, see below Figure 2. For example, production process stops four times during a shift in order to build four different products. During a setup procedure, production loses potential quantities.

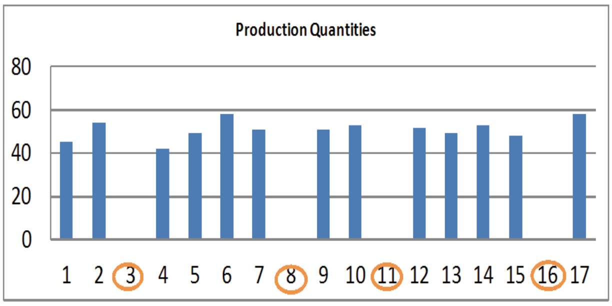

Fig. 3. *Effects of setups in a shift*

SMED is a tool that is used in Total Productive Maintenance (TPM) and is capable to minimize the changeover time.

There are developed 10 advanced steps to achieve SMED, supported by 5S of Lean Manufacturing for real-life cases [21]:

1) Implementation team forming.
2) Training.
3) Survey and screening of the situation prior to the method implementation.

4) Activity classification.
5) Transforming internal into external activities.
6) Improvement, internal activities minimization.
7) External activities improvement.
8) Standardization and forming the SMED procedures.
9) Save quantification of savings reached by SMED.
10) Continuous Improvement Process.

When a setup activity runs in only one workstation of a production line, the successor workstations will be starved, because of the lack of materials. Predefined quantities of semi-finished parts, likewise buffers or Kanban quantities should feed the workstations that are in danger of starving.

3.5 Induct JIT methods and consolidate the exact size of containers (Kanban System) for semi-finished components.

This step refers to calculation of containers that should feed the production line with materials. According with the manufacturing process, suitable amount of quantities could be estimated for a predefined production rate. The amount declares the size of containers for each component. As many customized products are manufactured from the line, even more components are needed to be available according with Bill of Materials (BOM) for each product. In many cases, products are assembled by more than one part and this proliferates the amount of components. Kanban System is based on signals (Kanban means signal) and moving containers. Containers should have a suitable amount of materials that normalize their move. Higher the amount of materials than the expected, less replenishment time for containers. On the other hand, less amount of materials means many replenishment times, see below Figure 4.

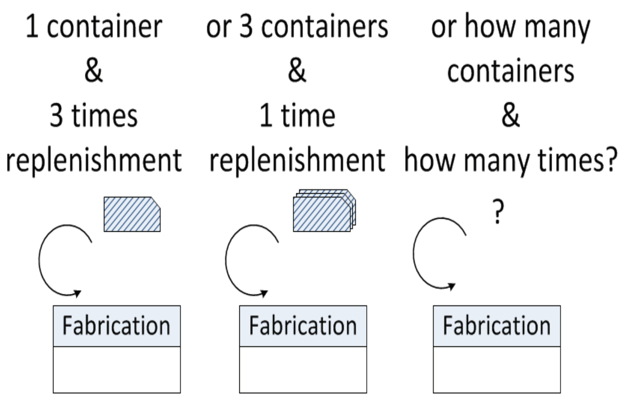

Fig. 4. *Kanban System & replenishment frequency*

Accurate amount of materials is the key to normal flow and cost efficient production system. If the replenishment frequency is high, production rate will need to be also high. Production rate is usually predefined and cannot be higher than its limit. Such a situation may lead to starvation of workstations or even to overproduction. Production rate and materials replenishment frequency should follow the demand rate.

3.6 Reduce inventory levels of semi-finished products or components (Work-In-Process) and find suitable decoupling points (the fewer the better).

This step refers to bottlenecks, buffers and excessive inventory through the flow of production line. The reasons for such cases spread from technical and quality issues of semi-finished products to logistics or business strategy. It differs from the previous step on the stored items. The previous step indicates components and parts handling in contrast with current step that indicates semi-finished products handling. Inventories across the value stream are usually described as FIFO Supermarkets, namely as an excessive but also controlled WIP. FIFO Supermarket feed the successor workstations of a production line and withdraws materials from predecessor workstations, see below Figure 4. Also, there could be more than one FIFO Supermarket in a flow production line, in accordance with each production case.

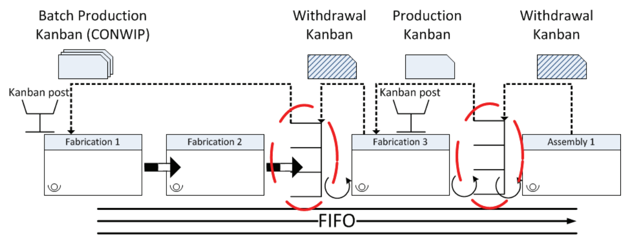

Fig. 5. *Decoupling points as FIFO Supermarket*

The supply process is achieved by Kanban Systems. Predefined containers carry specific quantity of materials. As the previous step, size of all containers should follow the production rate in efficient replenishment frequency. Kanban Cards hanging on Kanban posts where they wait for transportation. Scheduling algorithms for solving pull sequence of the cards can be implemented, during waiting time on Kanban posts. Each card constitutes specific quantity of materials and also specific number of containers that carrying these materials.

The challenge is to reduce the inventory levels by reducing the number or the size of containers. This will give a boost to production by shortening the lead time and also the production cost.

3.7 Build a First In - First Out (FIFO) Supermarket in decoupling points and flush costs backwards.

The term of Supermarket is used in Lean-Flow Manufacturing and connotes frequent replenishments of containers by Kanban Signals. Containers are moved from Supermarket to processes and backwards with Kanban Cards. A usual sequence is the first container it comes, the first should leave. By Kanban system in a FIFO Supermarket with predefined containers gives a real time inventory costing. This refers to backflush costing or backflush accounting. This approach of product costing is used mostly in Just In Time (JIT) production systems. The most significant attribute is that value of materials is issued on accounting system by its consuming time. It is an automatic and real time method to conduct material and product costing. Only when an end product is assembled or ready for sale, the consumed materials are issued for costing. By this way, a faster method of cost calculation assists on end product value estimation at the right time. Also, it gives real time numbers from the whole logistic system, suitable for inventory costing.

3.8 Reengineer the production scheduling and solve the makespan problem for mixed-model flow line.

This rule refers to sequential jobs that should be done in a predefined duration, likewise in a shift of 8 hours. In Lean Production, the tool that defines the program planning is named Heijunka. This is a planning board that declares what task to do and when, concerning tasks duration, resources availability and other factors. Time and cost minimization is the key solution for every, sequencing and scheduling problem, but also the business strategy plays a key role [22]. For example, it could be more essential to keep specific costs in higher levels, because of quality reasons.

Scheduling algorithms that continuously calculate optimized solutions concerning setup times, production rate, cost efficiency, delivery time and Kanban quantities run in every *production round* (every *production round* finishes by every changeover in order to produce a different product in the same line). A good time for this is when Kanban posts are above the semi-filled level.

The makespan problem gives scheduling solutions for Kanban Cards that are dedicated to specific materials and semi-finished products. The solutions are usually come from objective functions that deal with tasks' constraints, machines' constraints, sequence relationship, etc. Makespan is the total time for accomplishing a series of tasks by minimizing the total time duration. Job shop scheduling, Bin packaging problem, Genetic algorithm scheduling, Economic Lot Scheduling, Economic production quantity, Modified due date scheduling heuristic and Shifting bottleneck heuristic are some of the most common scheduling algorithms in production logistics that contribute to makespan problem solving.

3.9 Connect production sequence with replenishment sequence of materials.

A radical algorithm for material sequencing is Evolutionary Production Sequencer (EPS) that was compared with two other known algorithms. The sequencer gives solutions, rapidly and efficiently, to sequencing problems for Mixed-Model Assembly Lines. In a previous work, one-card Kanban System with EPS, as pull sequence algorithm is simulated and assessed positively [23]. There are also many metrics that assess the smoothness of a sequence algorithm. An integrated procedure using these metrics can be followed in order to come up with a total scorecard assessment by comparing different sequence algorithms. The most suitable algorithm for providing the smoothest or in general, the best sequence could be revealed by such an assessment procedure [24].

By the first rule, daily demand rate is calculated. By the eighth rule, production sequence is formed by Kanban posts and Kanban Cards of semi-finished products that are located in FIFO Supermarkets. In this rule, Kanban Cards are dedicated to specified containers that include materials or spare parts that could be handled by Kanban System, see below Figure 5.

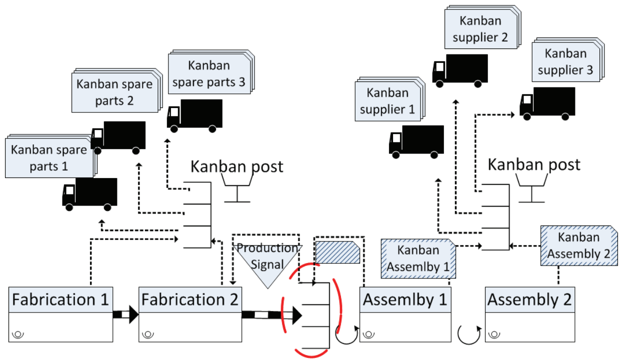

Fig. 6. *Kanban System for materials and spare parts handling*

Containers that are depleted in production line are replaced by full containers with the same material. The full containers come from FIFO Supermarkets. The empty containers in FIFO Supermarkets are replaced by full containers from suppliers. The whole system is conducted by Kanban Cards. Single Cards are replaced immediately and Batch Cards are replaced after sequence planning.

3.10 Connect the production sequence with the supply chain sequence.

Mixed Model lines produce many different products for different customers that are located in different places. Every transportation vehicle should carry mixed model cargo that should be delivered in different places to different customers. As an example, we assume a cargo of 20 pieces. The 17 of them are different to each other and they will be delivered to 10 different customers in 5 different locations.

The mixed cargo and its quantities came from the mixed demand that came from a mixed model production and a mixed model replenishment sequence of materials. The market defines the customization degree of a cargo and its mixture.

Moreover, the sequence of production, as well for replenishment of materials and supply chain is the same with the demand sequence. The sequence of demand should synchronize all the other sequences of production, material replenishment and the whole supply chain in a Mixed Model Production Line [25]. Attributes of costing for sequence forming are also significant.

The algorithm for makespan problem should concern also the mixture of market, the due dates, the cost factors of customization and the production pace.

3.11 Provide exactly the right amount of end products, at the right time, every day.

The demand is adapted to production process by the Takt time. Takt time is the time needed to complete work in each workstation, by following the daily mixed demand rate. It is the time span during the last workstation should complete its work for building a product. This implies that a product is finished every

Takt time. Because of this, the last workstation is the pacemaker of the production line. The real Takt time should be smaller than the calculated Takt time in order to overcome unexpected daily pitfalls and to satisfy unexpected daily fluctuations in demand and customization process. The same pace is followed by materials replenishment and supply chain frequency. One sequence with one pace for all can produce and deliver customized products at the right time, in the right quantity, see below Figure 6.

The upper left area with orange margins displays Kanban Cards sequence for raw materials replenishment. The upper right area with blue margins displays Kanban Cards sequence for materials replenishment and the supply chain. The lower area in green margins displays a production line with one FIFO Supermarket in a red dashed eclipse. The same method could also be established for spare parts replenishment. Kanban posts gather Kanban Cards in batches and scheduling algorithms for the sequence, providing solutions for supply chain planning.

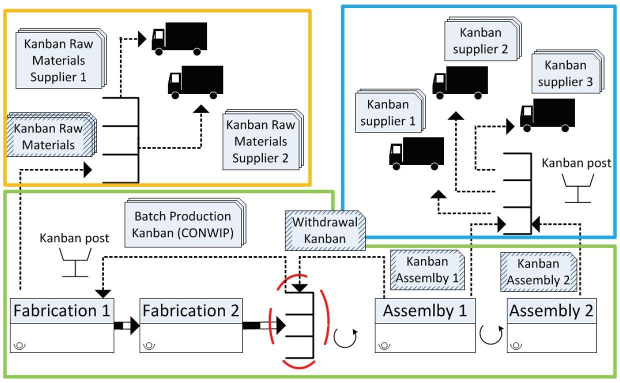

Fig. 7. *One pace and the same sequence for every factor of production*

A continuous flow production of customized products can be faster or slower in order to deliver goods at the right time. The pace of the flow is defined by Takt time. High Takt time gives small pace and small Takt time gives high pace. When production is overloaded, Takt time should become smaller in order to become faster.

Rebalancing of production line and sometimes reallocation of resources is needed. Many algorithms for this purpose were developed for Mixed-Model Production Lines. The same situation has effect on customization process. Rebalancing of designing phase and reallocation of designing resources are also needed. This is called leveling or balancing the design process.

4. CONCLUSION

Every system has its own limits, such as limits of production logistics, setup time, lead time, Kanban quantities, production sequence and replenishment turns.

Batch manufacturing for mass production is analyzed by mathematical algorithmic optimization procedures. The flow manufacturing in a mixed-model production line needs further fathoming.

This paper tries to explain the situation of production logistics in Mass Customization industries. Industrial environment consists of many interconnected factors. All the steps that are described above, deal with these industrial factors. Each step is described and their connections to production logistics are highlighted in this work.

Accuracy in logistics is inevitable. Not only production rates and replenishment frequencies should be accurate, but also the amount of materials and semi-finished products should be estimated.

The rules of eleven are challenges for production lines and not only actions that should be taken in a production case. The term “steps” instead of “rules” could also be used, but in some industries the aforementioned sequence of rules could change and the “step” could be collapsed. Known methods to reach the desired targets are briefly described. They should be tested and assessed by real-life cases, including fabrication and assembly processes as well. Any related future work could propose updated methods of Production Logistics in a Mass Customization Implementation procedure. It is also necessary for real-life case studies to implement and assess other relevant implementation methods. The comparison between the eleven steps and other relevant techniques will be crucial for the future.

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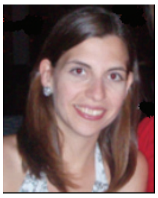

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