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COLLABORATIVE NETWORKED ENTERPRISES: A PILOT CASE IN THE FOOTWEAR VALUE CHAIN

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Present paper describes major RTD challenges and key technologies in order to respond to the demand for consumer oriented highly flexible and networked production systems. Shoe manufacturing is considered as a pilot sector, and a factory for the production of highly customized footwear is discussed as an example of agile and balanced production system, capable of integrating and cooperating with various actors of the footwear value chain.

1. INTRODUCTION

Nowadays, manufacturing industry is facing frequent and unpredictable market changes, respectively imposed by consumer needs and expectations on one side, and by competition enlarged at global scale on the other.

In particular there is an increasing consumers' demand for products with high technological contents, capable of addressing improved quality of life at all levels. Furthermore, requested manufacturing products shall more and more be highly personalized, endowed with comfort and /or fashion contents, new functionalities, healthy for humans and sustainable for the environment.

Therefore, at production level, a new approach is needed to meet such perspective, based on new balanced manufacturing systems and on cooperative enterprises, capable of following the rapid market dynamics as well as the continuously changing consumers' attitudes and expectations.

2. THE FOOTWEAR VALUE CHAIN

2.1. The footwear sector

Footwear sector represents one of the traditional pillars of the "Made in Europe" as well as one of the most important sectors of European manufacturing.

Today, market trends tell about an exigent consumer, who is more and more searching for novelties, for stylish products and for technologies: footwear market is definitively requiring more and higher value added products on demand, in terms of comfort, health and sustainability.

However, when considering the shoe manufacturing sector, the scenario appears extremely fragmented and rigid, not capable to fully respond to market challenges.

Footwear value chain is constituted by many specialized knowledge intensive, as well as low technology based SMEs. Each phase of the shoe production is deeply characterized by traditional approaches, often human centered, with different and opposite management policies along the footwear value chain, always oriented to batch quantities and local maximization (Pillar et al., 2003).

As already happening for other sectors, the Footwear sector is living a crucial season in the increasingly complex economic environment: new frontiers of competitiveness are being faced, in a global scenario where east and far east competitors benefit from incomparable advantages in terms of volumes and labor costs.

A huge effort is therefore necessary: major introduction of information technology and automation on one side, and integration among different actors and technologies in a network of real time collaborating enterprises on the other, are some key factors to be achieved to respond to daily challenges, and to face the global competition.

2.2. Footwear value chain actors

As mentioned before, the footwear value chain is characterized by a strong fragmentation: shoe as product is composed by an average of 20 among parts and components, different as for materials and production processes, provided by various independent actors.

Shoes are designed and manufactured along a complex process which:

- involves stylists and modelers on product design;
- has articulated interactions, at material supply chain level, with last makers, tanneries, leather and synthetic material suppliers, components suppliers (e.g. soles, which by themselves recall for several operations, suppliers and dedicated supply chain)
- is mostly based on external third party services suppliers at manufacturing level (i.e. component cutting, piece stitching, shoe assembling and product finishing before commercialization).

A general low technological level characterizes the whole production process as well as the interactions from suppliers to producers, to network distribution, up to retailers.

3. MAJOR CRITICAL ISSUES AND NEEDS

Today, the footwear sector is characterized by many specialized and low technology based SMEs. Automation level in production systems and equipment is low: basically, more than 60% of the operations and therefore of products added value is human centered. As a general remark, the production process – constituted by three main phases: cutting, stitching and assembling– is often hardly automated. All the steps involve an operator, either assisting the machine, as it happens in cutting and in some assembling operations, or directly performing the job manually, as in the stitching phase.

It can be easily understood how present human based approach negatively impacts in terms of costs on global scale competition with Far East countries, with huge low cost work force, causing phenomena like delocalization of some or of the whole production process.

Furthermore, another major critical issue can be identified in the inertia between the fast changing consumer and retailer demand and the slow responding manufacturing chain: today the time horizon for fully responding to a new market demand recalls for 2/3 months. Consumers' requests and retailers are not involved in the "real time" loop, and distribution network prove to be slow and ineffective.

In product realization, most enterprises are based by 2D design technology and related production process, which characterize as old fashioned, proprietary and closed solutions. At conception level, there is a lack of digital tools capable of integrated product design: today actors cooperating along process use different - neither integrated nor interoperable - design environments, and often base their interactions on "trial and sample" approaches. Major lacks can be registered at product information and order management levels: there is no real integration at supply chain level. Platforms necessary for traditional SME producers and retailers to catch up, do not yet exist: only legacy solutions represent state of the art, barely able to interact, if at all.

Business processes between manufacturers and their material suppliers, as well as processes between manufacturers and retailers (and consumers) are today not effectively – or at all - addressed. Lack of global standards, deeply developed and widely accepted, nowadays also represents a main issue.

In fact, standardization process in footwear sector is running slowly, both on information and on production data flows: knowledge is difficult to structure and integrate, in a global scenario where growing delocalization implies loosing the manufacturing knowledge.

4. MAJOR RTD CHALLENGES AND KEY TECHNOLOGIES

In such a situation, the conception, design and realization of production systems capable to produce always changing high value added shoe products, needs a new generation of manufacturing technologies at all factory levels, in order to build a network of cooperating enterprises, based on new balanced production and automation systems.

To achieve an agile production of consumer oriented high value added footwear, all the phases of the process must be reconceived and automated, to enhance local and global flexibility and cooperation among enterprises, based on synergies and integration along the steps of the value chain, and exploiting a manufacturing approach based on balanced production systems.

The whole path between purchase and start of production of - small batches of - shoes shall be reduced to a minimum: the revision paradigm recalls for complete integration from direct consumer ordering via web interactive services, to flexible and dynamically changing organization schemas, up to real time response in production. Point of sales, design, Enterprise Resource Planning (ERP) and Product Data Management (PDM) environments, as well as production plants shall be highly integrated, so that both the dispatching of orders and the feedback from production can be nearly immediate.

In such a direction, major RTD challenges to be faced deal with:

- *Integration of customers and retailers in the real time loop*: new dedicated concepts shall be developed respectively addressing new co-design and vending solutions.
- *Development of innovative internet and ICT based real time distribution networks*.
- *Integration of SMEs knowledge into new technologies* and improvement of their competitiveness.
- *Development of innovative open design and production solutions* based on emerging technologies.
- Development of *standards for products and processes*, to structure knowledge and integrate actors along the value chain

Specifically, in order to realize the proposed paradigm, the following key technologies are necessary:

- new *ERP-PDM tools* capable of managing minimum batch production orders up to a single sample order, so promptly responding to request for lower quantities;
- new solutions, cooperating with ERP-PDM tools, to create a *unique real time internet based network integrating manufacturers, vendors and suppliers*;
- new *planning and Manufacturing Execution System (MES) solutions* capable of scheduling and managing inbound logistics and production life cycle according to small batch production orders;
- new *3D integrated CAD-CAM software instruments* capable of rapidly and automatically adapting products designs to always changing consumers needs;
- new *shop-floor supervision and automation technologies* that implement highly agile, reconfigurable and balanced production lines;
- new *flexible operating machines and controls* capable of self-adapting their working cycles to a high variety of new different products designs.

5. ITIA-CNR RTDI FACTORY FOR PERSONALISED SHOE PRODUCTION

Proposed technologies, as well as related methodologies and tools, were developed and are currently being used in the innovative RTDI factory for the production of personalized shoes at ITIA-CNR premises in Vigevano (IT).

Such factory represents, as Manufuture best practice (Manufuture, 2005), an example of flexible paradigm in the conception, engineering and networked production of consumer oriented customized shoes (figure 1).

5.1 Consumer integration and flexibility in product order

In the factory context, consumer's integration is realized through dedicated facilities and foot measurement technologies. Consumers can directly order a personalized pair of shoes in a specifically developed Point of Sale (POS), by choosing among a variety of models, colors, materials. Order information is completed by consumer's feet geometrical data, which are computed by means of scanning devices (Carpanzano, 2006), (Chiodi et al., 2006), (Mass Customized Shoe Design and Manufacture, 2004).

As an immediate consequence, and in contrast with the mass production paradigm, production orders reflect the heterogeneity and unpredictability of customer orders: each one is unitary and different from the previous one (different models, geometries, materials, and sequences of operations).

Such heterogeneity has been managed by specifically developed tools, capable of dynamically adapting data structures to the various specific requests and by innovative production lines and manufacturing cells, capable of flexibly adapting and re-configuring.

Figure 1. RTDI factory for personalized shoes production

Figure 2 shows the overall structure of the information, coordination and production systems conceived to manage mass customized shoe production.

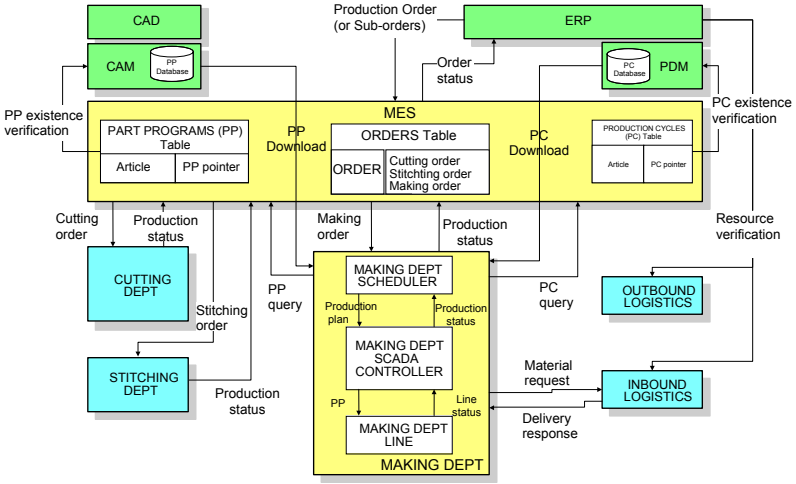

Figure 2. RTDI factory: information, coordination and production systems.

At design-time, each consumer order is processed and CAD module semi-automatically generates specific CAD data, stored into the PDM repository. To such an aim, "quick adaptation functions" were deployed in the 3D CAD system, to achieve a unique last-shoe design by merging specific model style requirements, as well as morphology of the consumer's foot and biomechanical requirements. The output of this phase is a complete "project" of the shoe and of all its components: CAM module processes such data and generates part programs plus useful information intended for various machines at plant level.

At order-time, the ERP module (among other functions) processes new Consumer Orders, collected via Internet, and generates Production Orders. After factory job scheduling (limited to departmental level), it makes Work Orders visible to the Supply Chain Management (SCM) and the MES modules, classified by productive phase or by resource. The MES module dispatches order information and technical data to each department subsystem, through SOAP message or via interactive web services, also informing the Logistics system about the overall job routing.

At conceptual level, a new order management and dispatching philosophy is prosecuted, to orientate heterogeneous processes towards common shared concepts, while, at deployment level, an introduction and harmonization of communication protocols and data-formats was realized towards a major interoperability and interchange-ability of systems cooperating in the same production chain.

Therefore, factory ERP and PDM management architectures flexibly handle concepts like models, measures, customer and production orders, operation, etc. in a commonly defined way, to underpin the network of weaved information. This ensures linear and efficient retrieval and dispatching of useful data, during order processing.

At shop-floor level, department supervisors schedule locally their operation, respecting factory job scheduling, then process the orders. Cutting, Making and external Suppliers mainly work adopting a controlled "pull" approach. This better compensates the difficulties of overall scheduling at company level, due to the uncertainty factors introduced by promoting heterogeneous and unitary orders. Stitching is actually dispatched through the overall Logistic system.

At production-time, each subsystem at plant level sends feedbacks to the MES module, which in turn informs the ERP. The SCM module collects similar information from the suppliers via an interactive web interface. Updated information is made visible to all the Intranet modules: MES, SCM (to drive job progress) and POS (to inform the Sales assistant and, possibly, the Consumer).

Such a “digital” approach allowed the integration and the cooperation of modelers and manufacturers with material and components suppliers on the challenging task of the customized shoe, where each geometry and therefore component shall be changed and undergo the whole engineering process each time.

A network of collaborative enterprises has been set up around the RTDI factory, encompassing a variety among last makers, material, components and sole suppliers, up to footwear producers, capable of “real time” interaction. Such mechanism was made possible through the realization of the SCM module, based on web and XML oriented approaches. Such SCM module offers to each external supplier a convenient interface to consult specialized views of their job-list, and possibly download the order-specific CAM technical data, to choose work orders to process, and to give a feedback about their progress.

5.2. Agile solutions for balanced production systems

As a fundamental premise, in order to fully understand the impact of customization on shoe production, the following considerations shall be made on main phases of the process:

- cutting shoe pieces: main driver of this phase is represented by material and its maximization. Materials must be optimized by nesting the pieces with the best layout, depending on the nature of the material, natural (leather) or synthetic. This heavily contrasts with the heterogeneous mix of unitary orders launched in production (material/colors combinations with always changing geometries), causing a huge complexity to manage;
- stitching shoe pieces: all the components building the upper (i.e. the shoe without the sole) are stitched together, according to a predefined sequence of operations specific to each shoe model. The nature of these operations deeply involves the human factor, so reducing the advantages of introducing automation in operations themselves;

- shoe assembling: main driver of this phase is the shoe construction type, meaning the specific sequence of operations (namely 20) to be executed in order to assemble the final product, involving the last, the upper, the sole and other components. Today assembly lines are specifically conceived and balanced on a reduced set of products (often one construction type), to be iteratively manufactured in series, using all sizes;
- internal logistics: today such phase consists of trolleys, containing and moving production batches of the same item. Such an approach contrasts with the complexity introduced by small – up to single – production lots.

In order to effectively integrate value chain actors at manufacturing level, so maximizing the advantages of the real time cooperation, new automation solutions for balanced and agile production were deployed along all process steps.

At planning level, a two hierarchical level scheduling architecture was conceived: finite capacity scheduling functionalities were developed, through the interaction between high level scheduler, responsible for the factory planning, and shop-floor schedulers, responsible for the production within each phase. Such an approach allowed the creation of mechanisms for dynamic response and re-organization of production, capable to cope with new incoming orders.

Advanced nesting and cutting solutions were developed, integrating current cutting technologies with computer aided functionalities as for automatic building of cutting sessions with always changing pieces geometries derived from 3D CAD. Furthermore, devices for automatic pieces detection and collection were deployed. Such an approach enabled to hold the traditional approach oriented to material maximization, by managing the complexity of heterogeneous production orders cut in parallel.

At shop-floor level, a flexible and agile assembly system has been deployed and currently is devoted to the simultaneous production of personalized and completely different shoe models. In the perspective of heterogeneous one pair orders, continuously and unpredictably changing, "new" objects to be produced should be sent in production without stopping the process to change parameters, setup up machines, etc.

To satisfy this goal, the assembly system is based on an innovative, modular and scalable control architecture, integrates flexible operating machines and controls able to manage and, if necessary, to re-configure to maximize the production of heterogeneous products. Each shoe is pushed along the line from a work-post to the next, following the shorter route and respecting the specific operation cycle defined for each model, independently from other concurrent orders. The result is a system where orders, completely different in terms of model to be produced, sizes, fit and components, must coexist and be produced in the most efficient way. Along the system, shoes undergo various operations performed by machines and robotic cells which continuously self-adapt to the specific CAD geometries and CAM parameters of the worked piece, by interacting with control supervising systems.

Transversal to the aforementioned phases, the automated logistic system plays a crucial role in integration of both production phases and external suppliers. Core element of the system is a tagged box, i.e. the container of shoe pair. The main goal of the internal logistic system is to avoid any rigid sequence of box dispatching in the workflow by collecting and delivering "in time" required objects.

To cope with this objective, internal logistics is handled through an aerial system: an automatic box warehouse, connected to four I/O towers (cutting, stitching, assembly and suppliers), is responsible for serving all internal departments, keeping the 'association' between production boxes and related production order, which is hence traceable during the whole process. The various components are collected in the box as they became

available (from suppliers or from warehouse) and the box is then automatically moved along the various phases.

5.3. Validation of the overall system

Design and implementation of the RTDI factory were carried out in EUROShoE project (EUROShoE, 2004), within European Commission Vth Framework Programme. The RTDI factory as well as its network of cooperating suppliers, were proved in an extensive validation campaign (based on acquisition of nearly 2000 customers), during which consumers experienced the whole process, from product ordering till delivery of final customized goods.

Major elements emerging from validation are related to both conceptual and deployment levels.

At order management level, product data definition as well as a common language to identify items and to append structured data represented a crucial aspect to be solved. Though basic in the footwear sector, concepts like models, seen as family of products, articles and color/style variants are different among shoe companies: such difference implies the possibility to structure product features and related technical data in several ways, strongly conditioning the integration of internal and external actors. To deal with such heterogeneity of involved systems, the PDM solution was developed on various existent tools, integrating them by means of the Intranet and by a controlled use of the file system. A more centralized approach would have imposed some duplication of data, plus limitation in the full and coherent exploitation of each specialized tool: some of them in fact rely on their own internal database and/or directory structure. ERP logical architecture was used as a skeleton for the PDM data organization: concepts like models, variants, production orders, phases, operation, etc. were commonly defined to underpin the network of weaved information, inside the factory and with networked suppliers. This strategy ensures a linear and efficient retrieval and dispatching of useful data.

At Supply Chain Management level, traditional approach to production, based on big quantities, and materials managed by stock, could not be applied, in particular with components having geometry dependent on consumer measures, like lasts, insoles and leather soles. Furthermore, most suppliers in the shoemaking industry are small enterprises, with a poor IT equipment and low capability of adapting from big production lots to 'on demand' little orders. The Intranet SCM module helped to mitigate this burden, offering to each supplier a convenient interface to consult their job-list, and possibly download the order-specific CAM data. Some promising cooperative mechanisms have been implemented, to split the component production in sub-steps, loading the RTDI factory with the more variable 'on demand' tasks (e.g. cutting variable geometry pieces) and leaving to the supplier only the specialized manufacturing (e.g. molding the component). This working method has given good results, helping in both the production of unitary orders and in the testing activity at design-time.

At production management level, the high level scheduler provided factory planning of departmental and of external production phases, respecting sequences and production constraints. Web oriented mechanisms were deployed for production order phase advancement, giving the possibility to monitor and to update the order situation remotely.

A decoupled approach was followed, leaving to each department scheduler the task of internal production planning. This approach helped in reducing the overall complexity, so avoiding a more strict interaction between two scheduling levels, and proved effective in managing minor changes in the planning and/or in the customer order.

Besides this, "pull" mechanisms, enabling each department to ask for specific available orders, were introduced in practice, in order to correct some production dynamics, and to optimize performance of some phases, e.g. cutting.

Considering performance of the RTDI factory and its network of suppliers, production rate was calibrated in order to launch orders twice a day. Maximum reached production was in terms of hundreds pairs a day: such a limit was not stressed over some extent, due to project conditions. The overall production process requires a variable time, from a few hours to some days, depending on various factors, as: the need of custom-made specific phases, the need to involve external suppliers, the complexity of the model.

5. CONCLUSIONS

Nowadays rapid dynamics of market demand in the footwear sector, characterized by consumer growing requirements and expectations, as well as by strong industrial competition, claim for new production strategies, encompassing the whole value chain.

The complexity and fragmentation of the shoe manufacturing sector was discussed in present paper, identifying major deficiencies of a technology poor and strongly human centered sector. Major RTD challenges and key technologies for the footwear sector address in particular the integration of customers and retailers in the real time loop, the introduction of IT and automation based solutions, capable of conjugating SMEs knowledge patrimony with new technologies, and integration among different value chain actors.

Network of cooperative enterprises, capable to exploit new organization schemas, as well as agile and balanced production systems, represent a concrete solution to place competition context on value added products rather than on cost.

The RTDI factory for personalized shoe production was presented and discussed as paradigmatic case. The business model of shoe customization imposed a significant definition of the whole manufacturing lifecycle, involving the creation of innovative production tools and the design of proper IT infrastructure

The path for consumer integration was explored through new measuring and design solutions: as a consequence, the whole product design, management and production processes were completely revised. Production planning and job dispatching represented a critical aspect of the architecture, because such functionalities had to cope with the unusual mix of heterogeneous orders and the quickness required to react.

Resulting experience testifies the suitability of internet and ICT based tools in real time integration of value chain actors, as well as the possibility of developing open design and production solutions through emerging technologies (e.g. 3D CAD-CAM and adaptive factories).

Considering the cooperation along the supply chain, the RTDI factory with its networked enterprises supports new collaborative innovation experiences on both products and processes.

Nevertheless, in order to further improve footwear sector competitiveness and networking along the value chain, major efforts are mandatory in the future particularly in the development of standards for products and processes, which are today not existing at all, as well as in the structuring of sector knowledge.

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