Computer simulation aids for the intelligent manufacture of quality clothing

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Abstract

The exploitation of “intelligent” factory set-ups could enhance the competitiveness of the EU textile and clothing industries, by enabling collaborative design-and-manufacture options, while achieving economies of scope with effective exploitation of (strategic/tactical/execution) flexibility. Simulation turns to be reference aid for developing and acknowledging the appropriate set-ups and the adaptive-schedules. The investigation, besides of reference concepts, summarises a case example, for explanatory purpose. Combined-mode schedules are considered, showing the benefits for prompt returns and leaving open middle/long horizons issues, still with quantitative checks on alternatives provided by virtual reality tests.

Keywords: Garments production automation; Adaptive-schedules manufacturing; Computer simulation

1. Introduction

The EU industrial manufacturing is heavily involved by the challenge of preserving the quality-of-life, creating jobs and resources for the benefit of value-generating businesses with compatibility of product/process environment impact. With aim at shrewdly administrating existing European industry staples, the upgrading of traditional manufacture, such as textile and apparel, need be emphasised, looking after methods and contrivances which might rise their effectiveness [1–5,32–34].

The paper considers the goal and explores ‘intelligent factory’ issues given by integrated information and collaborative design-and-manufacture. These actions should not simply be related to ‘factory automation’, as the achievements which might possibly ensue are mainly obtained by carefully merging the information flow into the material flow in such a way that the two affect each other when external inputs (commands or disturbances) apply. Shop automation, in fact, presents more problems in clothing manufacturing than in many other industrial areas, because of:

- the comparatively straightforward processing technology, not requiring highly complex/dangerous tasks;
- the wide range of skills used for the work-cycles, based on combined (rather than elemental) jobs;
the large resort to craft and training of expert operators to face non-standard actions;
the limp behaviour of fabrics and the wide range of materials used during processing;
the need of creating 3D shapes by the adaptive warping 2D pieces; etc.

On the other side, intelligent set-ups put forward knowledge-based options, which, when enabled, are a radical bend, as for the existing trend, since they are only seldom concerned by the dexterity, efficiency, flexibility and versatility figures of full automation, rather always possess broad capabilities (at least, comparable, as commitment and pace, with human adaptivity) for equipment setting and resetting and schedule updating and adapting in view of market requests [6–8].

Changes, in any case, need to be investigated in terms of expected returns. The European clothing industry, indeed, is required to accomplish a real revolution to win back world-wide competitiveness. High-standing apparel business, as first instance, is challenging area; items are sold with high added-value, turned out by consumers’ satisfaction and sale policies have to deal with [9–13,5,14–16]:

- fast changing fashions and exacting advertising/trades surroundings,
- quick evolving supporting technologies in the design/development steps,

as market saturation ought be faced by means of offers having, compared to competitors, value/price ratios winning buyer’s praise. Thus, looking after quality reliability and fashion inventiveness, manufacturers have to characterise by wit and knowledge driven settings at the devising steps, but cannot avoid labour-intensive shop lay-outs at the processing steps; then, productive break-up is but a course expedient in view of wages optimising and of skills balancing and does not seek for complexity in technologies or for advanced sub-items. In fact, productive decentralisation can follow one of the two axioms:

- let do jobs by specialised people to incorporate extra-value by advanced technologies,
- let do jobs by cheaper workers to improve effectiveness by better value/cost ratios,

but the first only is consistent with improved quality products.

Information technology changes, on these premises, need be adapted to the special case. An intelligent setting provides the means to supply unified view of the manufacturing process, even when the material flow breaks into several segments. The over-all business is shaped as virtual enterprise: the data flow is shared; the material logistic has transparent support. The firms aim at competitiveness, with focus on styling and on critical processing tasks, while the work-intensive phases (e.g. sewing) are eventually decentralised where operators wage is smaller. Is this an effective set-up? (possibly) yes, on condition that:

- the market accepts the full amount of ready-made suits or dresses, delivered by (large-enough) season’s batches (to optimise the productivity on the tactical horizons);
- the flexibility is included by ‘quick-response’ techniques, so that extra items are managed on-process, to personalise size or details (as case arises, on the operation horizons).

The two conditions are consistent with simple rules, such as:

- to aim at work-plans leanness, with visibility on cost build-up and quality transfer;
- to focus on the core business and to remove ‘intangibles’, which make the business with ‘little’ benefit.

Leanness entails decisions, based on benchmarks, with purport on management tasks (to distinguish administrative or bureaucratic requests) and on technical issues (to plan out product and process innovation). Preliminary step for effectiveness is the setting of performance ranks, at the strategic, tactical and operation levels of the manufacturing engagements [17,18], Fig. 1, to exploit flexibility through a properly sophisticated govern framework.

2. Distributed intelligence options

The mentioned rules comply with distributed intelligence, granting on-process flexibility, but do not come to the same thing with the unattended factory-of-the-future concepts. Textile and clothes industries, as said, still prefer to preserve high-intensive direct human work, with fragmentation of material flows; nowadays,
qualified businesses look after computer aids, aiming at using the information flow to oversee material procurement, marketing orders, etc. or, to a lesser extent, to rule the shop-floor schedules. These are technology-driven additions and return on investment has to be proved. Indeed, suits manufacture is asked to face demanding challenges, with pressure on prices, fast changing fashion, item customisation, etc. by means of offers based on certified quality, wide product mixes, quick-response with reliable due-dates, etc.; obviously, here too, ‘scope’ economies can replace ‘scale’ economies, following typical patterns, say: flexible specialisation, lean engineering, company-wide quality, continuous betterment, etc. which are enabled by knowledge intensive set-ups, making possible: integrated control-and-management; strategic, tactical and execution levels flexibility; function/resource redundancy removal; etc. Return on investment is assessed by the transparency of the productive cycles, monitoring the plant effectiveness to deliver products/services at buyer’s satisfaction.

In fact, the textile and clothing industry deals with single-technology artefacts (does not add external technologies) and draws benefits by sets of features, Fig. 2, showing its market-driven sensitiveness; instead, distributed intelligence set-ups entail qualified changes. The habit of productive break-up, looking after low-cost labour for manufacture phases with high manpower, turns out achievable goals (e.g. high quality apparel with customised variability) and proper tricks need be explored to win them back, whenever appropriate. Indeed, the ‘creation’ of high-standing clothes includes skilled labour mainly at the ideation phases; the strategy of keeping ‘critical’ jobs inside the main factory and distributing outside labour-intensive cycles can be pursued for prompt returns; on middle to long horizons, instead, a deeper analysis is most likely to show contradictions or unwonted issues, mainly due to the following facts:

- The design has unity responsiveness (productive break-up, in general, gives return with no hindrances when several technologies are integrated into complex artefacts).
- The final products require quality features strictly embedded and checked at each steps of the work-cycle and addition of approval tests is against scope economies precepts.

Fig. 1. On-process exploitation of the flexibility.
The enterprise’s know-how cannot be protected, as quality checks need be distributed over the process, with the result to help the rising of trained competitors. The trading organisation advantages of ‘quick-response’ methods, cannot be conceived, due to material dispatching delay and enterprise’s logistic policy.

Summing up, advanced manufacturing prospects several expedients to obtain enhanced effectiveness, on condition that the distributed intelligence options are exploited to the extent of removing or lowering the recalled inconsistencies and drawbacks, by referring to a virtual enterprise setting, with material and human attendance innovation, based on series of steps such as [20, 21]:

- the work-cycles and the production schedules shall balance on the strategic horizons, with effective exploitation of all available resources;
- the monitoring maintenance of the manufacturing process is followed up, aiming at steady quality, with the zero-defect production;
- the integrated control-and-management of the plant versatility is exploited, delivering the product mixes with just-in-time schedules, at the clients’ due-dates;
- the product-and-process up-grading is pace-wise carried, supplying transparent assessment of each intermediate achievement.

2.1. The computer simulation packages

The few comments show that, prospecting the role of distributed information systems, the success highly depends on the capability of really taking advantages of the pertinent data, to adapt products and processes on the (three) strategic, tactical and execution spans, avoiding wastes and redundancies with concern to market-driven delivery policies. Instead of optimal top–down production programmes, adaptive bottom–up schedules have to be achieved and, starting at the shop-floor level, on-process computer aids need be provided, to look after the right decisions. The factory automation software is a well developed branch and hereafter the packages used for process simulation are referred to; these are powerful decision aids for off- and on-line use [22–28], in fact:

- at the facility design–development stage: the resources setting is fixed in view of enterprise sale strategies and production programmes are stated for balanced throughput and due time;
- at the facility management-fitting stage: the production schedules are managed to overcome programmed (e.g. order itemisation) or unpredictable (e.g. failures) discontinuities.

To reach both goals, the simulation code has to duplicate the time evolution of every physical resource and to emulate the decision logic of the over-all enterprise. This means that the functional model of the

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Fig. 2. Characterising features of integrated intelligence for apparel manufacturing.
facility needs be developed, with due account of actual running conditions and the govern rules needs be explicitly detailed, with attention on justifying data and criteria. Quite often, knowledge-based programming is good support and object-oriented languages supply effective coding. Typically, modular simulation packages are preferred, authorising hierarchic inheritance (to expand or up-date models and to provide visibility of the relational build-up) and detailing, Fig. 3: (i) the declarative (resources description, system hypotheses, etc.); and (ii) the procedural (governing rules, performance criteria, etc.) knowledge [29–31]. The modularity of the simulation codes is useful option to focus attention on subsets of quantities, while leaving unmodified other parameters, depending on issues to be assessed. In fact, number of properties affecting plant effectiveness ought be investigated and this needs to be done distinguishing direct from cross-related effects. The testing of real facilities is clearly not possible and computer simulation has to deal with a series of packages, each one corresponding to the particular view of the problem, to be investigated. At the design–development stage, several production facilities are compared in terms of enterprise policies; at the management-fitting stage, several production plans are assessed in terms of delivery requests. The monitoring of value forming, by respect with cost build-up, is performed in virtual reality, to establish comparative enterprise forecasts and to anticipate achievements or drawbacks of (actually) selected production policies.

The approach is particularly useful for the clothing industry, where ‘intelligent factory’ set-ups are still observed with caution, since addition of technology-driven options to a labour-intensive environment cannot be accepted without having previously acknowledged the return on investment. Then simulation, after throughout investigation of achievements and drawbacks, offers affordable commitment, making possible to rank competing manufacturing facilities and plans. This viewpoint is given in the following, showing a case development as example explanation. The simulation software is obtained, with the outlined properties: the modular LCX-SIFIP package, based on the object-oriented MODSIM III language, can describe the over-all material flow (from fabrics to suits) with the concurrent data flow; the zooming toward special

Fig. 3. Knowledge-based modular simulation packages.
details (e.g. actual productivity of a given laying/cutting facility) is provided by addressing the purposely implemented modules. Topics are further discussed referring to data taken from the case manufacturing business.

3. Joint batch and one-of-a-kind processing

The domain of quality garments is addressed, presuming progressive changes from the existing habits: production flow bears break-up, uneven automation levels are accepted, batch scheduling is considered, and the likes; then small modifications are included, directly issued by the availability of distributed intelligence. In fact, until now, fashion industry operates with a season’s lead-time, trying to anticipate tastes and whims with sufficient (but not redundant) amounts of items as compared with the (expected) marked requests; this might be non-economical for having, both, under-/over-estimated the delivery programmes, but little can be done to recover effectiveness, unless the factory has proper flexibility for market-driven orders to be dealt with in real-time. The opportunity is, therefore, specifically studied, focusing on the high-automation sections, more affected by flexibility issues than the labour-intensive ones.

The manufacturing lay-out distinguishes at the shop-floor level different sections, each one specialised by homogeneous work-cycles, namely:

- fabric warehouse and material delivering,
- local buffering, laying and cutting sections,
- selective picking, stock-taking-out and dispatching,
- sewing sections, feeding and material logistics,
- fitting-out and pressing sections and products buffering,
- checking, packing sections and apparel warehouse,
- retailers supplying and market supervision.

The over-all production flow, Fig. 4, is analysed and the functional description is coded, for computer simulation, assuming to deal with a vertical factory, having laying/cutting cells, Fig. 5, either directly interfaced to manufacturing sections, either ruled as a virtual shop, with a manager dispatching materials.

![Fig. 4. Flow-chart of the garments manufacture process.](image1)

![Fig. 5. Flow-chart of a laying/cutting cell.](image2)
to decentralised sites. This leads to combined-mode planning, aiming at batch or at one-of-a-kind processing, depending on the current cycle. In fact, productive break-up is consistent with batch schedules, since large amounts of materials are moved from one section to the next, at well assessed times; to deal with one-of-a-kind products, satisfying changing market requests: (i) on-line resources need have broad dexterity, efficiency, flexibility and versatility figures; (ii) machines setting and resetting has to be quick and easy; (iii) material logistic should split, keeping on-line the market-driven items for next operations and forwarding the batches for decentralised processing.

The scenarios do not have clear-cut issues; demanding tests on real set-ups need be run, to set effectiveness. Simulation provides visibility on the current evolution of each resource, so that up-dated information is continuously available to adapt the production plans, in relation with the product mix timely on-process and with the desired due-dates. The option is exploited to make possible the interlaced processing of:

- the sorted out batches, according to optimal schedules on the tactical spans and suitable dispatching for decentralised further processing; and
- the one-of-a-kind items, according to customers driven orders, within the execution spans (granting ‘quick-response’ reactivity, directly within the shop).

Thereafter, the production planning operates by just-in-time set-ups and effective schedules on the tactical horizons, managing material provisioning as needs arise and dispatching the work-pieces depending on resource availability (with a supervisor for job-shop logistics), and keeping one-of-a-kind artefacts, with due exploitation of the (local) plant versatility.

The strategy to be assessed deals with an off-process optimised batch production; never the less, the combined-mode planning, by on-process managing the flexibility, should allow to deliver single
client’s orders, simultaneously processed for amounts rising at different percent of the total throughput, depending on the enterprise policy. For practical reasons, the investigation is better tackled, by separately analysing each segments of the manufacturing cycle, in order to reduce the degrees of freedom of each influence factor. The Fig. 6 gives the functional model (as it appears on the restitution display of the LCX-SIFIP code) of the singled out laying and cutting cell, provided with a local storing for fabric rolls and two tables for the unwrapping, each one alternatively feeding a cutting head. The display is surrounded by the updated information on the production flow and on the utilisation ratio of the involved resources. The subsequent selective picking-up distinguishes the parts to be assorted into batches (and mainly forwarded at decentralised plants for further processing), from the customised item ones (typically, to be immediately assembled by a next-door sewing section).

The batches are arranged beforehand and material sorting and fetching is accordingly programmed; the one-of-a-kind items appear as wild-cats issues, at clients’ orders. To accept the ‘unscheduled’ occurrences, extra locations in the local buffer and on the laying table are left, to look after flexibility. The ratio of extra-items as compared with over-all batch amount is important feature, characterising the customers’ satisfaction paradigm of the business policy. Making use of the LCX-SIFIP package, the process description is based on a modular lay-out, to separate the effect of influence quantities and to investigate details, providing the over-all view of the business, so that balancing of the material flow is preserved, without bottle-necks or supply shortages.

3.1. Investigating the laying-cutting section behaviour

The combined-mode (batch and one-of-a-kind) planning has critical middle phase at fabric cutting, where automation has reached high acceptance and investment’s return is simply related to productivity. Looking at the process, the different level of integration between tasks shows that effectiveness is conditioned by contingencies, which might frustrate the high productivity of a given cutting facility. At first sight, to cut a single layer, when the head is capable to deal with several tens at a time, is far from optimal, but once the all business is monitored, the bargaining among saturating the (outer) sewing sections (with batch feeding) and supplying the (inner) assembly line (of customised items) opens new perspectives, not to be immediately rejected.

The number of feasible options is generally quite large and the effects of (strategic, tactical or execution) flexibility are so cross-coupled, that company-wide descriptions most of the times rise at levels of high complexity to understand the actual reach of each chosen decision. The study needs characterise how each critical facility behaves and when the combined-mode planning becomes effective. Next steps are concerned by the ability of exploring on-process flexibility, provided by: process attuned managers, decentralised controllers; real-time supervisors. The govern actions are suggested by empirical data, yielding plausible decisions, by means of heuristic rules and qualitative reasoning. The collection of useful information is practically obtained, by testing the competing facilities with several delivery agendas and production schedules, until every situation is ranked and a decision pattern is found out as effective means to reach the enterprise goals.

Example results of this kind of investigation are shown making use of the LCX-SIFIP code to simulate the behaviour of the laying and cutting cell, already described in Fig. 5. The Fig. 7 shows a view of the cutting table, with the lay-out of the piled-up pieces, ready for the stripping and the collection into sorted packages to be forwarded to the sewing sections. In order to understand the real effectiveness of the on-progress manufacturing agenda, the display of the LCX-SIFIP code provides the statistics by current or cumulated figures, such as the averaged lead-time by respect to the scheduled due-date or the current lead-time, Fig. 8, with estimation of the work-in-progress situation by respect to the resources availability.

Further to snapshots giving the facility behaviour, the LCX-SIFIP code shows a set of special purpose restitution blocks, to study the effects of different set-ups or modified schedules. To understand how to manage flexibility with the combined-mode (batch and one-of-a-kind) schedules, for instance, one moves from off-process optimised (over the work-shift horizon) batch production plans and investigates the
facility productivity (items per hour) when 10 or 15 or 20% of the items are one-of-a-kind artefacts. The assessments can be repeated, looking after utilisation ratio figures: of the local fabric buffer, Fig. 9a, or of the cutting head, Fig. 9b; or work-in-progress figures: current number of laid down items, Fig. 9c, or current number of actually laid and cut items, Fig. 9d. The productivity of the laying and cutting cell will depend on several options, such as, Fig. 10: (i) the reserved roll locations of the feeding buffer; (ii) the current batch size (and the number of extra items) laid down; (iii) the number of extra laying windows, left out of steady schedules, etc.; (iv) the study is readily expanded also considering other options, such as: (v) the length of the laying table (as a whole or as attribution of extra items); (vi) the number of superposed fabric layers and the amount of apparel sizes allocated to each laying cycles, etc.

3.2. Exploiting virtual reality simulation results

By simulation, different options can be compared. The LCX-SIFIP package is oriented to a segment of the manufacturing cycle, using exchanged information to rule the all process. An enterprise might include several laying and cutting cells; the recalled data shall be repeated, to attune the properties according to sets of subsidiary aims, as facility characterisation needs cover the all material flow. The considered section is (typically) fed by a central warehouse and the
information system provides continuous up-dates of the current situation, including, for instance, the mapping of the fabric rolls misfits so that, during unrolling, data are used to set the unwrapping for “best” parts positioning. Downstream, the sewing sections, normally, characterise by longer processing time; thus the material flow has to branch off, distributing the pieces among several parallel units. This segment is concerned by different work set-ups, including, as said, productive break-up to low wages regions. In the example combined-mode scheduling, the one-of-a-kind products are processed within the same plant and the batches are gathered and packed for decentralised processing. Cost monitoring has to face, in the latter case, material logistics, quality control and work-cycle duration; in the former case, investment in flexible automation, before establishing the effectiveness figures and the return perspectives of actual changes. Then only, plant effectiveness figures are available and have to be compared with (actual or virtual) market data, to understand whether the flexibility provided by the combined-mode planning does or does not achieve the desired returns.

As said, the ‘intelligent’ factory setting is still not considered by clothing industry; it could, possibly, be started step-wise for special situations. The combined-mode schedule is a possible development, on condition that proper sewing sections are available (to make possible both, batch and one-of-a-kind, assembly) and that the laying and cutting phases are suitably integrated for effectiveness. The simulation study is pushed up, to validate solutions at different level of flexibility, since actual effectiveness depends on the market evolution, but returns, even if tied by investments in technology, do not spring up as long as actual benefits are left in-exploited; in fact, flexibility has to be tested at different functional ranges and time horizons, for example: at the organisational range (under process-attuned managers), to select the over-all product-mix variability on the strategic horizons; at the co-ordination range (with decentralised controllers), to optimise the products-batches and fabrication agendas on the tactical horizons; at the operation range (under real-time supervisors), to deal with discontinuities (single-order items or misfits) on the execution horizons. Then, effective exploitation is
Fig. 9. Work-loads of (a) buffer; (b) cutting head; (c) laid; (d) cut items.
actually achieved, if sufficient experimental data are known.

4. Conclusions

The clothing business is considered and compared with opportunities that ‘intelligent’ manufacturing could make possible. The study is developed to introduce some options of flexibility, in a world-wide context, where work-division is mainly established on objective separation of technological levels. These concepts are, at the moment, practically ignored by apparel manufacturers, due to peculiarities of their business; with the economies of scope, competition between enterprises will issue by monitoring the value added by manufactured (and actually sold) apparel, rather than looking after pre-set optimisation plans of (still unsold) items (with, e.g. the policy of storing large production batches and running after buyers with advertising policies or with low selling prices). The size of one-of-a-kind items should progressively expand and that option is investigated for high-standing clothes using mixed schedules so that customer satisfaction is obtained with no need to expand inventory, even when buyers require personalised quality and quick service.

The discussion offers hints to look for the integrated manufacturing approach, where combined-mode (batch and one-of-a-kind) scheduling is supported. This different set-up is investigated through computer simulation; the means is to be used to acknowledge the actual potentialities of the facilities; and, after then, to assess of most effective production plans during life-long operations by the adaptive exploitation of flexibility at the different (strategic, tactical or execution) ranges. Aiming at high-standing clothes with one-of-a-kind product organisation and customised satisfaction, quick-response and total quality become demanding requisites to win the competition in a world-wide market; aiming at high productivity plants (with related investment in automation), the batch production has to be simultaneously dealt with. The combination of the two rises among intelligent manufacturing options as soon as the economical consistency is proved; simulation turns to be reference means for developing and for acknowledging, both, the appropriate set-ups and the effective schedules.

Fig. 10. Cell productivity for different set-ups.
The subject is dealt by the LCX-SIFIP package and typical results are given to exemplify the opportunities, with particular attention on the intermediate laying and cutting phases, at an already high level of automation, with investments to be amortised by comparably high productivity. With combined-mode schedules, this critical requirement is reached by managing flexibility and recovering one-of-a-kind delivery, within a context achieving the productivity standards of mass-production and flow-shop organisation, with optimal planning and off-process govern by steady control flow. The combined-mode scheduling adds flexible manufacturing for customised products, with adaptive planning and on-process govern by task-driven control; the merging of information and material flows aims at standard quality, since transparent access is provided to the whole process.

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