The fabric feeding management for automatic clothing manufacture

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Abstract: The exploitation of “intelligent” factory set-ups enhances the competitiveness of the EU textile and clothes 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 paper, besides reference concepts, summarises a case example related to the management of the fabric warehouse, in order to grant adaptive sorting and dispatching of bolts, by on-process optimisation of the actually used cloth, with account of fabric quality-data and of time-varying schedules. The combined-mode schedules show the benefits for quick response, leaving open middle/long horizons issues; checks on alternatives are provided by virtual reality tests.

Key words: Fabric warehouse automation, Quality manufacture, Computer simulation

1. INTRODUCTION

The *factory automation* concept bears little popularity among clothing manufacturers: the *information* flow (from ideation and strategic planning, to communication, flexibility ruling and quality assessments) runs separately from the *material* flow (from fabrics and supplies, to suits, dresses, apparels and underwear). Textile and clothes industries still prefer to preserve labour-intensive work-cycles, with fragmentation of material flow and *productive break-up* to low-wages countries; qualified businesses, at times, look after computer aids, aiming at using the information flow to oversee material procurement, marketing orders, etc. and, more specifically, to help devising innovative artefacts or, to a lower extent, to rule the shop floor schedules. Front end automation, in particular, lags behind; this concerns the flow-shop

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out-fits for mass-production through planning and scheduling organisation ruled by (off-process chosen) optimal control; this deals, as well, with flexible manufacturing of customised offers, by means of adaptive planning and scheduling driven by on-process govern. The *productive break-up* policy, thus, mainly aims at: «let do jobs by cheaper workers to improve effectiveness by better value/cost ratios», rather than at: «let do jobs by trained operators to embed extra-value from advanced technologies».

A different way to achieve return on investment leads to customer-driven product mixes, with quick-response frames and certified quality patterns. This brings to *intelligent* factory, with integrated control on, both, material and information flows; standard quality is steady issue of process visibility and up-keeping actions; client whims are readily satisfied by data transfer and on-line adaptivity. *Factory automation* will not cover the all *material* flow, rather a subset of it, but shall expand on the all *information* flow, to supply unified view of the production process, even when the material flow breaks into several segments. In the paper, a contribution in that direction is given, dealing with the manufacture of quality suits. The process description refers to a modular lay-out; the fabric storing-sorting section, only, is addressed to enable *intelligence*, with the joint exploitation of material-and-information, by warehouse automation and supervised fetching/dispatching with account of the pieces flaws or mismatches.

2. DISTRIBUTED INTELLIGENCE OPTIONS

With focus on the information frame, knowledge bases and knowledge processing shall be properly analysed. Qualifying bases embed: - fabrication agenda adaptivity: effectiveness aims at customers satisfaction, with pressure on fast changing fashion and quality preservation, by means of operation, tactical and strategic flexibility, in keeping with process monitoring; - fabric quality management: optimality looks at properly exploiting the available material, with account of nominal peculiarities (e.g. for fancy cloth) and of acknowledged faults (distinguished into classes and sizes).

An integrated information system qualifies by real-time adaptivity driven by on-process data; it supports economy of scope, say: flexible specialisation with lean manufacturing, company-wide quality, continuous betterment with simultaneous engineering, etc. Efficiency is built removing function/resource redundancy, as discontinuities and unexpected occurrences are overrun by prompting the technological versatility with the conditioning knowledge.

As a matter of facts, the 'creation' of high-standing clothes is still ascribed to handicraft; the innovation aims at enhancing the skilled labour at the ideation phases, improving the critical jobs with resort to intelligent automation and granting competitiveness with the build-up of items' *value* at

buyer's satisfaction; rules require privileged knowledge sharing.

Combined control-and-management of flexibility is consistent with varying product mixes and with changing work-conditions. The strategic horizons comply with the business policy; quick-response replaces inventory by market-pull agendas. The tactical horizons deals with optimal schedule; versatility assures assorted batches with high productivity. The operation horizons tackle discontinuities; wild event tolerance and recovery help fabrication continuity. Intelligent manufacture grants flexible specialisation, but does not come to the same thing with the *unattended* 'factory-of-the-future', rather with *craftiness* helping steady high quality.

The fabric supply system is clearly critical to grant fabrication continuity, forwarding the items on a market-pull base. The information flow shall provide all pertinent data: warehouse general inventory, with cloth types, lengths, procurement policy, etc; individual roll special data, with handling rules, characteristic features, fault classification and mapping, etc.; these data, indeed, are actually background knowledge of front-end operators; they shall become foreground information to implement combined control-and-management logics. The goal is achieved, based on the factory automation software, a well developed branch of the computer technology, that simply needs include the peculiarities of the textile/clothing industry. A few hints are recalled in the following section, dealing the shop warehouse.

At the level of generalities, computer simulation and testing with virtual set-ups should be mentioned as powerful decision aids, for off- and on-line use to deal with flexibility. The tools are typical issue of the IT, providing: - at the facility *design-development* stage: resources setting needs comply with enterprise sale policies; agendas are stated for balanced throughput and due time; - at the facility *management-fitting* stage: production schedules are updated by on-process data, to face planned (e.g. itemisation) or unpredictable (e.g. failures) discontinuities. Simulation codes are, now, standard options, mainly, based on object languages and modular structures. Modularity is useful, to focus the attention on subsets of quantities, while leaving unaffected other parameters, drawn out from the facts to be assessed. The plant effectiveness, actually, depends on a large number of properties and the investigation should distinguish direct from cross-related effects, so that the knowledge frame is step-wise built up to the required level of completeness.

Extended tests on real facilities are clearly not possible. Then, simulation has to deal with a series of checks, each one providing the particular view of the studied factory. At the design stage, production facilities are compared as for enterprise policies; at the management-fitting stage, production plans are assessed as for delivery requests. The monitoring of value grow, by respect to cost build-up, is performed in virtual reality, to establish comparative enterprise forecasts and to anticipate benefits or drawbacks of the (finally)

selected enterprise policy. The clothing industry benefits moves that way; the 'intelligent factory' concept is observed with caution: technology-driven additions, to a labour-intensive environment, cannot be accepted without fully acknowledging the return on investment. The throughout testing of achievements and drawbacks of virtual plants offers an affordable commitment, making easy to rank competing facilities and/or plans.

3. THE FABRIC WAREHOUSE: DESIGN DATA

For competitiveness, the manufacture of quality clothes privileges styling and critical tasks (e.g., cutting), possibly, moving work-intensive phases (e.g., sewing) where labour wage is smaller. Return on investment establishes on condition that: - market demand takes over the amounts of ready-made suits or dresses, delivered by (large-enough) season's batches (to optimise the productivity on the tactical horizons); - flexibility is dealt with by 'quick response' opportunities, so that 'extra' items are managed on-process, to personalise size/details (as case arises, on the operation horizons).

FABRIC FEATURES: - Composition - Number of ends and picks - Weave - Colour fastness to light - Colour fastness to perspiration - Colour fastness to dry-cleaning (using perchloro-ethylene) - Colour fastness to washing - Colour fastness to dry pressing or ironing - Colour fastness to rubbing - Colour fastness to dry spotting water - Colour fastness to rubbing: organic solvents - Breaking strength and elongation: longitudinal, transversal - Breaking strength: grab method - Tear strength - Resistance to abrasion - Resistance to piling - Resistance to snagging - Resistance to dry ravelling - Seam slippage - Size stability to washing - Size stability to dry cleaning - Crease recovery

Figure 1. Typical characterising features of woven fabrics

Efficiency requires work-plans *leanness*, with visibility on cost build-up and quality transfer and removal of 'intangibles', with 'little' business benefit. Leanness entails benchmarking decisions, with purport on management (to embed administrative rules) and on technical issues (to plan out product and process innovation). Hereafter, the factory particular view tackles over the fabric warehouse. Due to flexibility, the fabrication agendas shall modify as for trade-driven (e.g. individual buyer whims) or leanness-bent (e.g. scrapes reduction) data. The latter option is outcome of fully exploiting available information by means of proper fixturing and processing equipment.

The cloth characteristics are object of proper standards and measurement techniques. It is possible to know: weigh, thickness, worsted number, warp and weft strength, bent and twist compliance, crease and crumple count, woof class, etc. and, in general, the different nominal properties associated to

given commercial brands, *Fig. 1*. Fair trade, moreover, establishes a set of rules to specify the defects pertaining to individual cloth bolt.

A fault is defined as a non-conformity as compared to fixed agreements. The European Clothing Association, ECLA, suggests a reference set of specifications, covering: - yarn defects: broken thread, curling, twin top yarn, uneven glossiness, knot, etc.; - warp defects: barred weaving, furrow, stack, faulty warping, chopped off warp, etc.; - woof defects: lacking yarn, wrong weft, stretched/winding thread, fake reach, etc.; - flaws after dyeing, printing, finishing: unevenness, stains, blurs, creases, slobbers, etc.; - selvage flaws: folded listing, holed selvedge, damaged edges, etc.; - further deficiencies: skewness, drawing asymmetry, holes, inclusions, uneven width, non steady yarn, scrape marks, etc..

The process of deficiency sizing distinguishes: - *slight faultiness*: defects do not affect the cloth roll practical exploitation, due to location or low probability of being seen; - *heavy faultiness*: defects, if transferred into finished garments, are apparent and compromise quality; - *fatal faultiness*: the defective pieces of cloth, if used, make final artefacts unsafe or wrecked.

Business agreements include classing, sizing and mapping of defects. The cloth roll useful length is bounded between starting and ending strips; further strings mark the location of faults with, possibly, colour codes. Detection, location and marking are mainly accomplished on automatic unwrapping fixtures, so that classing, sizing and mapping are easily encoded on smart-cards or other chips, solid to the individual bolt (the addition of fillets or traps follows habits consistent with the manual processing of clothes).

The fabric cost is a non-negligible part of quality garments (from 40%, as a standard) and an enterprise will greatly benefit from waste decrease. The interest in special tools, such as **CAFE**, Computer-Aided Fabric Evaluation, increases: - for textile shops, to bind product and process data and to establish setting and recovery actions assuring steady quality; - for garments shops, to devise efficient cutting policies, so that the (residual) defective stripes are moved off the used parts, properly exploiting the material and carefully avoiding the risk of faulty artefacts. The **CAFE** rig directly follows the loom and (usefully) enables corrective feedback; the monitoring is done by a camera (to perform pattern recognition) and restitution devices (to provide the length and width location). The mapping report is printed on tickets or encoded on read-only cards; the use of read/write cards would be helpful, to make easy the address of individual fabric bolts, during subsequent processing in and out the warehouse.

For an effective cloth management, the pieces to be cut on a given horizon should match the characterising quality/defect features of the stored material. Joint to the individual bolt, up-dated information shall provide: • fabric nominal identifier; • quality reference data; • rack and array location; •

residual useful length; • defects mapping. Related to forecast work-plans, the current information will give: • requested nominal amount and delivery schedule; • pieces nesting programming and sequencing; • cutting policies, with due account of fault maps. The knowledge of faultiness degree and location (as for length and breadth) is used to compare the stored bolts by assessing the scrapes actually out-coming with the available nested cutting policies.

Figure 2. Warehouse lay-out for 350 mm (a) and 500 mm (b) diameter rolls

The betterment depends on many facts, such as: - delivery schedule horizon; - bolt placing and withdrawal capability; - cut pieces recognition and picking options; - defect sizing and description effectiveness; - fabric characteristics; - garments specifications; - faults removal policy; - data sharing and transmission devices. Efficiency requires balanced situations, when fully enabled hardware/software resources are managed with assessed return on investment. This quite naturally leads to increase automation, so that critical duties are moved off human reach into the domain of robot repetitiveness. For an effective cloth management, the pieces to be cut on a given horizon should match the characterising quality/defect features of the stored material. Joint to the individual bolt, up-dated information shall provide: • fabric nominal identifier; • quality reference data; • rack and array location; • residual useful length; • defects mapping. Related to forecast work-plans, the current information will give: • requested nominal amount and delivery schedule; • pieces nesting programming and sequencing; • cutting policies, with due account of fault maps. The knowledge of faultiness degree and location (as for length and breadth) is used to compare the stored bolts by assessing the scrapes actually out-coming with the available nested cutting policies.

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The warehouse deserves special attention, since today manual operation is main resort. An overview of the prospected lay-out addresses to parallel scaffolds of superposed bolts, *Fig. 2*, each row is composed by frames with structural curved shapes, to grant roll steadiness. A translating tower accomplishes drawing in and out tasks; a cross-bar with latching/unlatching pliers assure the fetching and holding sequences. The tower is borne by top and bottom rails. The latching is done by pliers slight sink and quarter rotation, assuring safe cross-bar release with minimal operation space, *Fig. 3 a) and b)*. The tower feeds a series of AGVs, with racks, to stock the bolts, before dispatching to the proper laying and cutting station. The pertinent data are simultaneously transferred and, once the mattress is composed and the cutting accomplished, the picking of resulting pieces is automatically performed to establish assorted bunches exactly with the forecast order.

Figure 3. Grasping of rolls (a: approach phase; b: rotation phase for safe latching)

4. WAREHOUSE MATERIAL AND DATA FLOWS

The advantages of process-data visibility need be assessed for actual running conditions. To comparison of competing solutions is beforehand ran by simulation: The **RSS-SIFIP** code is developed for the central warehouse feeding the subsequent laying and cutting sections; bolts are selected with up-dated account of, both, requested delivery order and cloth cutting plans optimised as for faultiness maps. The code avails of the **MODSIM II** object-oriented software and develops on a modular architecture to make easy resources changes or additions and/or control logic up-grading. Aiming at high-standing garments with market-driven customised satisfaction, quick-response and total quality are demanding requisites to win the competition in a world-wide market. Cost monitoring has to deal with material logistics and

piece cutting programmes, with attention on data communication and on automation appropriateness.

Figure 4. Overall architecture of the RSS-SIFIP simulation code

The **RSS-SIFIP** code, *Fig. 4*, distinguishes: the controller, with related data-base and CAD tool; the dispatching service; the addressable warehouse. The controller enables task schedule and co-ordination; given the fabrication agenda, it selects, from the cloth data base, the bolts allowing minimal waste and oversees the material and information transfer to the laying and cutting section. Dispatching includes the alternatives for roll latching/unlatching, withdrawal, buffering, transfer, and delivery to the individual laying/cutting station stores; the description of the all equipment is afforded at different levels: - for design, the translating towers (one for each bolt rank) and related cross-bar and pliers, the interfacing buffer, the shop-logistic facilities and the related releasing rigs are individually specified; - for operation testing, the overall service is combined into equivalent unified elements, each one with job-dependent properties. The cloth warehouse size is related to the enterprise strategic plans: e.g., with buyers-driven manufacture, total inventory is critical figure when quick-response is strict request.

Intelligent flow-shop should grant combined material and data processing. The **RSS-SIFIP** code turns to be a reference means for developing and acknowledging appropriate lay-outs and effective schedules. The fabrication agenda appears at the input; it is a file, with business-driven cutting schedules, specifying: - order identifier; - batch size; - fabric types; - clothes size mix; - mattress data (number of layers, number of windows,

etc.); - laying data (due to quality specification); - cutting data (due to defect maps). The agenda specialisation is automatically accomplished by the shop controller, by using the cloth data-base. This up-dated information of the existing bolts: physical location (row, rank and layer), fabric nominal attributes (type, etc.); bolt properties (residual length, defect mapping, etc.); other (e.g., pointers for expensive, temporarily not present cloth, retrievable by the dispatching fixtures).

A simulation code module selects the fabrication agendas: these are either pre-established to test and compare the enterprise delivery strategies, either generated mixing structured files with random orders to assess the adaptive flexibility effects. The cloth data-base needs be up-dated and, possibly, expanded with temporary information (e.g., on-duty bolt work-cycle, so that a single item could be engaged by subsequent agendas with no in between storing). The study has, conveniently, to assess the warehouse lay-out: - arrays spatial built-up (row, rank and layer); - cradle size (and distribution in view of bolt specialisation); - storing up policy (handling priority, modular allotment, etc.); - input/output buffering capacity; - and so on. In the present case, for instance, the intermediate buffering is simply provided by a set of AGVs or shuttles, with a rack to be either loaded with the bolts to be forwarded, either unloaded of the coming back ones.

Figure 5. Pop-up windows of RSS-SIFIP for monitoring simulation progression

The facility shall permanently be monitored. The RSS-SIFIP code, similarly, displays the current state by a multiple window arrangement, Fig. 5: • the left window gives the addressed warehouse module, showing the occupied or empty cradles; • the right window specifies the considered buffering section, with the related work-status and set of required cutting stations; • the lower window provides the series of cut pieces lay-outs; • a set of slits supplies current reference data; • another set of slits presents

cumulated process figures (utilised fabric, etc.). The knowledge of the defect maps may suggest special pieces nesting; alternatively, a subset of pieces could out-come with fatal/heavy faultiness: these appear marked-up and replacing pieces are separately cut from an extra length of the laid down cloth, Fig. 6.

The controller has to oversee the sequences of fabrication agendas; for efficiency, batch orders are forwarded with, mixed in, one-of-a-kind items, to satisfy given purchasers. This is always possible if the laying tables accept *extra-length* for out-of-batch articles (or for duplication, to replace faulted pieces, as just mentioned). The planning flexibility makes easy to include extra items or to push some others at a later batch, e.g., when the selected fabric is temporarily not available. The adaptive programming can report to on-line operators or to an *expert* module, with a rule-based decision logic. When this kind of investigation has to be pursued, the shop logistics is summed up into an AGVs equivalent dispatching service. In the practice, the bolts are looked for at first in the intermediate buffering section and only subsequently in the all warehouse: cloth recovery the re-routing of given AGVs for in-between work-station service.

Summing up, the simulator is task driven, each task split into a series of occurrence: a cycle starts with the new task (from the fabrication agenda); the cloth bolt selection is done, for the feeding-run rack-mix; the loaded AGV service follows, before the return-run or, possibly, an inter-station service; the information up-dating gives account of every in-between occurrence. The number of AGVs, having given in charge the dispatching, depends on the through-put; the simulation helps assessing the need of the intermediate buffering and alternatives can be devised with shuttles on fixed rails or other transfer means. The control logic, as well, can embed several options, e.g., rack selective loading-unloading, to keep in the foreground the bolts of fabric known to be requested within a given horizon span.

The simulation study is pushed up to compare facilities with different level of integration, as plants are conditioned by contingencies which might frustrate expensive changes, when actual advantages are left in-exploited. The results, given by the **RSS-SIFIP** code, provide hints on actual returns for different factory situations. Let refer to the following assumptions: • the available warehouse section composes of four scaffolds with 10x10 frames, for 400 total bolts, say, 20 equally-distributed cloth types; • the initial roll length ranges between 18 to 20 m, with 5 to 15 duly mapped heavy/fatal faultiness; • the artefacts mix has varying assortment, requiring a proper number of *cut span* on the laying table. Depending on the batch (number of products), the fabric laying with account of the defects mapping allows a considerable reduction of wastes, as compared to the plain afterwards recognition of non-usable pieces. The on-process use of cloth data requires

the handling of a larger number of bolts, but this is compensated as the later handling of the (same) bolts for cutting the replacing pieces is avoided. The bolt optimal search, in this case, turns to be simple due to the large availability of alternatives.

Figure 6. Windows for management of defected parts

Let, thereafter, modify the previous assumptions so that the number of requested items almost matches the available material and the fabrication agenda should comply a strict cloth type order. The bounded inventory keeps benefits, with higher effects for larger batches. The available bolt number is varied, to assess inventory influence with constant batches,. The study goes on with focus on the faultiness ratios; let assume: • to have a large inventory (20 bolts each cloth type) and to request a mix of 20 products (15 items each), for a total of 300 items batches; • the defects might vary between 2 and 20. The benefit of the early report of faultiness is quite evident. The situation modifies, with an inventory bounded at the current batch size. Basic results, obtained assuming full exploitation of the handled bolts, are shown, as explanatory examples, at the presentation. For high standing, one-of-a-kind production, the bolts are progressively consumed turning the useful length down to less to the minimum *cut span* of a complete suit. The influence of roll-ends is needing attention, specially for expensive materials. The previously found benefits modify and the two situations of high inventory, or batch limited inventory might be compared.

5. CONCLUSIONS

The paper introduces to the economy of scope, by intelligent clothing manufacture. The competition between enterprises resorts to the process-added value of *actually sold* apparel, rather than to large products batches, requiring to run after buyers, with advertising or lower sale prices. High-standing clothes are noteworthy, as clients require personalised quality and quick service. The discussion offers hints to look after the integrated manufacturing approach and the fabric warehouse management is specifically dealt with. The process description is based on a modular layout, to separate the effect of influence quantities and to *investigate details*, preserving the overall view of the business. In this study, fabric faultiness is directly considered, showing the benefits out-coming from the before-hand exploitation of the defect maps to lower the material wastes.

One should emphasise the fact that, to-day, the clothing industries are work-intensive set-ups and extensively resort to the on-line operators versatility of to modify production, while the process progresses; this possibly hinders the benefit of *intelligent* manufacturing, based on the concurrent run of the material and the information flows for adaptive flexibility: - at the organisational range (process-attuned managers): to select the fabrication agendas; - at the co-ordination range (decentralised controllers): to optimise the cloth bolts choice; - at the execution range (real-time supervisors): to adapt the material dispatching service.

The example discussion shows that flexible automation can deal with foregoing information (cloth defect maps) on self-sufficient bases; actually, the benefits depends on a large number of cross-related facts and actual implementations, hard to be fixed, remain out of the reach of front-end operators. The area of high-standing garments, satisfying varying market requests, is exemplary case where automation provides critical support for quality certification. A complex innovation of, both, material and information resources shall be promoted, e.g.: • cloth warehouse with high dexterity, efficiency, flexibility and versatility fixture and with effective data-bases storing and management capabilities; • sophisticated shop logistic service for the material dispatching ruled by a decision logic incorporating on-process information by plausibility reasoning. The changes, however, need be investigated in terms of the expected returns; simulation studies are dominant help, to compare competing alternatives referring to actual production contexts and, moreover, to provide explanatory examples with training purport immediately related to sets of feasible implementations.