Textile and Clothing Industry: An Approach towards Sustainable Life Cycle Production

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Abstract—**In our economic system there is an urgent need for product quality and sustainability. This need is in the face of a growing destruction of non-renewable resources and the ceaseless degradation of the environment. It is based on wealth economics trading in new products to continue expanding well-being while limiting the ecological footprint including environmental effects, energy and material consumption, emissions all along the product life cycle. The goal of this work is the technical, ecological, environmental and social examination of the life cycle of traditional industry products. This paper focuses on the novel opportunity offered to textile clothing industries by trading off products-services, namely, enhanced products or extended deliveries, with a transparent accounting of resource depletion.**

Index Terms—**Sustainable manufacture, life-cycle, textile clothing industry, production modeling, extended enterprises.**

I. Introduction

Over the last two decades clothing manufacturing has become a truly globalised operation enabled by dramatic changes in the global political and economic context in which this industry operates [1].

On the economic side significant changes with impact on clothing-production patterns have occurred both in the industrialised and the developing world. Industrialised countries have witnessed significant changes in the structure of the retail distribution of clothing to the end consumer generally moving towards an increasing concentration of market share in the hands of larger national or international retail chains.

Apart from the more traditional department store and specialised clothing chains general retailers such as Wal-Mart, Carrefour or Tesco as well as hard discount retailers have also become major forces in clothing retail, leading to a concentration of bargaining power on the distribution side of the business and enabling access to remote low-cost manufacturing locations thanks to the sophisticated global sourcing, transport and logistics operations that these large companies can access or themselves orchestrate. Such concentration trends in the distribution sector have not been matched by a similar consolidation on the manufacturing side that remains highly fragmented and dominated by small to at best medium size companies.

Developing and emerging countries on the other hand became clothing manufacturing locations of choice as their economic and financial systems improved, their industrial and logistic infrastructure was developed rapidly and a massive migration of rural work force to the industrialising cities and development zones provided an abundance of cheap manual labour for a manufacturing system that does not required very high levels of skill and knowledge from its production workers. In some emerging countries like China, India, Pakistan or Turkey the expanding clothing manufacturing sector also increasingly benefits from abundant local supplies of textiles thanks to the build-up or massive expansion of textile production capacity from fibre – mostly cotton and man-made fibres such as polyester – often led by government-owned companies or private companies benefiting from privileged access to public funding.

Globally sourcing retailers and wholesalers massively exploited this opportunity for significant reduction of their purchasing prices to the detriment of textile and clothing manufacturers in industrialised countries which due to their higher input costs (labor, capital, energy, environmental and consumer-protection compliance, etc.) were increasingly unable to match prices offered by developing country producers. This led to constantly shrinking margins, thousands of company closures and contributed significantly to the job losses that occurred over the last two decades.

In order to stay competitive companies have been undergoing continuous restructuring and modernization processes (EMCC, 2008). As part of these processes they often invested heavily in new technology, research, product development and innovation capacities, adopted new business concepts and entered new higher added-value markets, resulting in continuous and recently accelerating productivity growth.

The changes in the global political and economic contexts have been truly transformational. The same cannot be said across the board for the further crucial dimensions of the manufacturing technology development, of preserving the garments quality as perceived by the customers and life cycle sustainability.

It is true that a number of semi- or fully automated technologies have been introduced on the garment manufacturing shop floor such as spreading, nesting, marker making for quality improvement and cutting system as well as the recent technical results in cutting table withdrawing and fabric parts handling [2] and to a certain degree in the ironing and garment finishing processes [3].

The industry's response of a major shift of manufacturing to low labor cost countries often far away from the point of sale/ consumption of the final product has in turn introduced additional complexities, risks and life cycle costs. Long lead times, inbound and outbound logistics, quality assurance

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procedures, a lowly skilled work force as well as a higher vulnerability to IPR infringements challenge these operations sometimes coupled with political or social instability or higher economic and financial volatility in these outside manufacturing countries [4]. The related costs and risks are borne by manufacturers and distributors alike and also limit them in the adoption of new business models based on:

- sustainable life cycle products design and manufacturing
- customer satisfaction through fast response to end market changes and deeply involving the consumer in scale customisation and personalisation of products;
- smart flexible networking in open value chains and business communities;
- use of the latest b2b and b2c e-business technologies.

Such new business models have, in a number of significant individual cases, proven their potential for significant economic value creation in an end market that becomes more and more segmented, fragmented and fast moving.

II. The Sustainability Paradigm

Recently, the ecological approach modifies the scientific background manufacturing strategy by adding important constraints to overcome the damages of the industrial economy, greatly based on the manufacture transformation efficiency, making withdrawals from finite earth stocks, and piling up waste and pollution amounts, exceeding the natural recovery potentiality.

In the near future new effective accounting schemes will be requested. The production of everything necessitates materials, compulsorily to be taken from somewhere. The processes require due monitoring. The balances split up the renewable and the non-renewable resources. The latter shall classify in term of (direct, instrumental, etc.) usefulness, (express, subsequent, etc.) toxicity, (local, global, etc.) rarity, and so on, assuming the unidirectional flow from provisioning, to useful products. The point-of-sale denotes the manufacturer's interest end, leaving entire responsibility of the use, misuse and disposal to the purchasers. These irresponsible supply chains are made legal by the current bylaws, but, in reality, this trend has to be renewed. Here is presented a new approach to manufacturing that enhances the new paradigm of products life cycle sustainability.

The description is coherent with the economic productivity, specified on the manufacture phase, and exploiting the instant supply/demand balance in the materials' provision, with no worry for the context. The method is faulty: the earth stocks will run out; the environment will turn lethal; only, the today consumers (producers and buyers) profit.

The manufacturing activity is vital to the economic strength of the nations even if the transformation of raw materials is a paradigmatic example of natural resources decay. Simple remedies require to recognize that the natural capital use requests refunding of all the withdrawals and· to assess the materials costs, with resort to fair legal metrology schemes. The refunding needs synthetic models describing the sensibility of the manufacture process to different paradigms. With earlier models, the delivered quantities added value, Q, is assumed to depend only on the contributed financial I and human L capitals. Simple linear relations have been assumed for increments description around an optimal setting, such as:

$$Q = Q_0 + a_i I + a_l L \qquad (1)$$

where a_i and a_l are algebraic constant selected for specific industrial sectors and specific management strategies. Enhanced models are in use, to include market entry thresholds (I_{min} and L_{min}), or saturations (I_{max} and L_{max}). Similarly, instead of bi-linear dependence, close to steady state, the lack of symmetry could have resort to non linear formulations.

Further, today, new paradigms, see Fig. 1, have to be taken into account, like mass intensity, energy intensity, extended service and function, health and environmental risk, resource conservation and revalorization.

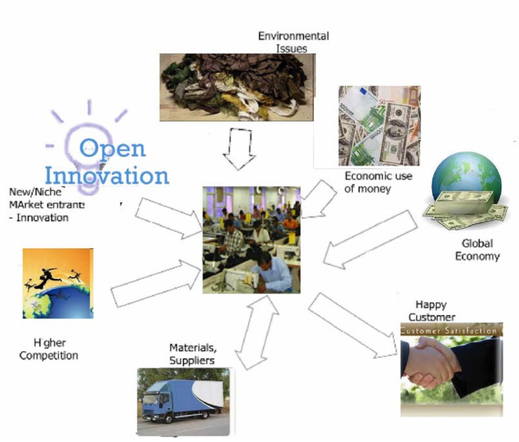

Fig. 1. Paradigms influencing garment manufacturing.

The environment protection is man's right at universal range, with outcomes to safeguard the future generations, not today, represented by efficient political parties or governmental agencies. Then, the democratic consensus or international agreements results deprived of justifications, whether limited to place the interests of the today citizens before. The fair socio-political approach, put forward by the knowledge paradigms, compels protecting the generations to come, by compensation ways, such as:

- to create a tax system, which consolidates the wealth corresponding to all withdrawal accomplished from the natural capital, following deposit/refund-like arrangements;
- to forbid natural capital withdrawals that exceed quotas, roughly equal to the reverse logistics recovery, or (hopefully) to the bio-mimicry stimulated generation, in view to keep the original natural capital level, by neutral yield.

The first way is formal, since, transforming different capitals, the equivalence criteria are, at least, ambiguous.

The second, if coherently applied, faces decay limitations, and today runs into the life quality decrease, towards the thrifty society. It is, moreover, possible to merge the two ways, using the "deposit-refund" choice as first instance, thereafter keenly researching innovative technologies, out of reverse logistics, which perform active replacing resources and full eco-remediation, to achieve neutral yield of the inherited natural capital.

The closed-cycle economic/ecologic processes are prerequisite of the manufacture markets to come. The analyses need to be quantitative, to make meaningful comparisons, fulfilling the assessments by recognized standards. The consistent closed-cycle appraisal brings to concepts such as the below new metrics (or similar equivalent standards).

III. A New Model for Sustainable Manufacturing

In recent years, great emphasis has been placed on the new-economy, with its possibility of generating wealth through intangibles: information, knowledge, technology, know-how, etc.. This leads to the introduction of new software and organization tools and to the modification of traditional ones by added high-intensity intelligence. Different estimates of the economic content exist [5], [6]. Careful analysis, has shown that including know-how and technology in an independent K factor, separate from invested capital I and human labor L, leads standard industrial companies to discover residuals, ranging from 2-3% to 20-30% or more in productivity increases [7]. Service enterprises can explore businesses where the new factor could even dominate.

Moreover, the assumption that industrial wealth, generated by capital I and labor L, can totally neglect the involved tangible resources T, needs to be revised. Since we live in a closed system, manufacturers and users benefit from raw material consumption, while third parties and future generations share depletion and pollution. Therefore, fairness requires that explicit accounting of the T factor should be done, imposing the cost of material and energy decay and collecting a tax from those who profit.

The value build-up in enhanced products or extended deliveries, Q, of the manufacturing industry appears related to four independent factors technical K, financial I, human L and natural T capitals, according to the non linear model:

$$Q = Q_0 + a_1 K^k + a_2 I^i + a_3 L^l + a_4 T^t \qquad (2)$$

where: K is knowledge and technology; I is invested capital; L is labor and T represents tangibles used and a_i are algebraic coefficients. The proposed relationship is a generalization of the formula proposed by Razzoli and Michelini [7] that results in the special case of k=i=l=t=1 and a_i all negative. The tetra non linear dependence assumes to operate nearby equilibrium assets and the factors have similar effects. Lacking one contribution, the balance is lame, and the reckoned productivity figures, untruthful or meaningless. The analyses investigate the piling up invariance is against the resort to nonproprietary technologies, or to off-the-market loans, or to work out-sourcing or productive break-up. Knowledge and technology K provide increased value by intangibles, enhancing capital assets I. The T-factor specifies the added value of transformed materials, energy, etc., in the same way as the L-factor is used to show the contribution of labour.

The K-factor becomes most significant, highly supported by the new economy, supplying the ability to trade in enhanced products, based on added knowledge and requiring suitably intelligent rules. It is related to the I-factor, assuring productivity based on intangibles, but cannot be reduced to financial assets. The T-factor is a penalty reference, connected with resource depletion. The sustainability choices need to be included in the price of every manufactured good, specifying the tangibles yield per unit service to account for non renewable resource depletion over the product life-cycle (from design and manufacture, to disposal and recovery). In this way, natural resources and the productivity of human labor come to be similar, competitive features. The T-factor is not yet fully recognized; each government enacts partial societal/environmental protection rules, mainly aiming at:

- defining admissible environmental impact figures, then limiting, or forbidding, the use of given products, unless proper conformance assessments are provided;
- supplying significant benefits for eco-consistent choices or collecting relevant taxes when high environmental impact is involved.

A price policy makes it easy to include material and energy consumption (by the tangible yield per unit service metrics or other equivalent standards), and this provides a rationale to grant fair-trade status, when reference rules are enacted on a world-wide basis. The issue is still rather disputed (the Kyoto protocols are a good example of the situation).

This model does provide hints to manage sustainability preserving wealth. For example, it offers a rule so that, any higher T cost will be balanced by equivalent K up-grading. The balance requires deep technical understanding of the phenomena and considerable political ability to deal with citizens and firms, still, reluctant to change behavior.

Also if the above given form cannot be used for real calculations, it supplies only ideas and qualitative relationships to go on the right way.

The expected technical trend is characterised by supply chains based on products-services, turning wealth generation from a mostly product market, to a mainly service market, since extended delivery combines manufactured commodities with enabling utilities. This trend is primarily dependent on engineering design, when life-cycle performance is specified (with the guidelines for operation, maintenance and disposal). Stress is placed on two facts: bringing out the explicit dependence on material resource consumption in pricing products and establishing third party certification for eco-labelling assessed by objective metrics. With the first, the depletion of natural resources is reflected in life-cycle pricing, affecting trade patterns, and requiring technical-and-scientific innovation, to provide product oversight and control up to disposal, as well as political and legal changes, to establish a manufacturer's responsibility at the point-of-service.

The spreading of extended supplies is, thus, connected with creating extended enterprises or virtual organisations, namely, alliances of partners merging skills, know-how and resources and joining efforts to co-design, co-manufacture, co-market, co-maintain, co-service, co-recycle, etc [8]. These would provide products-services for the benefit of customers and for the safety of the environment. Moreover, technology driven assets, though required, are not sufficient for sustainability, and legal changes shall add. Governments, on a compulsory basis, must do something to stimulate eco-consistency in consumer behavior with pricing policies based on waste charges; to discourage (or forbid) the over use and over marketing of resource depleting products.

If suppliers have a contractual obligation to support the life span of their deliveries, the trading price will include eco-consistency charges for use, maintenance, refurbishing and replacement. The life-cycle pricing becomes an explicit competitive feature between enterprises, on condition that objectively referenced trade arrangements are assured, controlled by independent authorities. Fair-trade, in fact, requires equal opportunity regulations, to prevent single individual corporations or countries from exploiting the heritage of mankind, dispossessing other people and future descents. This brings light to another fact, namely the requirement for third party certification based on objective metrics and operating with world-wide concern.

IV. Extended Enterprises and Cooperative Manufacturing

The connection between the two options, the enhanced products (or extended artifacts) and the extended enterprises (or networked concerns), leads to a series of issues, not yet wholly recognised. The EU industrial context is mainly populated by small, even nano, enterprises, achieving comparative effectiveness by joining flexibility to leanness.

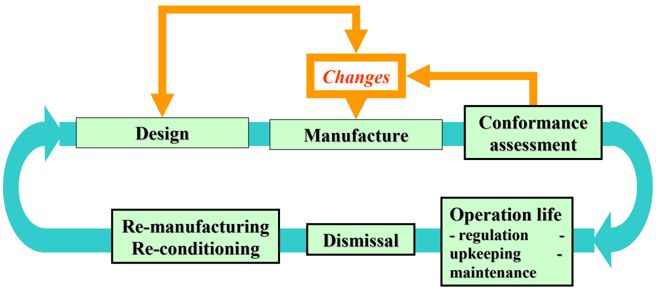

Fig. 2. Product life cycle management issues.

An extended delivery is conceptually established at the design steps, when the visibility on the life-cycle (dismissal included) is set among the built-in attributes. The practical implementation of potentialities, however, is actually deferred at the level of virtual organisations, when connected distributed infrastructures, Fig. 2, are enabled, to accomplish data collection and transfer for the product life-cycle management. After dismissal, re-conditioning or re-manufacturing shall become relevant options: reconditioning and remanufacturing. Re-conditioning has the goal to back establish overall conformance to specification, by combined industrial processes addressed to manufactured goods, at their primary life end (re-conditioning is limited, if re-setting is partial); re-manufacturing recovers parts and material possessing properties matching the original ones, by combined industrial processes addressed to dismissed products, and candidates them to new duty-cycles (the issue is limited, if the processed parts do not recover the original characteristics).

Although the expected advantages of interconnected infrastructures are properly recognised, the practical developments presently still suffer several drawbacks:

- lack of common reference models, to be shared as standard facility;
- lack of effective interoperability mechanisms and approaches;
- lack of eligible protocols and frameworks, without detailed characterisation;
- heavy design and engineering efforts, between proprietary technologies;
- rapid software and hardware obsolescence, frustrating provisional goals;
- actual obstacles in the effective transfer of locally tested instruments;
- lack of viable leadership, proposing low-cost linking environments.

Several collaborative set-ups can today be observed, mainly built on providers-ruled relationships and exploring web-based connected distributed facilities, with the related risks on data protection and transaction security. New and safe collaborative forms and behaviours, indeed, are emerging within large factories, with resort to purposely-enabled equipment, but number of inhibitors exists, when factual alliances of complementary partners try to merge into structured clusters.

Now, networking is enabling technology to grant extended supplies effectiveness, and formal collaborative environments need establish to give evidence of product life-cycle data. An integrated policy shall develop according to a set of goals, Fig. 3, properly tuning the on-duty consistency with due concern of the delivery technological sustainability from procurement to dismissal. The virtual organisations to such purpose play a winning role, at least for two reasons: to provide collaborative forms and behaviors for product life-cycle management and to rule conformance assessments within networked certification infrastructures. The drawbacks today associated with virtual organisations are, mainly, issue of the fast growth of technology-driven offers, ahead of market requirements. If the analysis on product-service delivery is correct, then connected infrastructures will become market-driven option. The extended enterprises, accordingly, will develop for well defined offers, specialising the web connections to individual requirements, so that, even in front of defective cross-link occurrences, decisive helps establish by properly finalised patterned frames, enabling the surfacing of filtered knowledge whether the series of consents verify, for the selected tracks leading to:

- interoperability by integration and sharing of federated information;
- management of distributed activities, based on self-acting clusters;
- supply-chain transparency given by eco-consistency assessment records;
- goal-oriented co-operative knowledge problem-solving capability;
- sectional bounded and case-driven trust building processes;
- similar enhancing opportunities, based on distributed intelligence.

The enhanced product concept, according to the analysis, is first step for sustainability, whether further steps are: life-cycle visibility, consumption monitoring and decay certification. Then, the extended enterprise concept results in an interconnected structure, Fig. 3, with inner and outer loops and multiple selective links. The patterned frames provide scaled benchmarks, which make easy selecting the procedural methods to enhance profitability, carefully keeping the leanness of the prospected extensions. The examples provide hints to the designers, to orient the interconnected infrastructures to support clustered enterprises by competitive advantages, in front of suppliers, users, controllers or dismissal operators.

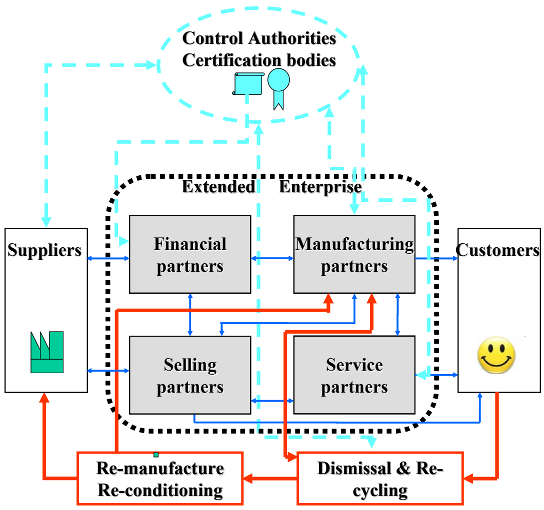

Fig. 3. Example networked organisation for the whole supply chain set-up.

The request of sustainability falls in-between basic goals, as soon as the related incumbents are critical demands. Eco-consistency, thereafter, does not need procedure changes; it simply widens the series of checks, while the patterned frames deal with the particular product enhancement. The extended enterprise originality depends on setting the on-duty abilities and on supplying the guarantee that the infrastructure behaves with given performance; the connecting web makes delivery effective, with assessment of the return on investment and with recording of falls-off, including tangibles yield (resources effectiveness), when eco-consistency paradigms are considered.

This leads to a further reason that makes extended enterprises market-driven winning options. The supply-chain transparency is basic accomplishment for the cost assessment of non-renewable resources consumption. The collaborative nets, besides survival opportunity for the clustered firms, offer patterned frames opened, under appropriate security levels, to customers and to control bodies. The users ought be involved into conservative behavior up-grading, with due account of recovery schemes leading to method innovation, according to rules recalled in the following. This virtuous trend has, possibly, to be promoted and steered by cultural and legal frames, through enhancement and enforcement mechanisms, progressively assuring consistently educated improvements. In the meanwhile, the data provided by the supply-chain transparency could be exploited for recording the conformance checks of the enhanced products, with the attendance of control authorities.

This scenario is, possibly, optimistic. The rule of a Government Agency, indeed, is consistent in front of (compulsory) sporadic checks, all in all, slightly affecting the artefacts availability. In front of life-cycle long incumbents, the formal access to Agencies might become severe restriction for the individual users freedom, not even fully assuring environmental protection. The link of the clustered partners to third party certifying bodies opens a different way to face exhaustive incumbents, while preserving personal data security and eco-consistency information recording. These smart networks, with patterned frames topology, are multi-faceted realities, with, certainly today, several drawbacks, but quickly changing into lean set-ups, as soon as market-driven requirements need be satisfied. System integrity and security control will evolve to reach the smartness range of the frames timely adapted to varying incumbents, with inner and outer partners, dedicated clients and authorised supervisors.

V. Integrated Simulation Environment

The success of the new manufacturing systems highly depends on the capability of really taking advantages of the pertinent data, to adapt products and processes on the strategic, tactical and operative spans, avoiding resources redundancies with concern to sustainability policies. 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 the off-line and on-line life cycle stages. The off-line stage refers at the system design-development: the resources setting is fixed in view of enterprise sale strategies and production plans are stated for balanced throughput and due time; the on-line stage refers at the system management-fitting stage: the production schedules are managed to overcome programmed (e.g. order itemisation) or unpredictable internal (e.g. machine failure) and external (new urgent order) discontinuities.

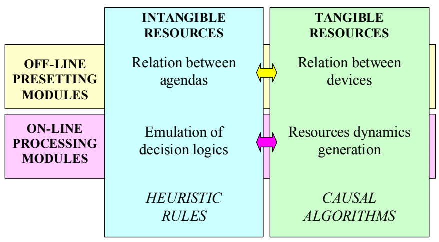

Fig. 4. Modularization of the simulation environment.

To reach both purposes, 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 resources has to 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, see Fig. 4, and detailing the declarative (resources description, system hypotheses, etc.) and the procedural (governing rules, performance criteria, sustainability indexes etc.) knowledge.

Multi objective performance index is proposed that takes into account with the weights properly defined by the end user the main criteria of success, see Fig. 5: life cycle cost, sustainability in terms of energy efficiency and green manufacturing (effects on the environment), human safety at work (based on ergonomic factors), reduction of direct and indirect labor and materials, lead time and delivery figures or time to market according to customer's expectation, plant adaptability and flexibility facilities.

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 in terms of traditional and eco performances ought be investigated and this shall be done distinguishing direct from cross-related effects.

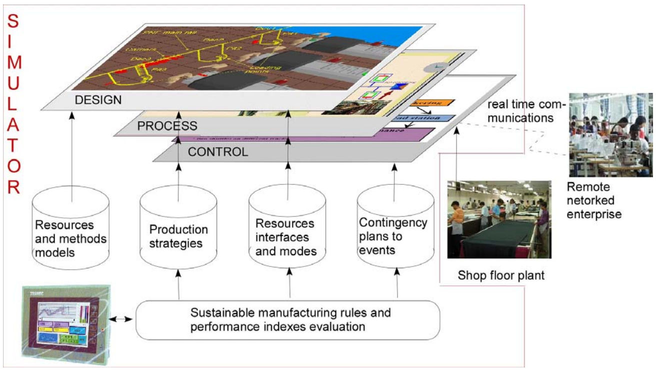

Fig. 5. Integrated simulation environment architecture.

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 requirements and eco consistency. 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 traditional manufacturing industry like textile clothing, where 'intelligent factory' set-ups are still observed with caution, since addition of technology-driven options to a labor-intensive environment cannot be accepted without having previously acknowledged the returns on investment. After throughout investigation of achievements and drawbacks, the simulation, offers affordable commitment, making possible to rank competing manufacturing facilities and plans.

VI. Conclusions

The paper goal is to give some hints to include eco paradigms in the assessment and comparative evaluation of different stages of manufacturing processes and product life-cycle. We specially emphasize re-use and re-cycling as important LC phases, due to approaching water, energy and raw material shortages.

On product we mean anything which is used by simple users (a garment, a furniture, a car, a cup, a bike, or a part of them, etc.), or which are used by dedicated users to produce or manage other products (a machine tool, a robot, etc.), or which are used to manage everything else (a firm, a factory, a ministry, etc.). We differentiate between simple products and extended products and between tangible and intangible assets (aspects) and service is taken into account as a product, too.

The tangible yield per unit of service metrics and the sustainable manufacturing model say, that the delivery of a firm can be calculated taking into account four main factors, as Knowledge (innovation), Investment, Labor (financial and human capital) and Tangibles (materials); a non linear relationship is proposed that can be modified by appropriate constants and additional factors.

Based on these calculations real data can be given on all effects and side effects of products and productions, e.g. recyclable wastes and energy efficiency can be properly evaluated.

The proposed ideas and formulae have to be adapted for real world situations not only to assist designers, production engineers and managers in their work, but politicians and other decision makers as well.

Acknowledgment

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