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Supply chain design and sustainability in the textile sector

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Abstract. A project where optimization techniques and life cycle assessment methods are used to select a supply chain balancing economical and ecological factors is described. In particular, the optimization component will be analysed, modelled in mathematical terms and solved with methods previously appeared in the literature. The supply chain considered is the one of a top-brand firm in the textile sector.

Keywords: supply chain design; sustainability; k-shortest paths; textile sector

Introduction

Within the EU-25, clothing and textiles account for approximately 3-5 % of our environmental impacts [1], and globally this figure is even higher as Europe and the US have delocalised and outsourced most of the textile production, in an effort to reduce costs to the bare minimum. This has been possible at the expense of the quality of life of workers in developing countries, and of the environment, as risky and hazardous processes are subject to less stringent legislations. Recently things have been slowly changing: some segments of the customers` market are switching to the so-called *Lifestyle Of Health And Sustainability* (LOHAS) [2]. Key to LOHAS is the respect of the environment and of the workers` conditions. While in the mid to long-term we expect that LOHAS will be widely adopted, at present only some brands and sectors can afford to enter the LOHAS market, especially the prestigious fashion industry that holds high commercial gains by benefitting from the first mover advantage.

The Swiss textile and clothing industry has a tradition for quality and innovation. The Swiss customers are also sensible to environmental issues, as Switzerland has the highest per capita consumption of textiles associated with organic farming. Switzerland is therefore in the position to profile itself as the lead provider of knowledge on highly ecological, socially responsible, and competitive textile products and processes. However, in order to achieve this, we need to provide the Swiss textile industry with support tools to design and implement *sustainable supply chains*.

Sustainability in supply chains is not easily measurable, as it comprises both quantitative economic aspects, and also qualitative and quantitative aspects (such as environmental friendliness and social equity compliance). Moreover, the evaluation of a supply chain must also embrace the direct and indirect manufacturing processes, which might have considerable impacts on the overall performance. Finally, even if a company has evaluated a supply chain for a selected product, the extrapolation of the results to other products or different supply chains must not be taken for granted at all.

Various projects address the task of assessing the sustainability of a supply chain. *EcoIndex*^{TM} [3] is based on qualitative principles and management practices and is to be used as an educational tool. *Considered Design* [4] offers a tool employing a numeric scoring system. However, Considered Design is an input oriented method, meaning that the material types are rated according to their environmental performance. Although the rating of the materials is based on *Life Cycle Assessment* [5] -- at least in part -- the tool does not reflect a LCA approach. This reduces the accuracy of the tool. *Intertek* also offers a tool that allows the computation of the LCA of a supply chain [6]. We remark that all of these approaches start from an existing supply chain to measure its performance. When one leaves the supply chain designer free to choose among alternatives, in order to design a *best-compromise* supply chain the problem might rapidly become unwieldy, as the complexity of the supply chain grows. This happens even for a simple garment such as a shirt. Therefore, the supply chain manager needs a tool to (re-)evaluate supply chain options with respect to sustainability improvement potentials and to base improvement actions on a solid ground. Such a tool is the main outcome of the Swiss CTI project *EcoLogTex*, which will be described in the reainder of the paper. The required sustainability data has to be obtained from the textile industry suppliers who, in exchange, are offered the possibility to benchmark their processes with other manufacturers in the same product and process category. As a result, the textile company will be able to provide its customers with reliable and transparent information on the sustainability performance of its products.

Description of the Ecologtex project

This project aims to deliver a web-based software application, named EcoLogTex, for the *sustainable design* of the supply chain of textile and apparel companies. The key idea is to integrate Life Cycle Assessment (LCA) in each step of the supply chain in order to add the environmental perspective when designing an efficient supply chain. The Life Cycle Assessment methodology will allow specifying all the environmental impacts of the production and distribution processes related to the product distributed down to the shelf of a shop.

The main components of EcoLogTeX are:

- *Benchmarker*: it is a web-based software application in which suppliers (of goods, of processes, of services) enter the relevant data for their products and services attracted by the gains in competitiveness as suppliers to the textile company and thus fill the data for a holistic supply chain evaluation. The supplier has two advantages in using the tool: first, it can qualify as a potential supplier for the textile company; second, it obtains a quick check of its *sustainability performance* in comparison to its competitors, leading to an even higher quality of their offer.
- *Supply chain designer*: it is a stand-alone software application for the design of sustainable supply chains. The tool can explore the potentially very complex current and alternative supply chain situations and identify the space for design alternatives, based on the background data from the *EcoInvent* database [3] but also specific supplier data from the EcoLogTex *benchmarker*. This allows for continuous improvements towards a sustainable supply chain. A detailed description of this component will be provided in Section 3.
- *Reporter*: it is a stand-alone software application for producing reports to be published on the company website regarding its supply chain sustainability. It uses the data provided by the suppliers and confirmed by an independent party (e.g. the *EcoInvent* database).

Also, we expect a positive side-effect of the project: as the use of the EcoLogTex *benchmarker* will spread, more anonymous data will be collected on each type of process and product. Non-governmental organisations can therefore benefit from this wealth of data.

The EcoLogTex supply chain designer

The *Supply chain designer* is the core component of the project, since it provides alternative supply chains to production managers according to the important she/he gives to different factors such as economic, time or environmental aspects. More in details, the manager will be asked to regulate the weights of the different factors involved into the otpimization process leading to the most promising supply chain. In such a way she/he can find the best supply chain design according to the policies of the company. Notice that such a process will normally ne an iterative one, where the manager sees some proposal on the screen, modifies the weights of the different factors based on the results and the expectations and proceed likes this until she/he is satisfied. The input of the optimization comes both form the contracts the company has with the different suppliers/carriers (mainly in terms of production/delivery costs and times) and from more general sources of information such as the *EcoInvent* database, where general environmental impact information is provided for the different steps of the supply chain. Notice that the information is in our case refined by the information collected within the *Benchmarker* component. On the other hand, the output of the *Supply chain designer* will be the central input for the *Reporter* component of the project.

Mathematical model

Given a product with specified operations to be carried out for its production, the optimisation problem at the basis of the *Supply chain designer* can be represented in mathematical terms on a directed graph $G=(V, A)$ where V is a set of nodes representing the states of the product production, where node s is the starting node and node t is the final state (finished product at the destination warehouse). The arc set A contains all possible production/transportation steps encountered in the supply chain, and walking arc $a= (i,j) \in A$ (with $i, j \in V$) will mean that the product moves from state i to state j through process a. Notice that not all arcs will be present (depending on the compatibility of successive production stages) and that the resulting graph is a layered graph, where at each layer there are alternative production histories of the product. A simplified graph is depicted in Figure 1.

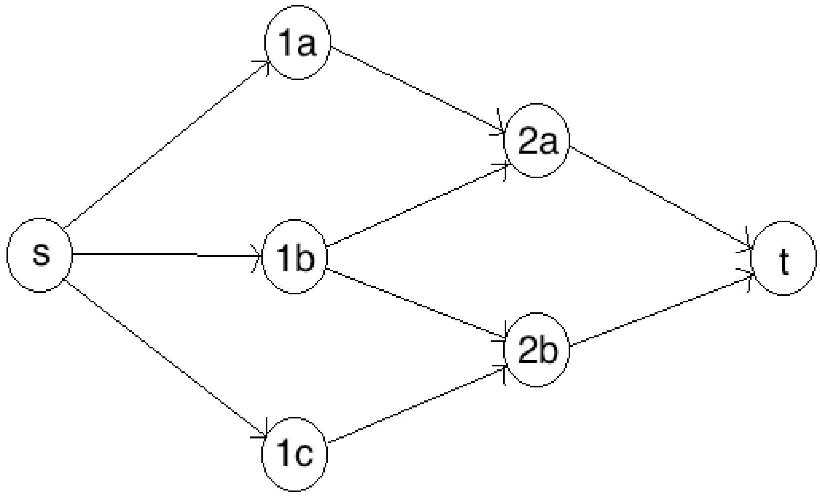

Fig. 1. an example of graph associated with a supply chain. For each layer (production/ transportation process) different alternatives are present, with given interlayer compatibility.

A set of labels is associated with each process/arc *a IN A*. They represent the indicators later used by the optimization in a weighted fashion. In details, for each arc, the following labels/indicators are present: *cost(a), time(a), lcai[1](a), lcai[2](a), ..., lcai[8](a)* where the last 8 labels represent the different LCA impacts considered during the calculation. Labels are real number between 0 and 1 representing the indicator normalized between the lowest and the highest possible values for each category. This normalisation makes possible to compare (and weight) quantities that otherwise would have very different definition domains (ranging between 10^{-4} and 10^4). Notice that in case the arc $a = (i, j)$ is associated with a production process, the indicators will only depend on the tail node j, and all arcs entering node j will contain the same indicators. Finally observe that all arcs entering node t will have all labels at 0 by construction.

A set of weight w_{cost}, w_{time}, $w_{lcai[1]}$, $w_{lcai[2]}$, ..., $w_{lcai[8]}$ have finally to be specified by the supply chain manager using the application. These weights are positive real number summing to 1 and are used to specify the importance of each one of the factors during the optimization.

The problem of finding the best supply chain, according to the weight selected by the user reduces therefore to the well-known *Shortest Path Problem* [7]. Given the weights, the path P from s to t with the minimum the following function is the best path:

$$\sum_{a \in P} \left(w_{cost} cost(a) + w_{time} time(a) + \sum_{k=1}^{8} w_{lcai[k]} lcai[k](a) \right)$$

Due to the context in which the method is used we however prefer to present the user with the best k shortest paths, with k usually in the order of 10-15. In such a way the user will be able to visually evaluate the solutions and eventually modify the weights of the various factors consequently, aiming at best matching the policies of the company, that often cannot be schematized into simple weights. Such a dynamic and iterative process will be based on a user interface currently under development (see Section 3.3).

Optimization algorithm

The algorithm used to retrieve the k shortest paths according to the given weighted combination of factors is the well-known state-of-the-art approach presented in [8]. Notice that in our case the required paths will be provided with an extremely short computation time, thanks to the very limited number of paths requested and to the limited dimension of the graphs associated with supply chains: the processes required to produce a textile product are not many, and even for large companies, the alternatives for each production/transportation step are usually limited in number (see Section 3.3).

Preliminary experiments

Preliminary computational experiments for the approach described in Section 3.2 have been carried out on some realistic artificial scenarios, obtained by considering the characteristic of the real supply chains currently used by Hugo Boss for a few different products. In particular, a typical product has between 8 and 15 production stages, with a number of alternative factories/carriers ranging between 2 and 9 (with typical values below 4) for each stage. The range of values for most of the factors is fairly large: for example a shipment can be either very fast, expansive and with large environmental impacts, or slower, cheaper and more sustainable. Notice that there are often correlations among the different factors.

Results on the constructed instances proved that a few seconds are always enough to rank all possible supply chains (paths) according to the given weighted objective function. Notice that in some cases more than one thousand paths are retrieved. As explained in Section 3.2, in the context of our application only a few paths (10-15) will be presented to the user for each given combination of weights. This indicates that the algorithm described in Section 3.2 perfectly fits the need of the project, since it runs in negligible times in the given conditions.

In a later stage of the project, after the completion of the *Benchmarker* component, real data will be available and it will be possible to run the algorithm on real alternative supply chains. At that stage the user interface of the *Supply chain designer* will also be available. Some sliders will let the user define the importance of the different optimization factors. Based on these values, and on the consequent weighted objective function, a ranked list of the most promising supply chain alternatives will be provided. For each solution, the different enterprises carrying out the different working phases will be shown, with the respective value of the weighted objective function. For each production step, the values of the single optimization factors will also be shown. The user will be able to move the sliders at any time, to modify the weights of the different optimization factors. The *k* shortest paths algorithm will be run dynamically at each change of the sliders, and the results will be adapted consequently on the screen.

Conclusions

In this paper, we have described the aims of the EcoLogTex project, which is expected to deliver a set of tools for the analysis and design of supply chains in the textile sector from a sustainability point of view. The idea is to use LCIA to compute the environmental impact of the various processes and material flows in the supply chain related to a textile product and to use such impacts in the calculation of alternative designs for the implementation of the supply chain, integrating them with cost and time performance indicators. Thanks to this approach, it will be possible to run the sustainability assessment of a supply chain "ex-ante" rather than "ex-post", thus allowing textile companies to better focus their effort in the difficult task of maximising their environmental performance, while keeping the costs at a reasonable level. In particular, the supply chain designer has been formalised in mathematical terms and practical solving methods have been described. The approach has finally been shown to be feasible when used in realistic scenarios.

Future work will be twofold: on the one hand, uncertainty, which is intrinsically present in the factors used for the optimization will be taken into account. On the other hand, the user interface of the supply chain designed will be completed and the tool distributed.

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References

Tukker, G. Huppes, J. Guinee, R. Heijungs, A. de Koning, L. van Oers, S. Suh, T. Geerken, and P. Nielsen. Environmental impact of products (EIPro). Technical Report EUR 22284 EN, Institute for Prospective Technological Studies, Joint Research Centre, European Commission, 2006.

M.J. Cohen. Consumer credit, household financial management, and sustainable consumption. International Journal of Consumer Studies 31(1): 57–65, 2007.

EcoInvent Centre. Swiss Centre for Life Cycle Inventories. www.ecoinvent.org. Last visited March 2013.

Nike Inc. Nike considered design, 2010.

G. Finnveden, M. Hauschild, T. Ekvall, J. Guinee, R. Heijungs, S. Hellweg, A. Koehler, D. Pennington, S. Suh. Recent developments in Life Cycle Assessment. Journal of Environmental Management 91(1): 1–21, 2012.

Intertek. Instant LCA web portal for textile and footwear, 2012.

E.W. Dijkstra. A note on two problems in connexion with graphs. Numerische Mathematik 1: 269–271, 1959.

E. Martins, M. Pascoal. A new implementation of Yen's ranking loopless paths algorithm. 4OR 1(2): 121-133, 2003.