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Decision support for collaboration planning in sustainable supply chains

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Abstract

Organisations have to deal with increasing challenges in their supply chains. Their decision makers brought to balance economic performance with environmental and social issues. Methods and concepts for jointly optimizing economic, environmental and social cost of operations in supply chains are challenging. Decision support systems could help organizations to support sustainability in their supply chains. A collaborative decision-making framework for sustainable supply chain planning is proposed in this paper. This framework facilitates the development of multi-party collaborative relationships across a network to improve the sustainability of delivered products. It supports a new information and communication technology (ICT) system platform. The platform provides insight for infrastructure and visibility to support supply chain sustainability requirements. The proposed decision support system proposes simultaneously collaboration and sustainability functionalities missing in many existing supply chain planning systems. This system has been evaluated and validated through a pilot program across a range of food supply networks. The work is motivated and applied by a major European research program in the food-agri supply chain.

Keywords: Supply Chain Planning, Decision Support System, Sustainability, Collaboration

1. Introduction

Global and local supply chains are increasingly facing environmental and social issues including population growth, climate change, water and energy, pollution, health and safety, human rights and poverty. These concern impact material production, ranging from extraction and manufacture, to sourcing and delivery. Demand keeps rising and expects at the same time affordable products with minimal environmental and social burden. Organizations are wary of these issues along their supply chains, many times these issues are hidden from their visibility. This difficult balance and expanded production outlook add managerial and decision-making complexity. With these forces, economic efficiency is only a partial

business success criterion. Organizations require facilitating decision approaches to balance economic expectations and environmental and social footprints.

The Triple-Bottom-Line concept (3BL), incorporating the economic, environmental and social dimensions, has been proposed as an organizational and supply chain paradigm for this sustainability environment (Carter and Rogers, 2008). Balancing, or optimizing, 3BL can guide organizations in achieving sustainability goals demanded by their stakeholders. Planning helps in managing organizational and supply chain complexity. Coordination of decisions across and within organizational functions is central to this planning. Extending beyond the organization, logistics and production operations need to be planned and executed through increased collaboration between partner firms in a supply chain.

In order to make a step change when dealing with supply chain sustainability, this paper introduces an aided decision-making framework for collaboration and sustainable supply chain planning. This framework supports decisions to help organizations manage economic, environmental and social efforts of their supply chains in a collaborative way. This framework facilitates the development of multi-party collaborative relationships across the entire network to improve the overall sustainability of delivered products.

The proposed framework informs a new information and computer technology (ICT) system called the “Collaboration Planning Tool” (CPT). CPT proposes an infrastructure to visibly support supply chain requirements to deliver long-term sustainability across product supply networks. CPT supports developing aided decision-making and planning applications, taking into account dimensions not typically covered by existing supply chain planning systems, like Advanced Planning Systems (APS).

The proposed system is developed and evaluated through a pilot program with different food networks in Northwest Europe to illustrate real value delivery in a practical and operational environment. The intended focus is on the trade-off, or potential ‘win-win-win’ opportunities, between economic performance, environmental footprint and social impact. Using the CPT framework, and its platform, sustainability indicators and decisional process for supply chain planning may be comprehensively taken into consideration. On term of managerially prescriptive, models of how to design and manage collaborative supply chains is an outcome of this framework. According to our knowledge, CPT is the first framework to propose taking into account the three dimensions of sustainability when dealing with collaboration planning for supply chains at strategic, tactical and operational levels.

The paper is organized as follows. We first review existing planning systems for supply chains and their advantages and weaknesses. Second, we introduce concepts and methods related to sustainability and collaboration. Then we present an innovative decision support framework dealing with sustainability and collaboration when planning a supply chain. After presenting the scope and objectives of the proposed Collaboration Planning Tool (CPT) we describe the CPT components, modules, functionalities and the software structure. Some details on the application development environment for CPT are given. Last, we present three pilots of the developed system in the context of the SCALE project (Step Change Agri-food Logistics Ecosystems) (Project SCALE, 2012), a European research project. These pilots focus on planning collaborative and sustainable logistics and agri-food supply chains. Feedback and lessons learned from industry are given.

2. Supply chain management

In general, a company’s supply chain includes organizational partners involved in value creation and the sale of products—from suppliers to the final consumer. Supply chain

management means coordinating flows of materials, information and capital both within and between supply chain partners. This chain ensures the production and distribution of products at the right time, to the right place and in the right quantity, while respecting the requirements of consumers: and all at the lowest possible cost (Stadtler and Kilger, 2005; Beamon, 1998). In this section we will first review existing concepts and works in the literature related to supply chain planning and related coordination and collaboration issues. Then we overview aspects of advanced planning systems.

2.1. Supply chain management and supply chain collaboration

A supply chain is a complex system with many functions, activities and organizations. This complexity represents a real challenge to overall performance; challenging the robustness and resilience of supply chains. To overcome these concerns, the supply chain requires coordination (Holweg and Pil, 2008).

There are several definitions of coordination in the context of a supply chain. Coordination is a strategic response to the challenge posed by supply chain partner interdependence. Coordination is the act of managing entity dependencies with joint effort to work together towards mutually defined goals (Xu and Beamon, 2006). The benefits of coordination include better use of resources, reduced operating costs, increased profits, improved customer satisfaction and increased efficiency in product development (Hou et al., 2017; Prajogo and Olhager, 2012; Horvath, 2001; Affonso et al., 2006; Donselaar et al., 2000; Flynn et al., 2010).

Supply chain coordination can be supported through functions such as forecasting, production management, maintenance management, distribution management and transportation, product design, and upstream and downstream interfaces (Arshinder and Deshmukh, 2006; Pashaei and Olhager, 2015). It may also relate to simple activities. In a cross-dock warehouse, for example, the arrival and departure of trucks can be coordinated. Integration, collaboration and cooperation are also connected to supply chain coordination (Stevens and Johnson, 2016). The supply chain literature highlights that these notions are sometimes seen as complementary aspects of an overarching concept of coordination. Sometimes they are used to translate coordination mechanisms.

Cooperation represents joint execution of an operation that requires sharing resources (Narus and Anderson, 1996). Integration refers to a combination of different decision-making levels (Stadtler and Kilger, 2005). There are two types of integration: horizontal and vertical. The former concerns joint planning of flows at several layers in the supply chain. The later concerns the synchronization of two or three strategic, tactical and operational plans.

Even decision makers in supply chains show sometimes their distrust of constructing collaboration relationships and of its impact on the performance of their companies, collaboration according to research, is a necessity for building competitive advantages. Collaboration means working together by sharing resources, information, objectives and risks (Kim et al., 2006; Simatupang and Sridharan, 2004; Herczeg et al., 2018). Collaboration can be between supply chain members or between supply chains. We talk about collaboration when several organizations and companies working together are involved in normal commercial relationships. Collaboration is an answer when organisations and companies cannot alone find solutions to common problems to achieve expected performance indicators (Huxham, 1996; Corbett et al., 1999; Barratt and Oliveira, 2001; Wagner et al., 2002).

The mechanisms used most often in the literature include: (i) Contracts are used to improve the management of the interface between the buyer and the seller to reduce risk

(Tsay, 1999); (ii) Sharing information is mainly linked to demand and is used to reduce inventory and limit costs (Reddy and Rajendran, 2005); (iii) Information technologies consisting of real-time information tracking. Tools such as ERP (Enterprise Resource Planning), EDI (Electronic Data Interchange), CPFR (Collaborative Planning, Forecasting and Replenishment) and MES (Manufacturing Execution System) are used in these collaborative and coordination efforts along the supply chain (McCarthy et al., 2001); (iv) Simultaneous decision-making refers to the integration of decisions and simultaneous execution of plans related to several functions in the supply chain (Barron, 2007).

Many works dealing with supply chain planning and collaboration focus on transportation planning. Collaborative Transportation Management (CTM) is an approach that has emerged to pool transportation resources through one or more supply chains between multiple partners while sharing information and risks. This collaboration could exist between carriers but also shippers can collaborate to propose common shipments to a carrier to minimize their transportation costs (Yilmaz and Savaseneril, 2012). The objective of the CTM is to increase the flexibility and minimize inefficiency of involved partners on term of transport processes/activities/resources and to ensure an acceptable sharing of gains generated by the collaboration (Felix and Chan, 2011).

Operations Research methods (optimisation, simulation) have been used to evaluate the impact of CTM at global level and individual level between partners. One of the major issues addressed in the literature on term of CTP is collaborative routing between carriers (Dai and Chen, 2012; Liu et al., 2010). Carrier collaboration considers how carriers can reduce costs by sharing their vehicle capacities and transportation requests. Two scenarios were widely taken into consideration when dealing with load of sharing trucks. First one is less than truckload (LTL) transportation that maximizes load-fill of the trucks. The second one is full truckload (FTL) transportation that minimizes backhauling (Liu et al., 2010; Dai and Chen, 2012).

2.2. Supply chain planning

Planning in the supply chain involves several important decisions ranging from strategically opening a facility to operationally scheduling a task on a particular machine. In order to optimise the preparation and coordination of these decisions, various plans are put in place. Generally, three levels are considered: strategic, tactical and operational (Bouchard et Al., 2017). The level of detail in the data they are based on, the breadth of their influence and their timescale differentiate these plans. They relate, respectively, to decision-making in the long, medium and short term.

Planning consists of developing directions in order to achieve objectives. Once in place, managers must monitor and adjust these plans in order to adapt to any changes that arise during their execution (Esmaeilikia et al., 2016). In supply chain management, planning can be long term (e.g. opening a new plant), medium term (e.g. development of production plans) or short term (scheduling). Therefore, there are three management decision and planning levels: (i) Strategic planning: which concerns decisions that have a long-term and broad impact on an organization. Externally, it has a primary aim of market satisfaction and building competitive advantage. Examples include the location of (production or distribution) sites taking into account potential suppliers, capacity, and flows of materials and products throughout the logistics chain. The location and allocation problem is a key concept, which corresponds to the design of the supply chain. (ii) Tactical planning: This concerns medium-term decisions such as production planning, purchasing, frequency of visits of customers, and transport rules. It is aimed at market satisfaction. (iii) Operational planning: This concerns

short-term decisions. It focuses on scheduling sequences and the allocation of resources to tasks. Examples include the sequencing of production tasks, the allocation of trucks to docks at a warehouse, and vehicle routing.

Planning systems have evolved to meet the needs of business and improve competitiveness. One of the first was MRP (Material Requirements Planning), which appeared in the 1960's and which is based on a simple system to calculate material requirements. It was later extended and became MRPII (Manufacturing Requirements Planning) in the 1980's, which is a form of finite capacity planning. Later, ERP (Enterprise Requirements Planning) appeared in the 1990's, which integrates other aspects and functional operations, such as marketing and engineering, that scope beyond production (Grabot and Botta-Genoulaz, 2005; Dickersbach, 2006). All of these tools require and store information. APS (Advanced Planning and Scheduling) tools have appeared that overcome the shortcomings of ERP with respect to decision making and analytical modelling, by integrating operations research techniques to optimize planning and coordinate flows at all levels of the supply chain; especially in an era of 'big data' and supply chain risk, uncertainty and complexity (Stadtler and Kilger, 2005; Hvolby and Steger-Jensen, 2010; Arunachalam et al., 2018). Many studies have highlighted the need to pay particular attention to uncertainty in supply chain planning, e.g. Brusset and Teller (2017). In a recent review (Govindan et al., 2017), uncertainty is due to: (1) parameters such as supply, demand, and costs, and (2) the uncertainty caused by natural or manmade disruptions. Two concepts have emerged in the context of optimization given supply chain uncertainty: robustness and resilience (Durach et al., 2015).

2.3. Advanced Planning Systems (APS)

APS emerged as a supplement to traditional planning methods, especially targeting problem solving (Dickersbach, 2006; Öztürk and Ornek, 2014). These tools take into account constraints and objectives throughout the supply chain, as they integrate planning modules for global optimization. APICS, the international professional organization for supply chain management, refers to a fully computerised APS system that uses advanced, optimized algorithms and simulation techniques to plan supply chain operations at the strategic, tactical and operational levels. Global optimization is made possible by taking into account all of the constraints found at different layers of the chain (suppliers, production, distribution, demand). Major APS modules include demand planning, production planning, production scheduling, distribution planning, and transportation planning.

Traditional planning systems such as ERP use a step-by-step method to allocate resources to demand, while the two are calculated separately. Often constraints, related to availability and capacity, are not taken into account. APS systems can overcome these shortcomings. They can coordinate procurement, production, distribution and demand by planning needs and capacities simultaneously. To achieve this, APS systems use advanced optimization and simulation techniques. In practice, they provide concrete evidence that the sophisticated algorithms developed in operations research can be applied in practice (Gayialis and Tsiopoulou, 2004). APS systems have two advantages. They enable the coordination of functions throughout the supply chain by integrating relevant decisions; and provide advanced optimization and simulation techniques can evaluate several alternatives and choose the best. If these two interlinked capabilities are to be effective the APS should be integrated into an ERP, WMS (Warehouse Management Systems) (Stadtler and Kilger, 2005) and MES (Manufacturing Execution Systems). APS decision support systems require information support. Having systems integrated to support coordination in the supply chain

with sustainability is where current focus is required and is lacking in APS systems design. It is this gap we seek to address.

3. Sustainable supply chain management

In current supply chain planning systems (such as APS), coordination is present but there are shortcomings. These shortcomings occur because coordination mechanisms are not properly applied. Collaboration is needed to complete the coordination process to improve 3BL indicators. This paper addresses two shortcomings that reflect the contribution and aim of the proposed research, collaboration and sustainability.

First, coordination (as it is considered in supply chain planning systems) does not take into account the challenge of sustainability. It is often the case that supply chain operations optimization models only have one objective function, minimizing overall costs. However, multi-criteria approaches are needed to jointly optimize economic, environmental and social costs. The concept of the sustainable or green supply chain has emerged and has very quickly evolved from being viewed as a constraint to being viewed as an objective for maximization (Sarkis and Dou, 2017). Integrating economic decisions and sustainable development (e.g. energy, water, CO2 emissions) can improve overall organizational and supply chain performance.

Secondly, the APS planning process is typically associated with a single organization. APS systems have started adopting supply chain management principles in optimising plans, but many APS tools do not realize the benefits of taking into account and optimizing supply chain collaborative and coordinating operating relationships. Vertical, horizontal and lateral coordination each occur in supply chains (Bahinipati et al., 2009; Bahinipati and Deshmukh, 2012). The implementation and optimisation of collaborative supply chain plans can be related to sustainability; providing greater competitive opportunities. Collaborative supply chains with sustainability are complex systems and can greatly influence supply chain partners (Bai and Sarkis, 2018; Bai et al., 2016). For these reasons, organizations entering collaborative relationships can greatly benefit from frameworks and tools to guide them through the planning process and to facilitate the development of multi-party collaborative relationships for improving the overall supply chain sustainability.

In the proposed decision support system presented in this paper we seek to overcome the two challenges, sustainability and collaboration, adding value to these forms of planning systems. The short-term objective is to highlight the importance of sustainability challenges for planning of supply chains. A scoping study undertaken by the SCALE project (Step Change Agro-food Logistics Ecosystems) (Project SCALE, 2012), involving 27 agri-food businesses from across North West Europe, found three key building blocks required for transformation to supply chain sustainability. These building blocks include: (i) taking into account the 3BL can improve competitiveness; (ii) being aware that considering simultaneously the three dimensions of sustainability is not easy and important enablers are to find in order to drive real transformation; and (iii) proposed trade-offs on term of 3BL indicators and coordinated action plans can be compiled for implementation. Moreover, collaboration across the supply chain is needed. Indeed, the strong belief of participating organisations in the SCALE pilots is that collaboration between partners acting along a supply chain can help designing and planning supply chains in a sustainable way. To achieve this objective new support decision-making tools, capable of taking into account at the same time sustainability indicators and collaboration scenarios, are needed to make the right decisions.

3.1. Sustainable supply chain planning

In the literature we can find several definitions of sustainable supply chain. According to Ahi and Searcy (2013) and Testa et al. (2016), 22 definitions exist for “green supply chain” and 12 definitions for “sustainable supply chain”. Based on all these definitions we can say that sustainable supply chain is the way to come up with a set of organisational innovations and policies on term of supply chain planning and management taking into account sustainability indicators. Sustainability involves multiple objectives of social, economic and environmental bottom lines (3BL) (Seuring and Muller, 2008).

Expectations of customers and markets, legislations, challenges of global trade are changing continuously. Supply chains must adhere to these changes on term of design, planning and management. One of major change factors is sustainability. Supply chain networks span national boundaries with large volumes of products moving between key value adding organisations in the network before ultimately reaching the end consumer. Sustainability in supply chains is critical, since supply chains have high environmental and social impacts. In 2010, the International Resource Panel of the United Nations Environment Programme published a report assessing the environmental impacts of consumption and production and found industrial supply chains as central to managing sustainability (United Nations Report, 2010).

In this context, decision makers should take into consideration sustainability issues through supply chain operations, flows, processes and activities such as carbon footprint, raw materials, energy and water consumption, waste management and reverse flows when dealing with designing, planning and managing supply chains. Many indicators related to the sustainable supply chain exist (Ahi and Searcy, 2015; Tajbakhsh and Hassini, 2015; Schulze et al., 2016). For this literature the 3BL indicators could be classified as presented in Fig. 1.

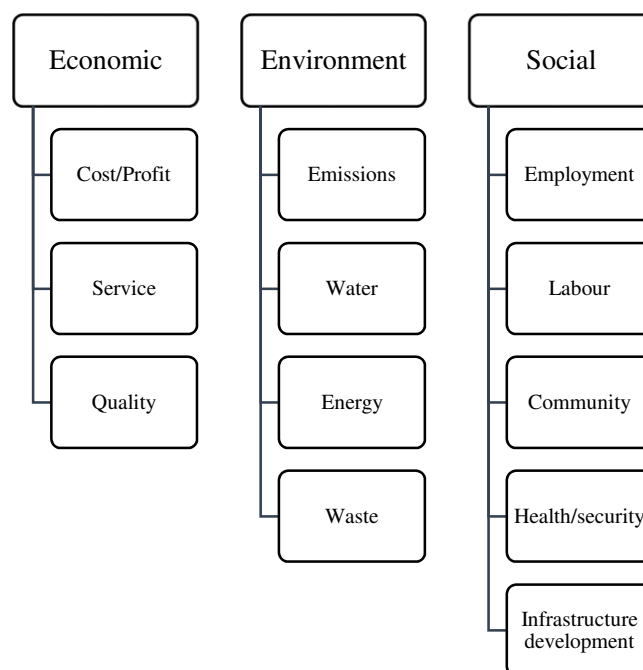


Fig. 1. Sustainability indicators.

Planning and management supply chains in a sustainable way involves three dimensions of objectives and trade-offs including social (Klassen and Vereecke, 2012; Ahi and Searcy, 2015), economic (Hassini et al., 2012) and environmental (Ahi et al., 2016). While there is considerable work that has been done to understand the impact of integrating sustainability into supply chain planning and management (Govindan and Cheng, 2015; Rezaei et al., 2016; Bai et al., 2012), there are still unaddressed issues of decision making and planning tools.

First, very few mathematical models and tools take the three dimensions into account simultaneously. The social aspect is rarely studied. Decision makers today need more than ever to understand 3BL metrics in order to: i) align behaviours across the network, ii) be able to optimize them by finding trade-offs and iii) analyse their impact. Moreover, new models, innovative tools and frameworks are needed, to support the alignment of strategy on term of sustainability and seeking broader optimal networks solutions rather than localised and disparate approaches. Operationalizing the outputs and providing visibility across the supply chain network is necessary. Developing new and adapted Information and Communication Technology (ICT) tools for managing the flow of decisions between supply network members is vital for supply chain sustainability goals. These are central concerns in development and application of a decisions support system for an advanced planning system; to be further described below.

3.2. Simultaneously considering 3BL and collaboration

We performed a precursory search on “google scholar” using terms “collaboration”, “collaborative”, “sustainable”, “sustainability” and “supply chain (s)” and choosing the two options “with all of the words” and “in the title of the article”. 55 papers until 2019 are found using 4 combinations of keywords: (1) collaboration, sustainable, supply chain; (2) collaboration, sustainability, supply chain; (3) collaborative, sustainable, supply chain; (4) collaborative, sustainability, supply chain. The 3BL dimensions, number of supply chain echelons, main supply chain actor(s) of these papers are summarized briefly in Table 1. We can see that only 20 papers deal with sustainability with its three dimensions and consider all echelons of the supply chain. This quick review illustrates that relatively few papers simultaneously consider collaboration and sustainability when dealing with supply chains and falls within the scope of recent literature reviews on this concept (Chen et al., 2017). Dealing with collaboration to attempt sustainability advantage is gaining more and more attention; however, there is a lack of consideration about social concerns such as number of created jobs and personal development. Also, horizontal collaboration across levels of organizations in the supply chain has received little attention.

Table 1
A brief summarization of the 55 papers found.

| Number of papers | 3BL dimensions | Number of SC echelons | Main SC actor(s) |
|------------------|-------------------------------------|-----------------------|---|
| 20 | Economic Environmental Social | 3 or more | Suppliers Transformer sites Distributor sites |
| 10 | Economic Environmental Social | 2 or less | Suppliers Transformer sites |
| 5 | Economic Environmental | 3 or more | Suppliers Transformer sites Distributor sites |
| 11 | Economic | 2 or less | Suppliers Transformer sites |

| | | | |
|---|--------------------|-----------|---|
| | Environmental | | |
| 3 | Economic Social | 3 or more | Suppliers Transformer sites Distributor sites |
| 6 | Economic Social | 2 or less | Suppliers Transformer sites |

Other literature reviews on supply chain sustainability and collaboration identified collaboration as sustainable supply chain management practices based on joint development, technical integration, logistics integration and enhanced communication (Ince and Ozkan, 2015). Collaboration between supply chain partners to reduce carbon footprint (Ding et al., 2016) has been popular; but also, general sustainability practices such as coordinating cleaner production, solid wastes generation and resource conservation have also played roles (Hoof and Thiell, 2014). These studies support the contention that collaboration is necessary for effective implementation of cleaner production in order to take competitive advantages from sustainable supply chain. Organizational tools such as communication, action and active relationship building efforts are necessary to succeed for multiple levels of supply chains sustainability coordination (Heijden and Cramer, 2017). Theoretical works have also confirmed that collaboration is more in favour of a positive impact on sustainability indicators (Touboulic and Walker, 2015).

Based on these various findings, most studies focus on understanding the positive link between collaboration and sustainability in supply chains. Second, they consider organizational, information, communication and best practices aspects of supply chains. Very few papers simultaneously consider collaboration and sustainability when planning supply chains. No true broad decision-making systems and advanced planning systems, take into account vertical and horizontal inter-organizational collaboration along the 3BL when planning the supply chain. This gap is addressed now.

4. Proposed decision support system for 3BL supply chain collaboration planning

A decision support tool for collaboration planning in supply chains based on a wide range of methods and algorithms of multi-criteria decision making are used to simultaneously consider the three dimensions of sustainability in a supply chain collaboration and coordination environment. The decision support system optimizes 3BL at strategic, tactical and operational levels when planning collaborative supply chains (see Fig. 2 and Fig. 3) for various elements involved in the system).

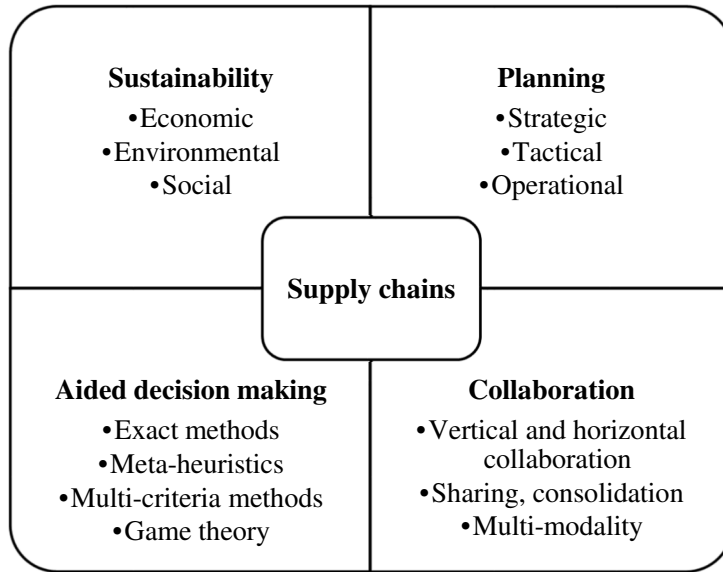


Fig. 2. General proposed framework.

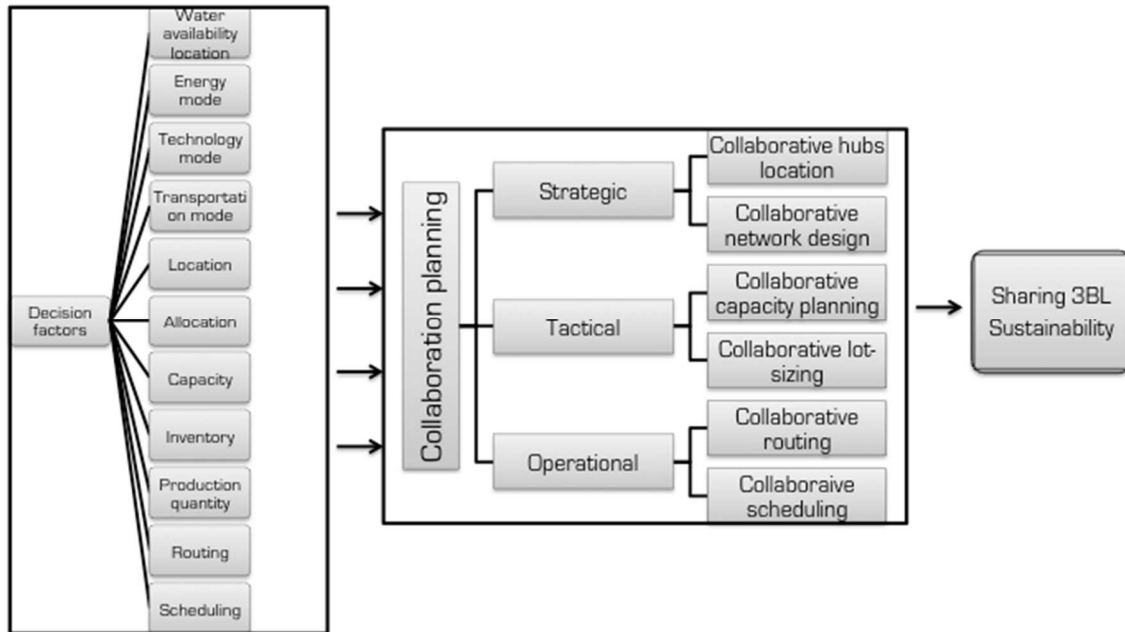


Fig. 3. A 3BL driven collaboration planning framework.

At the strategic level, the objective may be to locate a set of collaborative hubs between several supply chains in order to optimise the global sustainability costs across the supply chain. At tactical and operational levels, issues such as collaborative lot sizing, multi-modality (road, sea, train) transportation planning, and collaborative routing incorporate sustainability. The proposed tool is used to expand APS in ERP and other supply chain management systems.

These concepts and methods constitute the core decisional framework structured architecture sustainable supply chains collaboration and coordination planning. The 3BL indicators for a sustainable supply chain are massive and complex (Zeng et al., 2010; Wu et al., 2017). The format of the data could be numeric or linguistic. Thus, it is impossible and

unrealistic to integrate all indicators into the objective function(s) of a mathematical optimization formulation.

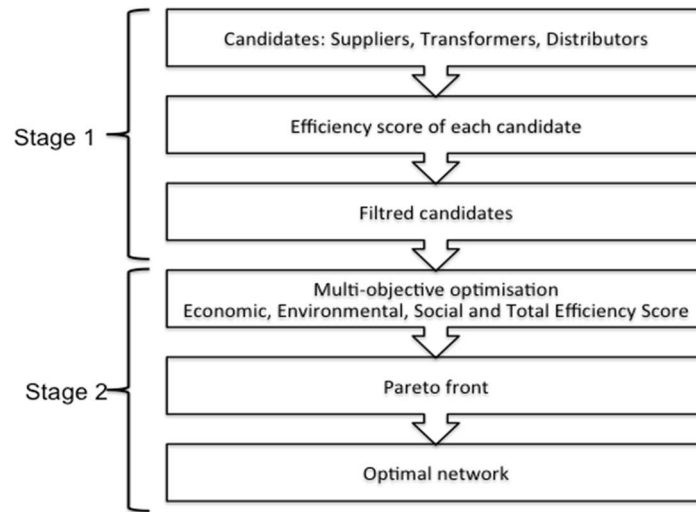


Fig. 4. Two-stage hybrid approach.

But in order to make progress of building a comprehensive system to address these complexities, the decisional framework is structured on a two-stage hybrid approach combining different multi-criteria decision methods taking into account 3BL indicators to design or re-design the sustainable supply chain. The structure of the two stages is shown in Fig. 4 and the setup of each stage is given in Table 2.

- The first stage consists of performing an initial evaluation of partners of a supply chain using several criteria and sub-criteria. Criteria that may be too complex to integrate into an objective function, occurring in the second stage, can be considered in this stage. The potential suppliers, transformer sites, and distributor sites are evaluated with different sets of criteria or sub-criteria in order to determine their efficiency with respect to supply chain performance. The calculation of the efficiency is performed by a combination of the Analytic Hierarchy Process (AHP) method (Saaty, 1980) and an Ordered Weighted Averaging (OWA) aggregation method (Yager, 1988). This efficiency will be considered and optimized in the second stage as one of objectives. An optional filter process is also integrated into the decision framework. If the number of partners is too large for the optimization of the second stage, the user activates the filter process, where only the sites with a better efficiency are included to the second stage.
- The second stage involves the application of a mathematical model with multiple objective functions. We take into consideration the three aspects (economic, environmental and social) of sustainability, as well as the efficiency calculated in the first stage. Furthermore, in the environmental aspect, we optimize the carbon footprint and water footprint, given their significance to environmental burdens. At last, we generate a Pareto front to aid the user's decision-making.

Table 2
Two-stage setup

| Stage | Key operation | Input | Indicators Considered | Solution method | Output |
|-------|------------------------------|--|--|---------------------------------|--|
| 1 | Efficiency Score Calculation | potential suppliers potential transformer sites potential distributor sites | All economic indicators All environmental indicators All social indicators | AHP OWA | Filtered potential suppliers Filtered potential transformer sites Filtered potential distributor sites |
| 2 | Multi-objective optimization | Filtered potential suppliers Filtered potential transformer sites Filtered potential distributor sites | Economic carbon footprint water footprint Efficiency Score | Multi-MILP optimization process | Pareto Front |

Using the described decision support framework, we developed a new decision support software system called the “Collaboration Planning Tool (CPT)”. CPT takes into account sustainability and collaboration as the main factors for adding value. The aim of CPT is to provide structured decision support system, and framework, combining different decision-making methods (DM) to optimize 3BL costs when planning a single or multiple collaborative supply chains. The main goal of this system is to enable the different DM-methods to interact to improve the decision-making process in supply chain planning.

The CPT system is a web-based software system. It provides global logistics information to supply chain managers. It simultaneously addresses multiple aspects of planning flows of raw materials and products from suppliers through production sites to distribution sites that distribute products to end consumers. The CPT system can help managers and decision makers of supply chains select the most suitable suppliers, determine facility locations (production, distribution) and allocate flows from suppliers to production sites, then to distribution sites and finally to customers, estimate procurement requirements for each product, and plan deliveries among different sites. Together these include various levels of planning, strategic, tactical and operational.

CPT can be used as an operational system to propose sharing and pooling scenarios and match resources availability such as human resources, vehicles, or warehouses, and supply chain needs. It can provide system performance reporting capabilities and show 3BL policy effectiveness of determined planning alternatives.

Once a collaboration type is chosen, 3BL cost optimization can be completed with synchronizing decisions. At any decision point the number and identity of the nodes is known along with parametric values. For instance, residual or slack resources such vehicles not completely loaded, warehouses not used at their capacities, energy under-use, at or above a specified upper bound would be known.

When selected 3BL are complementary, one could fit them in a mono-objective function and optimized with a central way. Then saving efforts will be shared between partners of the collaboration. If the selected 3BL are conflictive, the proposed DSS is able to deliver a Pareto frontier in order to come up with a set of efficient solutions. To elaborate the Pareto frontier, each indicator is optimized with a central way (for all involved actors in the collaboration). Then it will be possible for decision makers involved in the collaboration to fix some trade-offs and win-win situations. Nevertheless, it’s necessary sometimes to make investment, at

the beginning of the collaboration relationship (short term), in order to optimize global and individual 3BL indicators at long term. Also, reputation and brand protection are important issues for collaborative supply chains on term for instance of social issues such as congestion and health and safety.

CPT has a modular architecture composed of several linked modules. This architecture could facilitate the integration and connection with other management systems like ERP or LCA (Life Cycle Analysis).

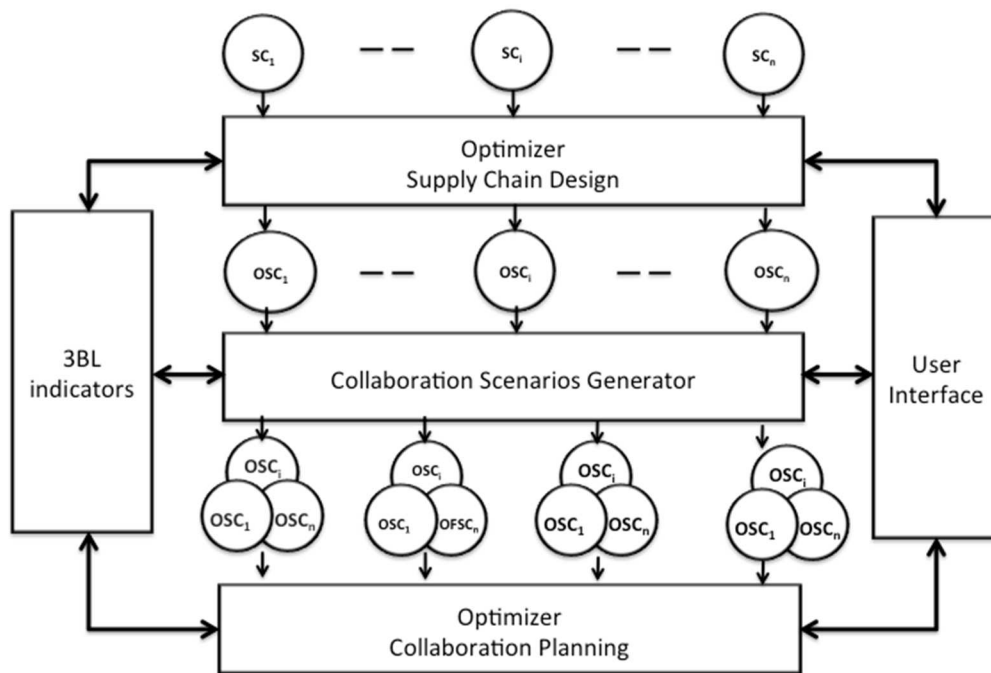


Fig. 5. Collaboration Planning Tool Architecture.

CPT has a modular architecture composed of several linked modules. To achieve a high quality of ICT visibility across the collaboration network, this architecture could facilitate the integration and connection with other management systems like ERP, APS, TMS (Transportation Management System), OMS (Order Management System) or LCA (Life Cycle Analysis). It could be connected with these applications through the database software as input-output exchanges. The main program needs to be implemented on a server, and then all users can access the system on their own computers by simply using an Internet connection. The objective is to use existing IT technology in new and innovative ways to support the implementation of the proposed DSS.

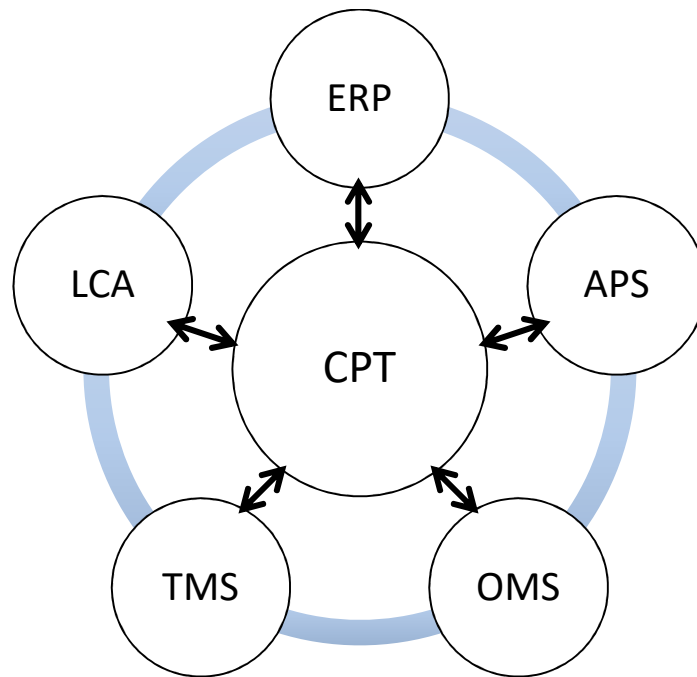


Fig. 6. Software integration

CPT is composed of five modules (see Fig. 5). These modules include an interface system, a 3BL indicator system, a supply chain design optimizer, a collaboration supply scenarios generator, and a collaboration plan optimizer. Each of these are now described.

- Interface: allows managing input and output data. It provides opportunity to:
 - a) create a new supply-chain planning project or open an existing one.
 - b) fulfil all required data concerning supply chain partners (suppliers, producers, distributors, and customer) and transportation modes (road, rail, plane, sea).
 - c) introduce the set of products and their bill of materials, and their demand (as shown in Fig. 6 and Fig. 7).
 - d) view supply chain maps (as shown in Fig. 8 and Fig. 9), distances between partners, transportation mode between partners and flows;
 - e) view different scenarios given by different solving methods (exact and heuristics) using graphics and diagrams to be compared to each other according to selected 3BL criteria (Fig. 10). This helps decision makers to select the best scenario based on fixed weights of criteria.

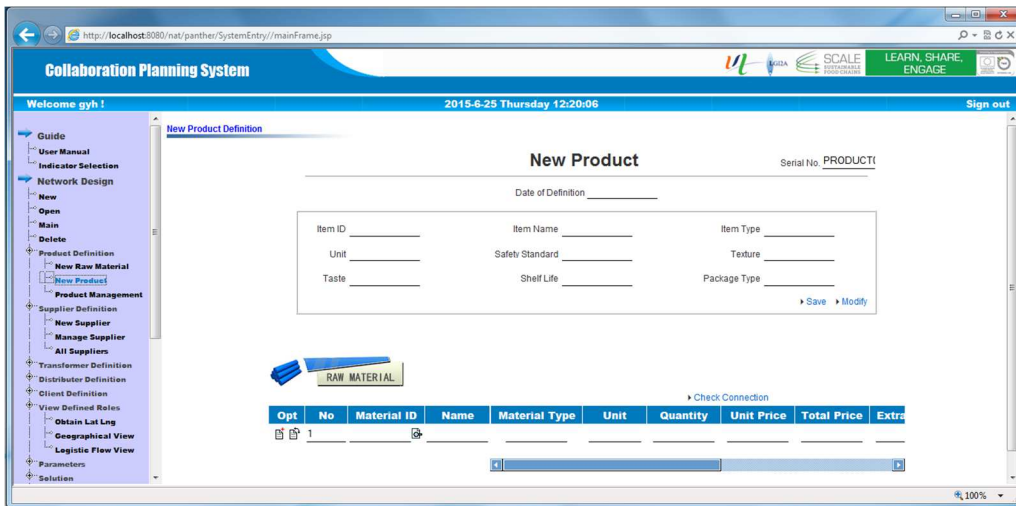


Fig. 7. Product definition.

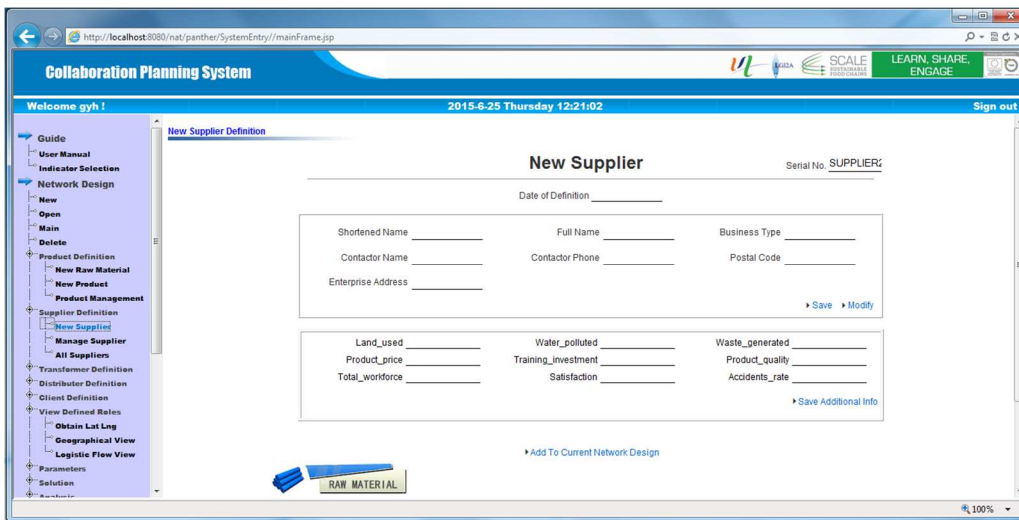


Fig. 8. Supplier definition.

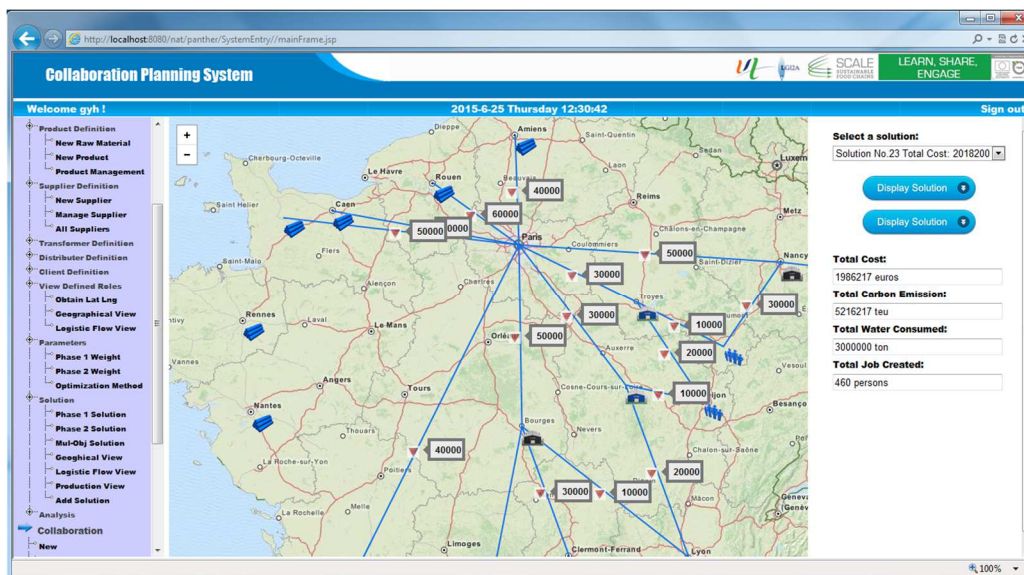


Fig. 9. Supply Chain map detail data.

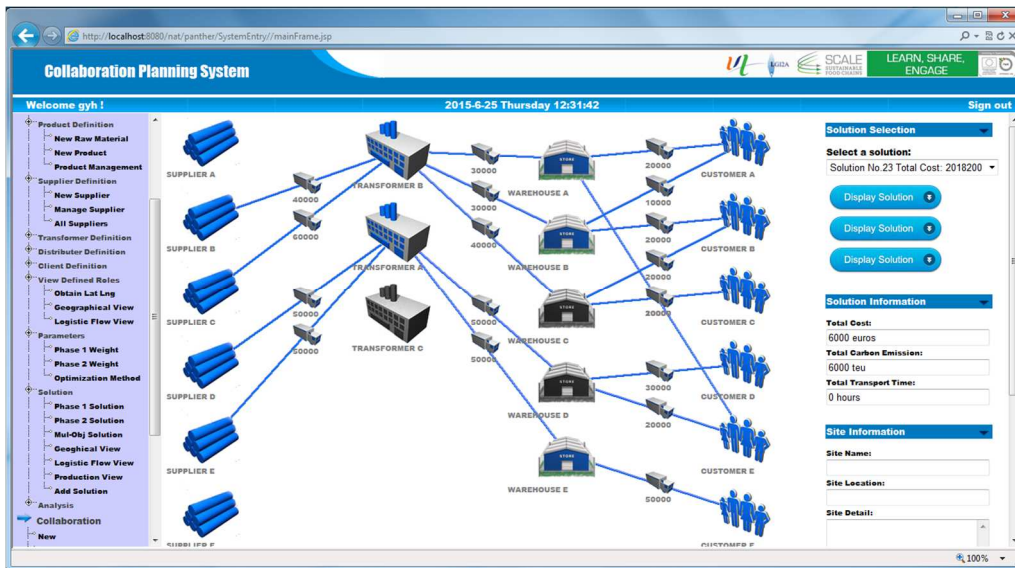


Fig. 10. Logistic flow view.

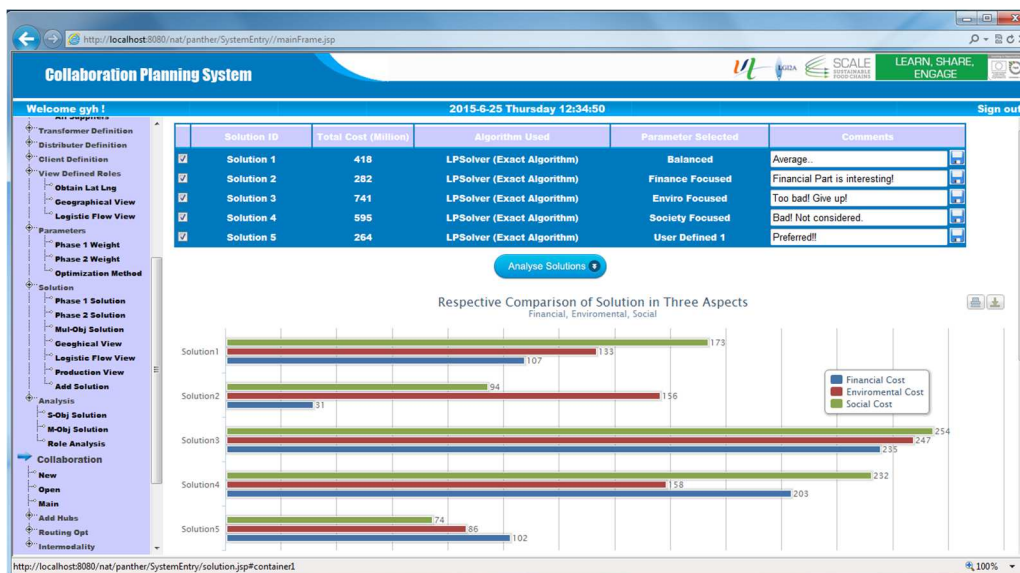


Fig. 11. Solution analysis.

- 3BL indicators: this module helps to select sustainability indicators to optimize in planning the supply chain design. It allows for criteria weight determination. It constitutes the first stage of the two-stage approach described in Fig. 11. The system provides three ways to set the weight of indicators: (1) Manual Input: one may simply set manually the weight value of each criterion. The system will automatically normalize the weight values in the objective function. (2) Five-Star Rating System: manual input may be too time-consuming when the amount of indicators is large, thus we provide a simpler rating system. As shown in Fig. 12, each indicator is associated with five stars. The user can rate the importance of an indicator by giving it stars. No star means the indicator is not important, while five-stars indicates the indicator is very important. (3) AHP (Analytic Hierarchy Process) method: AHP is a structured technique for organizing and analysing complex decisions. To use this method, a matrix will be displayed as shown in Fig. 13. In this matrix, managers can compare each pair of indicators to arrive a relative importance weight.

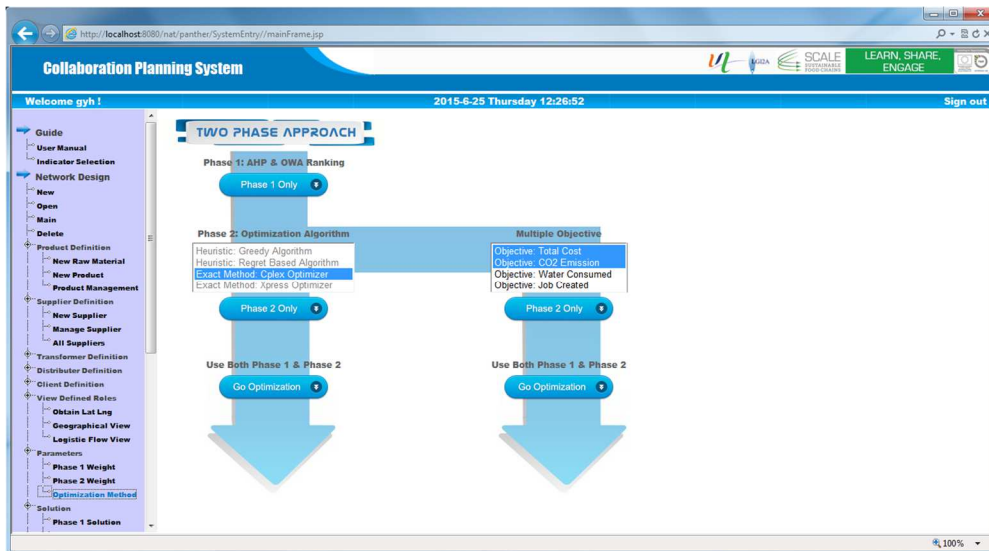


Fig. 12. Two stage approach.

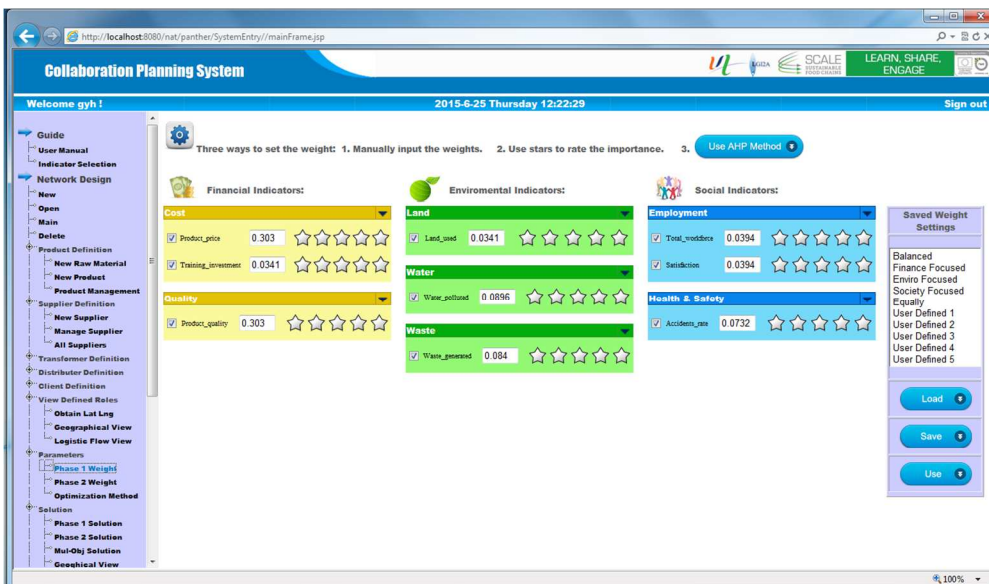


Fig. 13. Weight setting page.

- **Optimizer Supply Chain Design:** this module will consider only one side a given supply chain i (SC_i). This supply chain is identified in the first module using different potential lists (suppliers, producers, distributors, customers...) and different transportation modes. A set of sustainability criteria are also used in this design and are input from the second module. The core of this module is based on the second stage of the two-stage approach described before (as shown in Fig. 11). After setting the weight values in the second module, the next step here is to select an adapted optimization algorithm to design or re-design the global supply chain. The solving method could be an exact method based on MILP (Mixed Integer Linear Programming), a heuristic or a meta-heuristic; the user is allowed to choose. The system will start optimizing the supply chain (SC_i) designing and display the solution as an Optimised Supply Chain ($OSCi$).



Fig. 14. AHP method.

- Collaboration Scenarios Generators: this module can help decision makers to identify potential opportunity of collaboration among partners of one or several optimized supply chains resulting from the third module (Fig. 14, Fig. 15). For given supply chains, the module is able to propose collaborating a set of their partners by creating hubs or sharing transportation vehicles. The user must first select partners to be involved in a given type of collaboration (vertical, horizontal or lateral) and then it helps in the elaboration and the management of sharing scenarios of resources or facilities between these partners (hub consolidation, routing...). The modelling approach will take into consideration five below elements to model any scenario of collaboration: (i) Extent of collaboration (intra, inter), (ii) Context of collaboration (warehousing, transportation...), (iii) Alternative of collaboration (make available, exchange, sharing), or (iv) Level of collaborative decisions (strategic, tactical and operational).

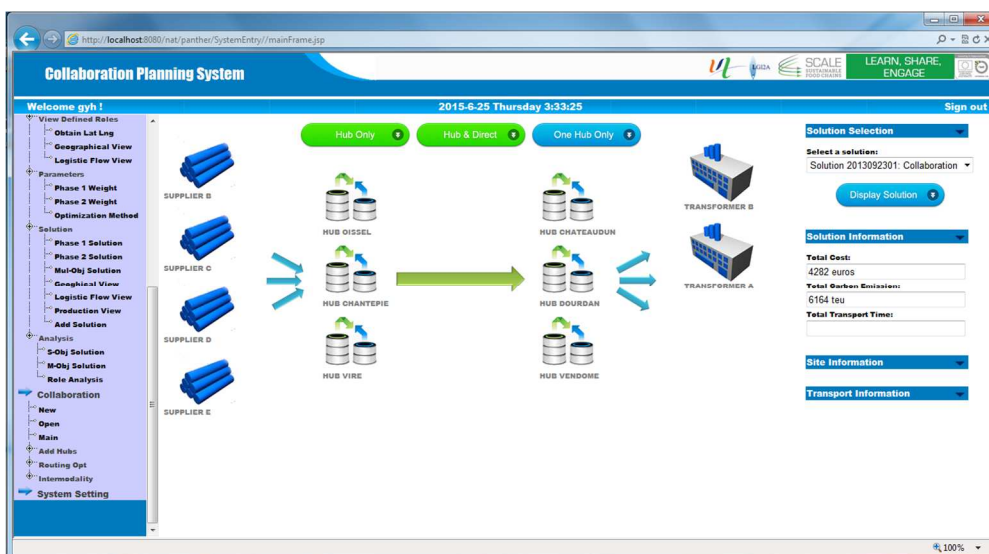


Fig. 15. Hubs location.

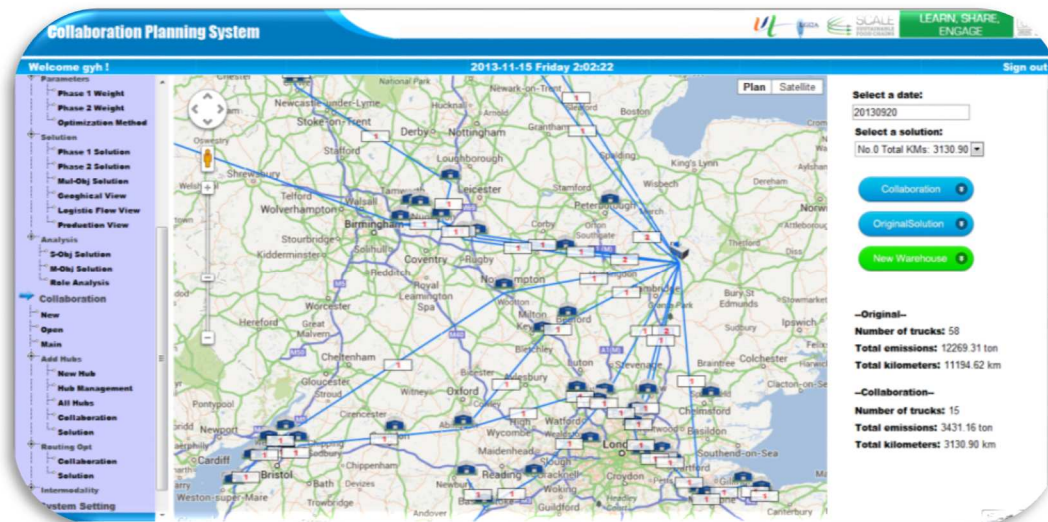


Fig. 16. Collaborative routing.

- **Optimizer Collaboration Planning:** The CPT can be used initially to identify inefficiencies or bottlenecks in the existing system but can go on to develop and evaluate the opportunity of collaboration among potential partners in either the same supply chain (vertical) or parallel chains (horizontal). For any given supply chain, the system can be used to optimise the hubs to use, the consolidation that should take place and the size and routing of vehicles. Once a collaboration scenario, type and mechanism are fixed in the previous module and targets of collaboration on term of 3BL indicators are selected in the second module, one could optimise its 3BL cost by synchronizing decisions. The decision maker implies taking some actions at considerable 3BL cost. At any decision time we know the number and identity nodes that have for instance residual resources: vehicles not completely loaded, warehouses not used at their capacities, energy under-used, at or above a specified upper bound. This module allows collaboration planning optimization between partners. After dealing with planning in the case of one company, new models based on MILP or meta-heuristics on how supply chains could collaborate in order to optimise global shared 3BL can be used. Hence two pictures could be compared the “AS-IS” without collaboration and the “TO-BE” with collaboration in order to measure the benefits of collaboration on term of 3BL. For instance, a MILP model is developed to optimise location of consolidation hubs. A MILP and meta-heuristics are elaborated as well to optimise collaborative vehicle routing between transportation providers.

5. DSS users

For many organisations inter organisational collaboration, or partnerships, have been managed and developed in an ad hoc manner with the individuals responsible for supporting business-critical relationships receiving little guidance and support. Therefore, a standardised methodical approach to developing, implementing and managing collaborative initiatives is necessary as a tool for improving the sustainability performance of supply chains across its 3BL aspects. The aims of the developed DSS are to help a set of collaborating actors to simulate and optimize their joint decisions related to several drivers and facilitators making their relationships efficient to work together. The tool provides the user with a gap analysis that determines its current ICT functionality and its requirements when seeking to measure

3BL improvements. Hence, the CPT tool could first be used as a scenario based simulation tool by:

- Policy makers from legal authorities to show and demonstrate opportunities to those who work across the supply chain (manufacturers, multi-user operating platforms) and who want to make a step change in their approach when addressing sustainability. The overarching imperative with change management is to align the stakeholders in delivering the change successfully. It is important to agree the goals and scope of the collaboration, the roles of the individuals involved, the processes to be followed, and finally the relationships between each of the individuals.
- Sustainability associations to build use cases and scenarios to show collaboration opportunities for stakeholders from different parts of the supply chain where relationships may not have existed previously and may potentially have been confrontational in order to consider together sustainability challenges. While many companies see collaboration as key to improving their 3BL performances, they require assistance when seeking to learn how to engage in collaborative relationships; how to overcome the barriers; and how to create an environment in which a culture of collaboration and sustainability can flourish. Intriguingly it has been highlighted that the more that organisations participate in collaborative initiatives the better they get at it.

Second, it could be used as a collaboration-planning tool by:

- Leaders across the supply chains who are making the business and investment decisions that will impact on how supply chains will collaborate on term of 3BL sustainability indicators. It gives the decision makers from focal companies to understand mechanisms of cost saving, CO₂ saving for instance when engaging in vertical and/or horizontal collaborations.
- Fifth Part Logistics (5PL) providers (Hosie et al., 2012) to help decision makers from different focal companies to reengineer their networks in order to improve 3BL performances in a centralised way.
- Forth Part Logistics providers (4PL) providers (Vivaldini et al. 2008) to come up with sustainable collaboration plans as centralised decision maker. For instance, transportation operations could be coordinated in a coalition and the total cost will be planned in a centralised way to make cost saving but also to make for instance a CO₂ saving for a coalition of carriers.

6. Pilots

The CPT system is one of the outputs from an innovative three-year transnational project across North West Europe. This initiative was known as Project SCALE (Step Change in Agri-food Logistics Ecosystems) (Project SCALE, 2012) and set out to change the way in which businesses review and consider their logistics operations.

The aim of the project was to help at the same time increasing economic competitiveness and improving the environmental and social sustainability of food and beverage supply chain logistics across North West Europe. Focusing on these supply chains is highly necessary in the context of rising long-term global food demands, managing volatility commodities pricing, in the challenge of dealing with resource scarcity and the need to reduce our environmental footprint. The project was partly funded by INTERREG IVB North-West

Europe (NWE), which is a financial instrument of the European Union's Cohesion Policy, with the balance being funded by the project partners.

The project was designed from the outset to bring together significant industry expertise with scholarly rigour to deliver several tools and frameworks that the agri-food sector could use to improve the efficiency and sustainability of food and drink logistics throughout the supply chain. Through the project these tools and frameworks have been tested across a range of food networks to demonstrate how new approaches can deliver sustainability improvement and real commercial benefits. In this context, the CPT system was used and tested within three pilots.

The first pilot considered two UK-based food ingredient manufacturers exporting their palletised ambient products across the European continent. In this Pilot, the SCALE project (Project SCALE, 2012) sought to introduce collaborative planning to drive efficiencies in the supply chain. The second pilot studied a supply chain run by a large multi-national food manufacturer with extensive operations in NWE who considered (part) changing the mode of transport from road/sea to road, sea, rail or a combination of the above. This supply chain had the added challenge of being temperature-controlled, requiring in transit storage at -25 °C. The third pilot supported the UK's largest food manufacturer in its evaluation of a modal switch from road/sea to road, sea, rail or a combination of the above across its vertical supply chain from mill to a series of bakeries across Ireland. This Pilot moreover reflected the correlation between driver behaviour and shift utilisation. Having completed the three Pilots, in which the SCALE team trialled and tested its tools and frameworks and gained extensively feedback and input from business stakeholders.

Another developed ICT assessment tool provided the stakeholders of the SCALE Project team with the ability to assess what was needed at the organisational level both in terms of ICT systems' functionalities and of 3BL indicators to monitor based on the requirements for the future. Specifically, for the pilots, the ICT assessment tool takes a pilot participant's view of how they think they are currently performing against the SCALE 3BL. It then asks them how they would like to perform against it in the future. The tool then suggests areas of ICT capability that they would need to retain or implement to be able to help them reach their goal. This level of engagement is necessary to understand the business needs, the rationale behind the pilot and the operating processes to support the case for the changes being made. The gap identified between the two assessments, forms the basis of a Business Requirements Definition, Concept of Operations and the full suite of ICT tools to develop, test, train and implement in the new scenario. The ICT solution identified for Project SCALE has been chosen based on the specific requirements of the Project. The solution contains a number of elements or subsystems that will deliver the final platform solution. CPT tool is one of these subsystems and used in connection with existing commercial software like TMS.

The Collaboration Planning Tool (CPT) provided a unique opportunity to measure the performance of a supply chain against a wide basket of 3BL metrics. It was used for the three pilots as a decision-making aid to optimise sustainability through their supply chains. Indeed, the CPT helped to measure existing 3BL performance as a benchmark and then provide a decision support to show how participating actors could outperform the actual picture. Even if in running the three pilots it was evident that data integrity presented some challenges in terms of accuracy and availability, particularly where third parties were responsible for the execution of shipments, using CPT helped us to show through pilots two interesting factors to improve sustainability of supply chains: multi-modality and collaboration.

First regarding multi-modality, in the context to rising food prices, demanding service levels, rising energy prices, alternative modes of transport present some tangible

opportunities to reduce the impact of operations giving rise to potential improvements on the 3BL. Indeed, in the third pilot vertical integration offered significant 3BL alternatives that can be unlocked with the orchestration of the multi-modal solution. The second pilot required horizontal collaboration, but the improvement in the 3BL was achieved by reducing the underutilised rail and euro combi trailers and switching modes.

Secondly collaboration arrangements in both vertical and horizontal types, supply chains provide opportunities to improve 3BL performance equitably between partners. In fact, in the first pilot two non-competing food ingredient manufacturers were asked to collaborate in palletised deliveries for continental food businesses. The Pilot concluded that savings of around 7% were achievable with all stakeholders aligned to the objective of driving the 3BL improvement; this was a co-competition case. The second Pilot demonstrated velocity in the supply chain (gate to gate transit times suggest or point towards a cut by 50%), agility to switch between modes depending upon demand and in response to disruption to a mode, making the solution more resilient to stress. Collaborating partners generating significant unit cost advantage, which can be distributed between participants. Fewer road movements resulted in less congestion and the release of harmful emissions into the atmosphere.

Throughout the application of CPT in the SCALE project we identified a number of lessons learned related to the three pilots. It is difficult to measure social sustainability, to standardize sustainability performance measurement due to different regional approaches of countries, difficult to measure the results of sustainability initiatives, and there are many different measurement methods. Collaboration is seen as an opportunity to improve sustainability in supply chains. It allows a rationalization of using supply chain resources at the three stages (suppliers, production and distribution) by sharing and pooling capacities. For instance, at the level of transportation, sharing capacities can make it possible to better load trucks and avoid empty returns. This would generate less CO₂ emissions and less noise on the roads, less congestion and therefore less stress for drivers.

Nevertheless, this enthusiasm faces some obstacles related to sharing cost, information and risk. This is mainly due to the cultural-social aspects of the various partners such as trust and transparency. Hence decision support tools are needed to show the benefits to be gained when supply chain partners engage in a collaborative relationship and ensure a certain level of trust by defining the scope and limits of this collaboration. This will give visibility on the data to be shared and the indicators to be optimized in a global or individual way. Our proposed tool fits very well with this challenge. Advanced models are developed, which account for logistics improvement opportunities regarding total cost, carbon emissions, water and energy consumption, and social impact (noises, jobs creation...). This enables the opportunity to analyse trade-offs between sustainability 3BL through using different model settings.

The proposed tool in its actual version deals with optimising 3BL indicators by providing Pareto frontiers in a centralised way. A global saving on term of 3BL indicators is given to allow decisions depending on the weights of criteria fixed by actors involved in the collaboration with a common way. Here an interesting future development is to realize on term of sharing of the 3BL savings. A module based on concepts like game theory, multi-agents approach will be designed and integrated to come up with win-win relationships.

The proposed DSS was tested through the three pilots. Based on the learned lessons, more development is needed in an iterative way. Indeed, we expect to test it with other companies involved in potential collaboration partnerships. At the end of the development, testing phase, user acceptance and end to end, a set of requirements should be checked by both IT-project and planning process teams before the tool can go into live operation.

7. Conclusion

In this paper an innovative and collaborative aided decision-making framework for sustainable supply chain planning was proposed and presented. Based on this framework a decision support system called “Collaboration Planning Tool (CPT)” was developed to provide the necessary infrastructure and visibility to support supply chains planning across their complex networks to deliver long-term sustainability. This work fills a gap in research on advanced planning systems which have not considered collaboration across the supply chain or sustainability in supply chains. This system was tested and piloted across a range of food supply chain networks. It helped to show that collaboration arrangements, both vertical and horizontal, in supply chains provide opportunities to improve 3BL performance between supply chain partners.

Lessons learned through using the proposed decision support system indicated that collaboration and multi-modality could present some tangible opportunities to reduce the impact of supply chain operations giving rise to potential improvements on the 3BL. However, in running real case pilots data integrity presented real challenges in terms of accuracy and availability for a such ICT system. Moreover, due to different approaches of countries it is difficult to measure social sustainability, to standardize sustainability performance measurement and align objectives of different partners involved in collaboration relationships.

Our future works could be directed to deal with additional functionalities in the proposed system as real time, robust control and resilience of sustainable supply chain operations. Since the system is based on a modular architecture, integration with other ICT tools like ERP systems could be investigated. We expect also to pilot the system on other supply chain sectors like automobile and aeronautic sectors.

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