SUSTAINABILITY AWARENESS IN SUPPLY CHAIN PLANNING UNDER UNCERTAINTY

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Nowadays great emphasize is being placed on the fragility and vulnerability of organizations regarding the uncertainty and unpredictable conditions. The environmental and social awareness are changing the concept of growth that guided companies for decades. Profound restructuring of supply chain, SC, is emerging regarding the sustainability impacts that is being placed in the top priorities of companies' agenda. Besides, the international dimension of SC, as well as the complex partnership networks present great challenges to the paradigm of fully integrated SC. Following these motivations, a novel proposal was developed to help the decision-making process within an uncertain environment. The goal of the approach is to develop a planning framework to help SC managers to balance between environmental footprint, social responsibility, service level to customer and economic criteria. A mathematical formulation is proposed and the model applicability is shown through the solution of an industrial example. The practical implementation involves the development of a decision model framework (MILP formulation) to optimally manage performance indicators and to assure sustainability requirements. The impact of sustainable policies in the SC planning strategy is evaluated for different managing scenarios. These bring new insights concerning SC planning under uncertainty.

Keywords:
supply chain;
sustainability;
performance,
efficiency,
optimal planning

JEL:
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1 Introduction

Currently, managers have to make faster decisions and commonly have to revise them rapidly. The accelerated digital transformation together with the intensification of sustainability considerations, increased the need to transform classical management practices. Also, the environmental and social consciousness are changing the concept of growth that guided companies for decades. So, sustainability is now a days a top priority for most part of the companies' agenda.

Also, a novel paradigm emerges from the modern world development, that emphasizes the requirements of applying new approaches to deal with traditional problems (Strimovskaya & Barykin, 2023).

Besides, recent worldwide occurrence like Covid-19 and the Ukraine War turned more visible the impact of uncertainty exposure and, therefore, the assurance of service levels to customers' results progressively more complex.

Following those motivations, this paper addresses the Supply Chain (SC) optimal planning supported on sustainability indicators, for the economic-operational, environmental and social dimensions under uncertain market conditions. Based on this objective two research questions were formulated, namely:

- RQ1: How much different are the planning solutions based on sustainability KPI objective compared with cost and benefit objectives?
- RQ2: How effective are MILP approaches on handling the optimal sustainability planning under uncertainty conditions?

So, after this short introduction, next section highlights some scientific contributions that help understanding the research proposal. The methodology used to guide the development of the ongoing work is then presented in section 3.

The mathematical approach used to solve the problem is detailed at section 4, and the validation of the proposal is done through the solution of a real case study regarding a Portuguese distribution SC, section 5. The achieved results are then discussed in section 6, and a set of conclusions as well as future work directions are considered at the last section, section 7.

2 Theoretical Background / Literature Review

In order to better understand the scientific contributions made so far in the area of Supply Chain Sustainability, subject to uncertainty, some bibliometric analysis was done at Web of Science database, using the Boolean sentence *supply chain planning* AND *sustainability* AND *uncertainty*.

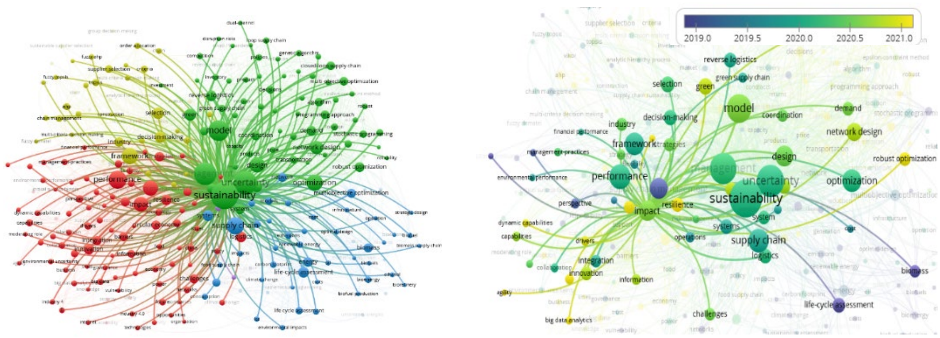

Figure 1: Bibliometric analysis (a) clustering of keyword cooccurences; (b) Timeline with the highlight of sustainable impact.

Using WOS, the scientific contributions were collected and then analyzed using *Vosviewer software* to obtain the clustering of cooccurrences, Figure 1 (a), and the corresponding timeline 1 (b). Accordingly, the results obtained showed 4 main clusters centered namely at: circular economy with uncertain challenges (red color), Supply Chain sustainability and Network Optimization (green color), Supply Chain & Life-cycle assessment (blue color), and the light green for frameworks & decision making, 1 (a).

Regarding the three years contributions (e.g. 2019 to 2021) represented in figure 1 (b), we can see that *agility*, *big data analytics*, *robust optimization*, *innovation* and *resilience* are recent occurrences (yellow clusters), while compared with life-cycle assessment (dark blue clusters).

A general perspective on the collected research papers shows some important challenges regarding the highlight topics & contents, the methodologies, and the implemented practices.

Following this perspective, Strimovskaya & Barykin (2023) showed the importance of the Industrial Informational Integration (III) as a new subject that claims a multidimensional approach to achieve the company's goals in a volatile, uncertain, complex, and ambiguous (VUCA) environment. The study deals with the resource allocation problem by applying efficient approaches based on mathematical modeling, experts' assessment, optimization methods, and others. Nevertheless, recent developments emphasize the need to apply a new paradigm to deal with recurrently problem, as well as the necessity of novel trends to SC design and planning (Mottaghi et al., 2022).

Besides that, Rusch et al. (2023) provide a comprehensive overview of current Digital Technologies (DT) applications in sustainable product management, SPM (e.g., product design/assessment, supply chain management, and business models). The study revealed that DT such as the Internet of Things (IoT), big data, artificial intelligence, or blockchain, are considered as enablers for a more sustainable and circular economy (Rusch et al., 2023). So, authors concluded there is clear room for greater adoption and optimization of DTs, so as to accelerate the transition towards a more sustainable and circular economy.

Regarding social measures, Bubicz et al. (2021) presented a systematic literature review that highlights how this dimension has been incorporated in supply chain management research in the period 2008-2018, and what research gaps still exist. A set of categories and cross-analysis between categories were defined to perform the study. The main research gaps and trends regarding social concerns in supply chains were identified and summarized. These revealed that social sustainability concerns have been increasingly addressed, but further research is required to obtain more comprehensive social supply chains.

The social commitment was transversally implemented on different areas. Torrado & Barbosa-Póvoa (2022) presented a study for the healthcare industry. The design and sustainably optimization of SC processes is vital, specially under an uncertain environment. Studies from the last 10 years addressing the *strategic-tactical* approach and for the *operational-tactical* were analyzed and a comprehensive contribution on each sustainable pillar, was drawn.

Concerning the industrial standpoint, a systematic review of the indicators used for measuring industrial sustainability identify a total of about 1041 indicators, with 290 for economic, 410 for environmental, and 341 for social dimensions (Mengistu & Panizzolo, 2023). Authors noticed that the majority of the indicators were mentioned only once and few had been frequently used, showing a lack of consistency (i.e., a lack of consensus) for measuring sustainability performance in different manufacturing industries.

On the other hand, distribution networks and particularly food supply chains registered a growing importance, both at the industrial and scientific levels. The challenges faced in food supply chains are at the intersection of several areas and go beyond the traditional cost minimization concern. Particularly, the uncertainties due to an ever-increasing product variety, more demanding customers and a highly interconnected distribution network. This implies that companies in the area need to manage the risk/cost trade-off without disregarding freshness, sustainability and corporate social responsibility (Jinil Persis et al., 2021).

Finally, concerning closed-loop supply chains Cardoso et al. (2016) proposed a mixed integer linear programming (MILP) formulation that integrates risk measures into the design and planning, while considering demand uncertainty of final products. The paper explores a European supply chain case study, and some managerial insights are outlined based on decision makers' risk profile and goal of the risk minimization (Cardoso et al., 2016).

3 Methodology

The research cared out in this paper follows a *Design Science Research Methodology* (Pries-Heje et al., 2017),that comprehends the steps of: i. *Problem ID & Motivation* (i.e., problem definition and its importance), ii. *Definition of Objectives of a Solution* (main characteristics to accomplish), iii. *Design & Development* (MILP formulation, that is the artefact), iv. *Demonstration* (suitable framework and use of the mathematical model to solve the problem), v. *Evaluation* (effectivity and efficiency of the MILP proposal, improving requirements and eventual back to design), and a solution Communication or the iterating back to the design through the integration of new objectives and analysis, figure 2.

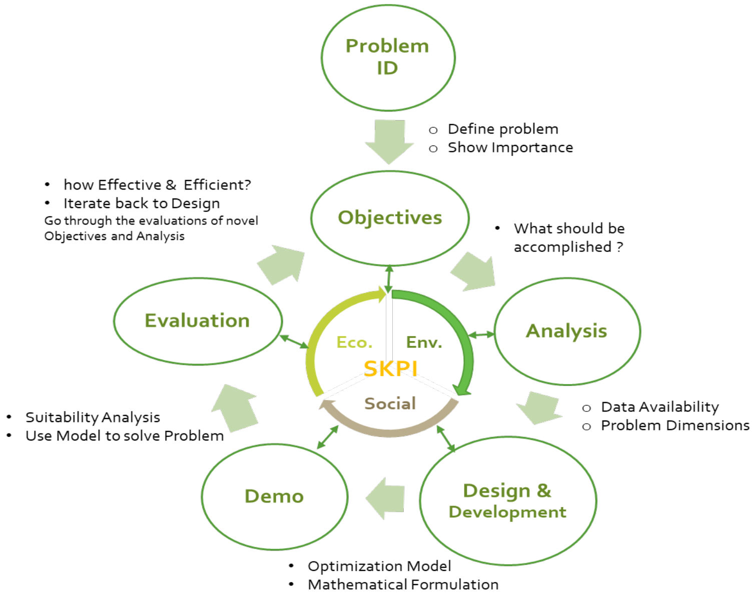

Figure 2: Methodology followed in the research work.

The former two steps (i. and ii.) were already described at the introduction, as well as the problem *Motivation* that was emphasized by the literature review and the bibliometric analysis.

4 Design & Development – MILP Formulation

This paper sections presents the main characteristics of the novel MILP (*Mixed Integer Linear Problem*) formulation proposed. The goal of the approach is to develop a framework to help SC managers at the planning decision level, under uncertain environment (i.e., Volatile, Uncertain, Complex, and Ambiguous, VUCA).

The objective function considers supply chain environmental commitment, social concern, and economic performance criteria, while ensuring the operational service level to customers.

$$\min z : z = \sum_{t}^{T_H} \sum_{w=1}^{Nw} p_w \varepsilon_{w,t} \Big|_{Sc} \qquad (1)$$

In here, index *w* is used to represent each indicator, on the set of *Nw* =12 KPI. The $\varepsilon_{w,t}$ is the absolute value of the difference between the observed value and the *target*, balanced by the coefficient p_w used to establish different evaluation scenarios.

$$\sum_{t=1}^{T_H+1}\left[\underbrace{\sum_{v=1}^{Nv}\sum_{l:l\,\epsilon SS_v} Fc_v\, Y_{l,t} + \sum_{l=1}^{Nl}\sum_{s:s\in\, SSL_l} Cr_s\, Sr_{s,t} + Cc_s\, Sc_{s,t}}_{Fixed} + \underbrace{\sum_{v=1}^{Nv}\sum_{l:l\,\epsilon SS_v} Ckm_v\, d_l\, Y_{l,t}}_{Varable}\right] \leq PB$$

The formulation constraints can be grouped in four classes, namely: 1) *capacity* constraints (e.g., vehicles capacities, warehouse capacities, cross docking capacities, materials related capacities, suppliers & customers capacities, reverse logistics capacities); *suitability* constraints (e.g., vehicle suitability, SS_v, for the transportation flow *l*, of materials *s*; warehouse spaces' suitability, SSL_l, other equipment & resource suitability's, reverse logistics suitability's, materials' suitability); *balance* constraints (e.g., bill of material for all materials in every location, *s*); *cost* constraints (e.g., fixed and variable costs, for a given *Planning Budget*, PB, based on the assignment of vehicles to material flows, $Y_{l,t}$ binary variables, (2)).

These are the main characteristics to accomplish in the MILP planning model.

5 Case Study – Demonstration and Evaluation Steps

The case study under consideration refers to a famous Portuguese Distribution Company with Iberic representation. The company offers integrated logistics, automotive services, positive cold facilities, reverse logistics, container unloading and urban distribution. Globally, the company manages 3 large product families: Industrial (e.g., pulp and paper, automotive); Food & Beverages; and other Non-Food products.

This study presents a branch of the company for the central region of Portugal, that manages about 800 clients, among them there are Shopping Centres, Hypermarkets, and other retailers. The ongoing research started with a sample of 107 customers.

Regarding the fleet of transportation vehicles, 4 typologies were considered that differs in terms of capacities (T1-10, T2-18, T3-20 and T5-33 Euro pallets), for a total number of 15 vehicles.

Warehouse capacities are distributed between storage areas (e.g. racks) and cross docking area.

Besides, a set of twelve KPI were selected, 4 for economic & operational (e.g., KPI1, to KPI4), 5 for environmental (e.g., KPI5 to KPI9) and 3 for social (e.g., KPI10 to KPI12) dimensions, respectively. The first set of KPI refers to vehicles' control, namely, *travel & route costs*, *service level* (e.g., rate between the delivered and ordered amounts), *vehicles' occupation rate* (e.g., full or partial charge), and to the regulation of *warehouse costs*. Concerning the environmental dimension, it cares about: *vehicles' carbon emissions*, *route dependent emissions*, *typology dependent emissions*, and *waste* produced and *energy* consumption in the OLC (*Operational Logistic Centre*), the warehouse facility on Central Region. Finally, the social KPI are related with *driver's working hours*; *working time table*, and *number of traveling stops* (used as a measure of the *Resting periods*).

Data were collected for a period of 10 months and a set of scenarios approach was considered to study planning uncertainty regarding customers demand levels for the 3 product families.

Moreover, former results involve both, direct measurements and calculated data. Carbon emissions were assessed based on the traveled distances, and route dependent emissions were stated based on the customers visited on each route and planning scenario. Also, typology dependent emissions were evaluated through the traveled distances per vehicle typology, summed up for the typologies used in each scenario.

The applicability of the proposed mathematical formulation is shown through the solution of the case-study application. The practical implementation involves the solution of the MILP formulation using GAMS Studio software.

6 Discussion of Former Results

MILP proposal was evaluated. The achieved planning results were analyzed for the sustainability dimensions that were modelled.

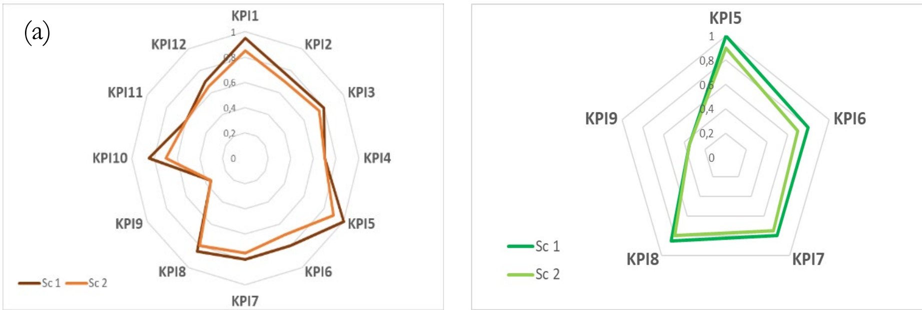

Figure 3: Results observed for the 12 KPIs (a) and details of 5 environment KPI (b), for the planning scenarios Sc1 and Sc2.

Key performance indicators, KPI, were normalized to allow a combined representation of the twelve scores, for two operational scenarios.

As shown in Figure 3, the major differences between scenarios were achieved for environmental KPIs, particularly for those related with travelling distances and vehicles assignment, KPI5, 6 and 7. Thus, KPI10 related with the *working hours,* and KPI12 for the *traveling stops* resulted also with the higher variability between scenarios. Globally, the worst value was reached for KPI9 related with the energy consuption and the best resources assignment during the planning period was obtained for KPI5 on Sc1.

7 Conclusions

The impact of sustainable policies in the SC planning strategy was evaluated for different scenarios. These bring new insights concerning SC planning under uncertainty.

The achieved planning results were analyzed for the sustainability dimensions that were modelled. The performance indicators give important managing insights and a more comprehensive planning was reached.

Future analysis will be drawn to explore KPI challenges and managing scenarios. Also, further developments will be done on the modelling approach in order to enhance planning decisions.

References

Bubicz, M. E., Dias Barbosa-Póvoa, A. P. F., & Carvalho, A. (2021). Social sustainability management in the apparel supply chains. *Journal of Cleaner Production*, *280*. https://doi.org/10.1016/j.jclepro.2020.124214

Cardoso, S. R., Barbosa-Póvoa, A. P., & Relvas, S. (2016). Integrating financial risk measures into the design and planning of closed-loop supply chains. *Computers and Chemical Engineering*, *85*, 105–123. https://doi.org/10.1016/j.compchemeng.2015.10.012

Jinil Persis, D., Venkatesh, V. G., Raja Sreedharan, V., Shi, Y., & Sankaranarayanan, B. (2021). Modelling and analysing the impact of Circular Economy; Internet of Things and ethical business practices in the VUCA world: Evidence from the food processing industry. *Journal of Cleaner Production*, *301*. https://doi.org/10.1016/j.jclepro.2021.126871

Mengistu, A. T., & Panizzolo, R. (2023). Analysis of indicators used for measuring industrial sustainability: a systematic review. In *Environment, Development and Sustainability* (Vol. 25, Issue 3, pp. 1979–2005). Springer Science and Business Media B.V. https://doi.org/10.1007/s10668-021-02053-0

Mottaghi, M., Bairamzadeh, S., & Pishvaee, M. S. (2022). A taxonomic review and analysis on biomass supply chain design and planning: New trends, methodologies and applications. In *Industrial Crops and Products* (Vol. 180). Elsevier B.V. https://doi.org/10.1016/j.indcrop.2022.114747

Pries-Heje, J. R., Baskerville ; Venable, J. ;, Pries-Heje, J. R., & Baskerville, J. (2017). Choosing a Design Science Research Methodology. In *Australia Choosing a Design Science Research Methodology* (Vol. 2). APA.

Rusch, M., Schöggl, J. P., & Baumgartner, R. J. (2023). Application of digital technologies for sustainable product management in a circular economy: A review. *Business Strategy and the Environment*, *32*(3). https://doi.org/10.1002/bse.3099

Strimovskaya, A., & Barykin, S. (2023). A multidimensional approach to the resource allocation problem (RAP) through the prism of industrial information integration (III). *Journal of Industrial Information Integration*, *34*. https://doi.org/10.1016/j.jii.2023.100473

Torrado, A., & Barbosa-Póvoa, A. (2022). Towards an Optimized and Sustainable Blood Supply Chain Network under Uncertainty: A Literature Review. *Cleaner Logistics and Supply Chain*, *3*. https://doi.org/10.1016/j.clscn.2022.100028