Design and Planning of Socially Responsible Pharmaceutical Supply Chains Considering Procurement Strategies

Inês Duartea\*, Bruna Motaa, Tânia Pinto-Varelaa, Ana Amarob, Ana Paula Barbosa-Povoaa

*a Centre for Management Studies of IST (CEG-IST), University of Lisbon.*

*Av Rovisco Pais, 1, 1049-001 Lisbon, Portugal*

*b Coimbra Business School-ISCAC/ IPC, Quinta Agrícola, 3045-601 Coimbra, Portugal*

*ines.r.duarte@tecnico.ulisboa.pt*

Abstract

Pharmaceutical supply chains operate in a complex global environment, facing challenges such as medicine shortages caused by raw material scarcity and demand fluctuations. In this context, the awareness of creating sustainable supply chains is high, and ensuring both economic viability and social responsibility is essential. This work proposes a decision-support tool based on a multi-objective mixed-integer linear programming model for the design and planning of pharmaceutical supply chains. The proposed tool leverages the Kraljic matrix to categorize raw materials based on their supply risk and profit impact, enabling the identification of efficient procurement strategies. The optimization model aids in making strategic and tactical decisions while fulfilling economic and social objectives. The economic objective intends to maximize the Net Present Value. The social dimension is explored through two different approaches: a) an objective function that prioritizes the location of entities in areas with higher incidence of diseases and b) the concern of affordability of different markets exploring the concept of demand-to-price elasticity. The model is applied to a case-study where several scenarios are analysed showing how strategic and tactical decisions are impacted by variations on both supply and demand sides, and how it impacts the performance of sustainability indicators. Moreover, it provides insights into creating socially responsible pharmaceutical supply chains and strategies to reduce vulnerabilities in raw materials sourcing.

**Keywords**: Pharmaceutical Supply Chains; Sustainability; Procurement strategies; Accessibility; Optimization.

* 1. Introduction

In the face of several challenges within globally dispersed supply chain entities that demand close integration in an uncertain environment, supply chains face an increasing awareness on establishing sustainable practices (Barbosa-Póvoa et al., 2018). Pharmaceutical supply chains are no exception, and they are crucial to support the health and quality of life of populations. However, medicines shortages caused by raw material scarcity, quality issues, and demand fluctuations persist, leading to unequal access to these products (FDA, 2019). Hence, promoting global access to medicines is crucial, making it imperative to integrate social concerns in the management of pharmaceutical supply chain objectives (Milanesi et al., 2020). Moreover, suppliers’ failures and insufficient raw material availability represent significant risks that can have far-reaching implications as they mark the initial phase of a supply chain, and effects can ripple through the entire supply chain (Jaberidoost et al., 2013). Given this, establishing effective procurement strategies can significantly impact the supply chain performance.

Based on the challenges outlined, this work presents the following contributions:

* Proposes a multi-objective model for the design and planning of pharmaceutical supply chains that includes both strategic and tactical decisions;
* Addresses vulnerabilities in the supply of raw materials and identifies effective procurement strategies envisioning the reduction of supply risk and profit impact, according to Kraljic Matrix’s classification of raw materials;
* Explores two social approaches focused on improving equitable access to pharmaceutical products;
* Incorporates economic and social considerations as objective functions, allowing the analysis of trade-offs between these two sustainability pillars.
	1. Problem Definition and Mathematical Formulation

In this work, the Kraljic matrix is used to classify raw materials regarding their supply risk and profit impact. This classification enables the identification of procurement strategies aimed at reducing supply risk and minimizing profit impact (Kraljic, 1983). This framework allows to categorize materials into strategic items, leverage items, bottleneck items and non-critical items, depending on two main factors: a) supply risk – associated with the availability of suppliers, substitution opportunities, make-or-buy opportunities, and storage risks; b) profit impact – related with the volume of materials purchased, the percentage it represents on the total purchase costs, and the impact that it has on product quality and business growth. When designing and planning pharmaceutical supply chains, it is important to consider appropriate procurement strategies for each raw material, as they play a key role in managing supply risk and optimizing profit impact. The strategic and tactical decisions made during this process significantly influence the overall performance of the supply chain. The mathematical model proposed is based on the model initially introduced by Duarte et al. (2022), which is further developed to integrate decisions on the selection of raw materials’ suppliers with diverse attributes such as location, capacities, and fluctuating costs over time. Moreover, planning decisions on the levels of supply of raw materials from each supplier are included, together with production, inventory, and distribution decisions. The objectives being considered intend to contribute to economic and social sustainability improvement of the supply chain and are integrated into the model through two objective functions. Moreover, an additional social approach is integrated to, together with the social objective function, fulfil two strong pillars of equity in access to pharmaceutical products: availability and affordability.

* + 1. Economic Sustainability objective

The economic assessment aims to maximize the Net Present Value (NPV) by summing the cash flows of each time-period at an interest rate. These cash flows are achieved through the net earnings (), which are given by the difference between revenues (amount of products sold at a certain price ), and the overall costs. As seen in Eq. (1), the supply chain costs considered are raw material costs (first term), production operating costs (second term), storage costs (third term), variable transportation costs (fourth term), hub handling costs (fifth term), contracted costs with airline/freighter (sixth term), inventory costs (seventh term), labour costs at entities (eighth and ninth terms), and finally the labour costs for the use of technologies (tenth term).

* + 1. Social Sustainability assessment

The social sustainability assessment is focused on improving equity in access to pharmaceutical products, by improving two strong pillars: Availability and Affordability. The Availability pillar aims to prioritize populations with higher incidence of a disease to which the product being produced and distributed is essential for prevention or treatment. Hence, the objective function defined in Eq. (2) maximizes the location of entities in areas with higher DALY (Disability-Adjusted Life Years) - a metric that reflects the burden of a disease as a rate per 100,000 population. In Eq. (2) the parameter is used together with the binary decision variable, , to prioritize the location of entity in geographical areas with higher DALY value. Additionally, a restriction is used to ensure that, when a manufacturing facility is open for production, it produces a percentage of its production to satisfy the local demand, guaranteeing the improvement of accessibility of the population of its geographical area.

|  |  |
| --- | --- |
|  |  (2) |

The Affordability pillar is explored through demand-to-price elasticity (Duarte et al., 2023). This approach aims to balance the supply and demand sides while considering affordability concerns. The elasticity coefficient, , translates the connection between demand and price and is determined by the absolute value of the logarithmic change in demand concerning price. Demand is categorized as elastic if its relative change is greater than or equal to the corresponding relative price fluctuation (), and inelastic otherwise (). This elasticity coefficient varies with the product () and the market ) since different markets have different affordability levels, affecting their sensitivity to price fluctuations. This approach aims to explore how the demand-to-price elasticity can be related with the quantity and price that a company can set, as well as the population’s capacity to afford that price, as defined in Eq. (3). The demand () is derived from a polynomial relationship with the corresponding price (, and establishes the minimal demand threshold for the minimum feasible price (Eq. (4)).

And considering a linear relation is achieved:

* 1. Case-study

The pharmaceutical company investigated in this study manufactures and distributes a meningitis conjugate vaccine. Low- and middle-income countries do not acquire this vaccine due to its price. Africa and Eastern Mediterranean region countries have expressed the desire to incorporate this vaccine into their standard immunization programmes but have encountered challenges in obtaining these vaccines because of its high price and limited availability (World Health Organization, 2019). The considered global pharmaceutical supply chain is composed of multiple suppliers, two factories (located in France and the U.S.), airports, seaports, and five markets - U.S, Australia, Europe, Africa and Middle East. A possible new factory location in Africa explores the possibility of increasing accessibility for this vaccine in this market. The vaccine under study (final product – Fp) requires four main raw materials for it to be produced: Active Pharmaceutical Ingredients (Rm1), supporting chemical materials (Rm2), vials (Rm3) and card package (Rm4). These raw materials are categorized in terms of supply risk and profit impact in the Kraljic matrix. **Rm1** is a **strategic material** (high percentage of the total purchase costs of the company and high risk of supply with only one supplier available, located in UK). Hence, the most efficient procurement strategy is to focus on long-term contracts with the supplier in order to minimize the supply risk. **Rm2**, a **leverage item**, has a high profit impact but lower supply risk. Exploiting purchasing power and minimizing costs should be considered as procurement strategies for this material. Diversifying suppliers is guaranteed by the possibility of supplying this material from two different suppliers, located in Texas and Lyon. **Rm3** and **Rm4** are **non-critical items**, characterized by a lower percentage of the total purchase costs representing a lower impact on profit, and a lower supply risk. Efficient procurement strategies involve simplification and automation of procurement processes, as well as guaranteeing abundant supply to keep supply risk low. Hence material Rm3 has three suppliers available located in Lyon, Kosamba, and Morganton, and material Rm4 has three suppliers available located in Essen, Mumbai, and Chicago. These suppliers differ between them not only in their location, but also in the price of the material they supply. As mentioned previously, demand is a decision variable and the obtained value is influenced by changes in the price of the product along time and the elasticity coefficient of the corresponding market namely, -4.94, -3.45, -0.69, -0.14, -0.05 for U.S., Australia, Middle East, Europe, and Africa, respectively. These values were calculated using procurement data from WHO's MI4A/VP3 database (Market Information for Access to Vaccines/Vaccine Product, Price, and Procurement) for the year 2022. The first two markets are characterized by an elastic demand to price, while the others are inelastic.

* 1. Results and Discussion

The results focus on three scenarios (1, 2 and 3) over two cases (A and B).

In the **first scenario (base scenario)** two cases are studied where lexicographic optimization was used: Case A corresponds to the optimum economic performance; Case B corresponds to the optimum social performance of the *Pharma Access* objective. Results for scenario 1 are shown in Table 1. Different supply chain structures are obtained depending on the prioritized sustainability pillar. The social sustainability pillar can be improved from 37.7 (Case A) to its maximum performance of 252.72 (case B). In its optimum performance, corresponding to Case B, all factories produce the vaccine at a production capacity at least equal to the local demand with a profit decrease of 1.3% (nearly 22.5M€). This decrease in profit for Case B is primarily due to higher labor and transportation costs, along with investments in technologies and entities necessary for the installation of the two additional factories, in U.S. and Africa.

Table 1. Supply chain topology and performance indicators’ results for scenario 1

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario 1** |  | **Case A** | **Case B** |
| **NPV (€)** | 1.810E+09 | 1.787E+09 |
| **s- Suppliers** **and** **f- Factories**  | sUK (Rm1), sLyon (Rm2), sLyon (Rm3), sEssen (Rm4);fFrance | sUK (Rm1), sLyon and sTexas (Rm2), sLyon and sMorganton (Rm3), sEssen and sChicago (Rm4);fFrance, fUS, fAfrica |
| **Transportation network** | Predominantly high-capacity trucks; Intercontinental transportation by plane (4 airports) and boat (4 seaports) | Predominantly high-capacity trucks; Intercontinental transportation by plane (3 airports) and boat (4 seaports) |

The **second scenario** explores the impact of a rise in the cost of raw materials on the design and planning decisions. Only Case A is analysed. Variations on the cost of a raw material are introduced on the supplier chosen on the base scenario. These variations (increase of 20%, 60%, and 150%) are introduced in the 5th year of a planning period of 10 years and aim to explore disruptive situations that significantly influence supply chain decisions. From the obtained results for scenario 2 (Table 2) it is observed that an increase of Rm1’s price by sUK will have implications on the profit reached, while the same supply chain configuration is obtained, since there is no other supplier available. An increase of 60% on the price of Rm2 by sLyon results in a different supply chain structure since a different supplier with a lower price is chosen (sTexas), even so, a global profit decrease of 1.8% is obtained. An increase of 150% leads to the selection of sMumbai to supply Rm4 to the factory fFrance, instead of sEssen initially chosen, and a profit decrease of 4%, corresponding to 72 million euros. It is relevant to point out that for the present case-study, considerable percentual increases on the price of the raw materials are necessary to lead to changes in the suppliers’ selection since the factory chosen in scenario 1 – Case A to produce the final product is located in France and the suppliers selected are the–ones located closer to this factory. Hence, the choice of other suppliers is associated with an increase of transportation costs, leading to a decrease of the NPV. In scenario 2, the optimum performance obtained for Pharma Access indicator was 37.7 as in scenario 1- Case A.

Table 2. Supply chain topology and performance indicators’ results for scenario 2

|  |  |  |
| --- | --- | --- |
| **Scenario 2**  |  | **Case A** |
| **Variations\*** | **↑20%** | **↑60%** | **↑150%** |
| **NPV (€)** | 1.799E+09  | 1.780E+09 | 1.737E+09 |
| **s- Suppliers****and****f- Factories** | sUK (Rm1), sLyon (Rm2), sLyon (Rm3), sEssen (Rm4);fFrance | sUK (Rm1), sLyon (Rm2, , sTexas (Rm2, ), sLyon (Rm3), sEssen (Rm4);fFrance | sUK (Rm1), sLyon (Rm2, , sTexas (Rm2, ), sLyon (Rm3), sEssen (Rm4, ), sMumbai (Rm4,); fFrance |

\*Percentual increase on the price of raw materials by suppliers chosen in scenario 1 – Case A, introduced in period 5 of a total planning period of 10 years.

An increase in the cost of purchased raw materials may lead to an increase in the price of the final product as a strategy for the company to recover the profit lost. This study proposes to account not only for the economic performance of a company, but also to consider social concerns related with availability and affordability of pharmaceutical products. In scenario 2, a 60% increase in the raw material cost provided by the initially selected suppliers in the base scenario was introduced. Building upon this, **scenario 3** introduces an additional variation of the price of the final vaccine in each market. These variations include an increase of 2% in the price of the vaccine for high income markets, U.S. and Australia, whereas a decrease of 15% is applied to the remaining markets. These price variations are introduced in the 5th year of a planning period of 10 years.

The same supply chain structure was obtained but with different demand responses, depending on the market and its sensitivity to the introduced price variations. In the markets where a price decrease of 15% was introduced, demand rose by 10.5% in Middle East, 1.96% in Europe and 0.75% in Africa, therefore increasing the affordability of this vaccine to these markets. On the other hand, a demand decrease of 9% in U.S. and 7% in Australia was obtained due to a price increase of 2%. Although the effect of the same variation results in consistent behaviour among markets, the magnitude of these responses is distinct, depending on the demand-price elasticities experienced by each market. The increase in the price of the vaccine being distributed and sold to the high-income markets of the U.S. and Australia leads to a decrease in the demand of these markets which can be explained by the existence of substitute vaccines produced by other companies in these two markets. This means that for the vaccine under consideration, the markets with greater purchasing power and higher affordability levels, are also the markets with higher product availability, leading to a higher sensitivity to price variations (higher elasticity coefficients). Hence, the markets’ response to the variations introduced results in a 6% decrease in NPV compared to the base scenario. In conclusion, to offset the profit loss from increased raw material costs, the company should consider more effective strategies other than raising prices in higher purchasing power markets.

* 1. Conclusions

This work proposes an optimization model for the design and planning of economically and socially sustainable supply chains. Different scenarios are proposed which reveal the importance of having efficient procurement strategies that allow a company to reduce the risk associated with raw materials supply, such as increased costs or disruptive situations. Moreover, this study highlights the importance and impact of considering both economic and social concerns when designing and planning pharmaceutical supply chains.

**Acknowledgements:** The authors acknowledge the support provided by FCT under the project PTDC/EME-SIS/6019/2020 and UIDB/00097/2020, and PhD Grant 2022.11365.BD.

References

Barbosa-Póvoa, A. P., da Silva, C., & Carvalho, A. (2018). Opportunities and challenges in sustainable supply chain: An operations research perspective. *European Journal of Operational Research*, *268*(2), 399–431. https://doi.org/10.1016/j.ejor.2017.10.036

Duarte, I., Mota, B., Pinto-Varela, T., Amaro, A., & Barbosa-Povoa, A. P. (2023). Modelling availability and affordability concerns in the design and planning of pharmaceutical supply chains. *Computer Aided Chemical Engineering*, *52*, 3369–3374. https://doi.org/10.1016/B978-0-443-15274-0.50537-0

Duarte, I., Mota, B., Pinto-Varela, T., & Barbosa-Póvoa, A. P. (2022). Pharmaceutical industry supply chains: How to sustainably improve access to vaccines? *Chemical Engineering Research and Design*, *182*, 324–341. https://doi.org/10.1016/j.cherd.2022.04.001

FDA. (2019). Drug Shortages: Root Causes and Potential Solutions: A Report by the Drug Shortages Task Force. *U.S. Food and Drug Administration (FDA)*, 1–6.

Jaberidoost, M., Nikfar, S., Abdollahiasl, A., & Dinarvand, R. (2013). Pharmaceutical supply chain risks: A systematic review. *DARU, Journal of Pharmaceutical Sciences*, *21*(1), 1–7. https://doi.org/10.1186/2008-2231-21-69

Milanesi, M., Runfola, A., & Guercini, S. (2020). Pharmaceutical industry riding the wave of sustainability: Review and opportunities for future research. *Journal of Cleaner Production*, *261*, 121204. https://doi.org/10.1016/j.jclepro.2020.121204

World Health Organization (2019). *Global Market Study: Meningococcal Meningitis Vaccines*. https://cdn.who.int/media/docs/default-source/immunization/mi4a/who\_meningococcal\_vaccines\_public\_summary.pdf