Agent based modelling for a sustainable distribution network: a Moroccan case study of a retail logistics network

Hajar Deqqaq and Abdellah Abouabdellah

Laboratory Systems Engineering, Research team ' Modelling and Optimization of the Industrial and logistic Systems ' MOSIL, National School of Applied sciences, Ibn Tofail university, Kenitra Morocco
hajar.deqqaq@gmail.com and a.abouabdellah2013@gmail.com

Abstract

Ruthless competition, pression from authorities and constant demand from customers to purchase an eco-friendly product, make the modern company condemned to reduce the social and environmental impacts for their supply chains. Not to forget optimize the operational costs making the logistic operations more sustainable. In this paper, we investigate the added value of sustainability on a distribution network via a multi-agent simulation. The aim of the proposed model is the minimization of operational costs and the environmental burden as well as maximizing the social benefits of the network. We are mainly interested in the way the distribution network and the facilities behave under sustainability constraints.

Keywords
Sustainability, logistics, simulation, multi-agent systems, distribution network design.

1. Introduction

Without a doubt, logistics network are complex systems with dynamics proprieties. Not only they deal with uncertainty of data but also, they have to be time dependent. The main contribution of this paper is to shed light on how Logistics networks perform in a dynamic environment. This performance, would help decision makers to predict the changes in the network configuration based on sustainability pillars: economic, environmental and social.
For decades, the logistics network design or distribution network design was linked to location science. More precisely: the location facility problem. The similarity of both problems is argued to be due to the fact that they have the same purpose. Both problems try to find the best location of distribution centers, hubs or warehouses in order to minimize the total costs. This traditional objective of operating the distribution network under minimum costs is justified by the crucial role that logistics networks play as a key of profitability, since they affect directly the costs of the supply chain as well as customer satisfaction (Chopra et al, .2004).
In today's business environment, the logistics systems widely evolved during the last decade. This said evolution is marked by: The decrease of the size of the transported lots and the size of inventories, the industry aims more towards just in time; Flexible transportation; Increased reliability; The availability of more transportation solutions of via one 3PL and 4PL; The acquisition of more logistic operations by the logistics agents such as the storage, the handling, the packaging and the maintenance; And the development of the e-commerce and the use of Information and Communication Technologies (Savy, 2006). But nowadays, this economic performance is not enough to face the challenges exerted from customers and from NGO (Non-Governmental Organization), on companies to address their sustainability level.
The rest of the paper is organized as follow: The first part of the article presents a background on sustainability optimization and agent modelling in distribution networks. The second part, exposes the proposed methodology. The third part presents the case study, the finding and discusses the results. Finally, we end the paper with a conclusion and future research perspectives.

2. Literature review

In the realm of Logistics planning and modelling, researchers and academics focused mainly on mathematical and analytical models as tools to capture the complexity of Supply Chains. To mitigate the risks of Distribution network configuration and planning in uncertain environment, more innovative systems such as the digitalization of decision making, trough the automation of the decision process, are crucial in today's rapidly changing environments.
To add more complexity of the overmentioned logistics systems, sustainable measures and practices are required to be taken under consideration during the design and planning of logistics networks. Recently, research in the Supply Chain Management (SCM) field, has increasingly focused on the environmental aspect and on issues related to sustainability of operations. The concept of Sustainable Supply Chain Management (SSCM), presented in the Brundtland report in 1987, means the consensus made between the three pillars of sustainable development: Economic, Environmental and Social performances of the logistics network of a company [3]. This trend has been investigated in the review papers of (Seuring et al., 2013), (Brandenburg et al., 2015) and (Eskandarpour et al., 2015). The authors examined the literature of SSCND and showed a special focus on mathematical quantitative models.
Focusing more on outbound logistics, Sustainable Distribution Network Design involves mid to long–term decisions, which means these decisions occur at the strategic/ tactical level of the Supply Chain. Several authors and previous studies addressed the modeling and the optimization of distribution networks in a deterministic environment where the data and parameters are known a priori. For example, (Tseng et al., 2014) present a model for a sustainable apparel supply chain, where they considered both operational costs and social costs of CO2 emission. (Deqqaq et al., 2016) introduced a bi-objective optimization for a green distribution network with multiple transportation modes; they used Life Cycle Assessment (LCA) analysis to calculate the environmental burden of the network. (Lam et al., 2015)Combined Quality Function Deployment (QFD) and Analytical Network Process (ANP) to design a maritime supply chain for a shipping company willing to achieve sustainability. (Deqqaq et al., 2017) addressed the optimization of a green distribution network taking into account the costs, the delivery time and the environmental impacts minimization.
To tackle the design of distribution networks, more authors focused on simulation based optimization as a technique to deal with to complexity of logistics networks optimization. The major leaps in computer sciences, made the hybrid optimization simulation modelling methods famous and on trend. Since, using the analytical modelling alone does not address the uncertainty in the model. And if so, it would not be as accurate as optimization-simulation techniques (Figueira et al. 2014).
(Jung et al. 2004) addressed the safety stock level for a chemical supply chain dealing with uncertainty. The authors used the simulation-optimization modelling approach to tackle constrained stochastic optimization problem.
(Wan et al., 2005) proposed an extension of the simulation based optimization. (Long, 2014a) proposed an agent-based distributed computational experiment framework for virtual supply chain networks. (Long et al., 2014b) in their following paper, an agent-based inventory–production–transportation model was built to simulate a supply chain, the authors combined the agent-based modeling and distributed simulation theory to come up with a four layered conceptual framework. (Wikarek et al., 2016) presented a multi-agent on a multi-level approach to model and solve a supply chain. The main finding was that the proposed methodology is more effective classical mathematical programming.
Hence, in this paper we propose an optimization with an ABM for simulation for the solution evaluation and the enhancement of the analytical model (AME) for the primary distribution.

3. Problematic and proposed methodology

Our contribution trough this paper is the use of both analytical and agent modelling techniques to the design and optimization of a distribution network. The figure 1 shows the studied network. Which comprises of a single manufacturing plant and a set of Regional Distribution Centers (RDC). The blue arrows represent the primary distribution (from the manufacturing plant to Regional Distribution Centers). The green arrows, portray the secondary distribution (from RDC to customers).
The research questions we intend to answer in this paper is:

- How to design an optimal sustainable distribution network?
- Decisions related to the storage facilities: How to determine opening/closing of regional distribution centers.
- How to model the environmental impacts in a more comprehensive way?

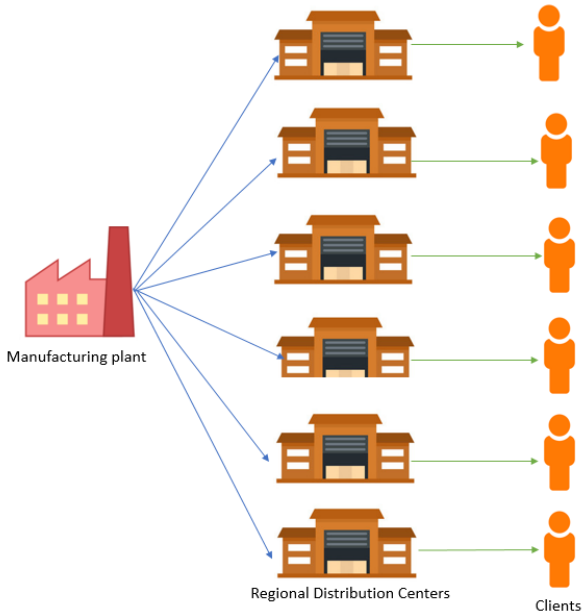

Figure 1: The studied distribution network

Figure 2 exhibits the followed methodology to answer these research questions:

- First, we present a Mixed Integer Linear Programming (MILP) formulation of the studied problem, taking into account the economic, environmental and social objectives;
- Then, we solve the optimization problem;
- Finally, we implement the optimal solution in Anylogic which is a platform combining both GIS (Geographical Information System) and an Agent Based Modelling (ABM) environment to represent the decision related to the size of the vehicles fleet and their utilization rate in a more realistic way.

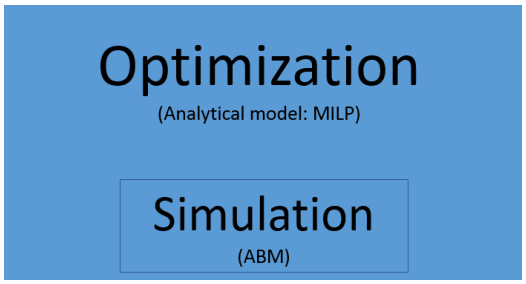

Figure 2: The hybrid optimization-agent based simulation method

3.1 The analytical Model

In this section, we develop a MILP model with the following considerations:

- One production site;
- One product or products with similar characteristics;
- Direct Shipment (from production site to customers) is not allowed;
- All facilities are subjected to a capacity constraint;
- No inventory costs are generated at the RDC (the platform is used only to group/ungroup deliveries);
- Total planning horizon is 1 year;
- The transportation mode used in both primary and secondary distribution is trucks.

Three objectives functions are formulated to deal with the problematic:

- Total costs objective function to be minimized
- Total environmental impacts objective function to be also minimized
- Total social benefits of the Distribution Network to be maximized.

Below are the sets, the parameters, the decision variables and the objective functions.

Sets
i Set Regional Distribution Centers (RDC)
j Set of sales points (clients)

Parameters
D_j Demand of client j
Cf_i Fixed costs of operating a RDC
dis_i , dis_{ij} are the distances between the RDCs and the manufacturing plant, and the RDC to clients
Cap_i are respectively the maximum capacity a RDC
C_m Maximum capacity of the manufacturing plant

Transportation costs Parameters for primary and secondary distribution trucks:
A is the fuel price per kilometer for trucks
B is the variable transportation cost per hour for trucks
C is the fixed costs of handling the products for trucks
S is the average speed of the trucks
Cap_{pt} , Cap_{st} are the capacities of trucks for both primary and secondary transportation
$Csub_t$ Subcontracted transportation cost, per kilometer, from a RDC to a sale point

Environmental assessment parameters:
Ic_{pt}, Ic_{st} Environmental impact for each Midpoint impact category for trucks
Ic_{RDC} Environmental impact for each Midpoint impact category for opening a RDC
Fn_c Normalization factor for each impact category

Social assessment parameters:
W_i is the number of created job at a RDC in region i
β_i a regional factor for RDC in region i.

Decision variables
Rdc_i Binary variable equals 1 if RDC is open and 0 if closed
X_i Quantity of product shipped from the manufacturing plant to a RDC i
Y_{ij} Quantity of product shipped from a RDC i to a customer

Total costs objective function

The economic objective function is represented by the Equation (1). The first term corresponds to the costs of maintaining regional distribution center, the second and third terms of the equation are the relative costs to the transportation of the product between two entities of the network using the company's trucks.

(Eq1) $$MIN(Total\cos ts) = MIN(\sum_{I} Rdc_i * Cf_i + \sum_{i}(dis_i * (A + \frac{B}{s}) + c) * N_i + \sum_{i}\sum_{j} dis_{ij} * Y_{ij} * Csub_t)$$

We suppose that all the deliveries will be made in full load. We introduce: N_i and M_{ij} (Equations 2-3) which are the numbers of shuttles per category of trucks made between every entity of the distribution network. Calculated from the quantities shipped to every entity divided by the capacity of trucks.

We will then have:

(Eq 2) $$N_i = \frac{X_i}{cap_{pt}}$$

(Eq 3) $$M_{ij} = \frac{Y_{ij}}{cap_{st}}$$

Environmental objective function

The Environmental Impacts (EI) objective function is expressed in the Equation (4), it follows the same structure as the costs function. We include the unitary environmental impact for each impact category instead of unitary costs. The functional unit (FU) is the distribution network. The LCA involves the transportation and distribution centers.

The LCIA of the system is calculated from the database Ecoinvent 3, using the software OpenLCA. The assessment method of the life cycle is ReCiPe Midpoint conforming to a hierarchical approach.

(Eq 4)
$$MIN(EIs) = MIN(F_{nc}(\sum_i \sum_c I_{cRDC} * RDC_i + \sum_i \sum_c I_{cpt} * dis_i * N_i + \sum_i \sum_j \sum_c I_{cst} * dis_{ij} * M_{ij}))$$

Social impacts objective function

(Mota et al, 2015) in their paper used the number of created jobs at a region as an indicator to measure social sustainability. Equation (5) represents to social benefits of the Distribution Network to be maximized. μ_i represents a regional factor related to employment rate calculated for each region i (Equation 6).

(Eq 5**)**
$$Max(SB) = Max(\sum_i W_i * \mu_i * Rdc_i)$$

With:

(Eq 6)
$$\mu(i) = \frac{country\ umployement\ rate\ per\ time\ period\ t}{umployement\ rate\ at\ region\ i\ at\ time\ period\ t}$$

3.2 Simulation model

In this paper, we are interested to simulate the primary transportation network, from the manufacturing Plant to the Regional Distribution Centers. Mainly, the simulation intend to optimize the vehicles fleet and their utilization rate. Moreover, A Geographical Information System (GIS) was used to locate the agents in the map and to determine routes from the manufacturing plan to RDCs. To construct an agent model of the primary distribution network, we introduce the following agent type:

- The Manufacturing Plant;
- The Regional Distribution centers (RDC);
- Transportation (trucks).

The developed agent architecture for the primary distribution. Figure 1 illustrates the distributed nature of decision-making in logistics networks. Decisions related to the fleet size is another component to sustainability, costs and the environmental impacts are strongly affected by the number of vehicles utilized for the distribution network configuration.

In the distribution network represented in figure 1, the RDCs receive an order from a client (sales points) then the RDC send and order to the Manufacturing plan. These orders are processed by the decision making system to choose the best RDC allocation and route. The figure 3 depict the order processing at a manufacturing site. The Anylogic Software was used as the simulation platform since it combines both the Agent simulation and a GIS. The model was constructed using a graphical modelling language.

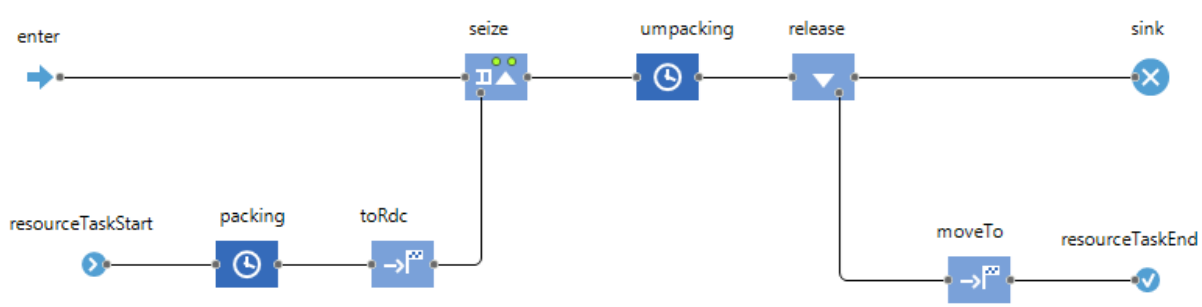

Figure 3: Order processing at the manufacturing site (in Anylogic)

4. Case study

The company's network is formed by one manufacturing plant and 12 potential location for Regional distribution centers. As for the transportation, at this moment, the company uses trucks as a transportation mode and the company own a large fleet of trucks which generate high costs. The Regional distribution center are rented and the operating cost of a RDC is assumed to be a fixed cost.

4.1 The environmental impacts assessment

To evaluate the overall environmental impact of the studied distribution network the OpenLCA software was used, under an academic license for the database "Ecoinvent 3.1". The Life cycle Impact Assessment method ReCiPe 2008 was chosen to evaluate the environmental impacts. This method comprises of two sets of impact categories with associated sets of characterization factors. Eighteen impact categories are addressed at the midpoint level and three at the endpoint level (Goedkoop et al. 2009). In this paper, only the midpoint indicators were assessed, we calculated the Midpoint indicators for each impact category with the LCIA method ReCiPe 2008 following a hierarchical approach. To simulate the environmental impacts of primary and secondary distribution, the option lorry 3.5-7.5t, EURO4/RER S is chosen from Ecoinvent database. Table 1, presents the obtained environmental impacts for each impact category for transportation and the RDCs.

Table 1: Data retrieved from the software OpenLCA for the environmental impact of transportation and of the facilities

Impact category	**Reference unit**	**Primary and secondary Transportation per Km**		**Regional DC per m²**	
		EI	**Normalized EI (points)**	**EI**	**Normalized EI (points**
Agricultural land occupation	m2*a	5,3081E-02	9,7869E-06	4,1028E+00	7,5667E-04
Climate Change	kg CO2 eq	1,0845E+00	1,6000E-04	1,6091E+01	2,3353E-03
Fossil depletion	kg oil eq	2,8439 -01	2,2000E-04	3,6516E+00	2,8313E-03
Freshwater eco-toxicity	kg 1,4-DB eq	**1,3402E-02**	3,1100E-03	8,4826E-01	1,9711E-01
Freshwater eutrophication	kg P eq	4,1857E-04	1,4400E-03	4,2131E-03	1,4535E-02
Human toxicity	kg 1,4-DB eq	4,3200E-01	1,3200E-03	7,4815E+00	2,2928E-02
Ionizing radiation	kg U235 eq	2,125E-01	1,6000E-04	9,8746E-01	7,4933E-04
Marine Eco toxicity	kg 1,4-DB eq	1,2683E-02	5,1500E-03	7,2816E-01	2,9571E-01
Marine eutrophication	kg N eq	1,2857E-03	1,8000E-04	2,1654E-02	2,9507E-03
Metal depletion	kg Fe eq	1,6135E-01	3,6000E-04	3,7400E+00	8,4007E-03
Natural land transformation	m2	2,1737E-04	1,8074E-05	1,8480E-03	1,5333E-04
Ozone depletion	kg CFC-11 eq	8,9034E-08	2,3661E-06	1,3355E-06	3,5333E-05
Particulate matter formation	kg PM10 eq	2,7688E-03	2,0000E-04	5,1744E-02	3,6807E-03
Photochemical oxidant formation	kg NMVOC	4,4925E-03	7,9183E-05	7,3393E-02	1,2933E-03
Terrestrial acidification	kg SO2 eq	6,2125E-03	1,6000E-04	1,3505E-01	3,5367E-03
Terrestrial Eco-toxicity	kg 1,4-DB eq	1,0017E-04	1,6896E-05	2,5596E-03	4,3200E-04
Urban land occupation	m2*a	5,8212E-02	7,5110E-05	2,2895E-01	2,9533E-04

4.2 The multi-objective approach

We coded the proposed model under the GAMS 24.7.1 environment. We solved every objective separately with a PC Intel I5 with 4 GO of RAM with CPLEX 12.0 solver. Three possible scenarios are presented in figure 4:

- Scenario 1: an optimal solution, obtained when minimizing cost;
- Scenario 2: an optimal solution, obtained when minimizing environmental impact;
- Scenario 3: an optimal solution, obtained when maximizing the social benefits.

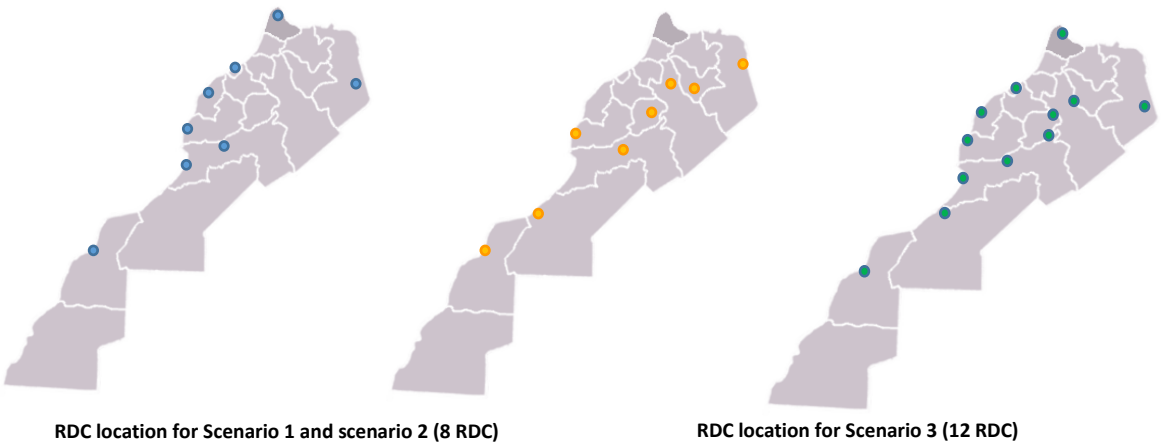

Figure 4 RDC location for each scenario

Table 2, shows that the single objective optimization approach offers solutions that are not viable for implementation within the company. Figure 4, presents the location of RDCs for each scenario, the single optimization approach return the same number of RDCs for both scenario 1 and 2. However the Environmental impacts minimization scenario locates the RDCs in the less populated areas. Moreover, the social benefits maximization comes with higher environmental impacts and higher costs.

Table 2: Single objective optimization results

	Min (costs) in (MAD)[1]	**Min (EIs) in (points)**	**Max social benefits (In number of created jobs)**
Total costs	2.216E06	2.216E06	2/624E06
Environmental impacts (EIs)	7567.17	7566	8784
Social benefits	164	201	321

Hence a multi-objective approach is required to reflect the compromise that has to be made between the three objectives: costs, environmental impacts and the social benefits. The ε-constraint method prioritize an objective among the others, it allows the optimization of one objective function subjected to the others objectives as constraints (Deqqaq et al., 2017). And in order to obtain Pareto efficient solution, we vary the constraint bounds. Since the total costs of the network and the environmental impacts scenarios return approximately the same network configuration, and since the total costs and the social benefits of the distribution network are top priority to the company, we are interested in studying the compromise between the economic and the social objectives. Figure 5, presents the tradeoff represented by the economic and the social objective after applying the multi-objective approach.

[1] MAD : Moroccan Dirham.

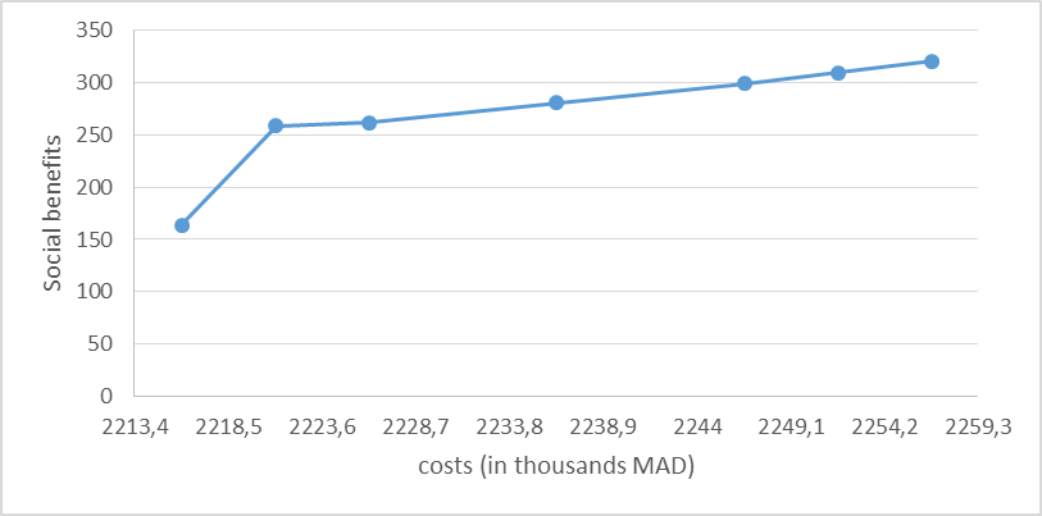

Figure 4: Approximation to the Pareto front obtained through the Ɛ-constraint method (Social benefits VS costs)

4.3 The simulation results

The manufacturing plant operates seven days in a week and has a capacity not to exceed. The RDCs place their orders each week. We consider that the waiting time at the manufacturing time follows a uniform distribution (Min=2h; Max=4h).

Initially, the company possesses a number of trucks, this number could be overestimated/underestimated for the optimal configuration offered by the optimization. We conducted a simulation experiment in Anylogic software. This later, combine both a GIS and an Agent architecture to model a selected scenario then run an optimization experiment, to maximize the utilization rate of the fleet of the vehicle owned by the company, followed again by simulation to test the viability of the solution. Table 3 shows that major gain is obtained after running the optimization simulation program. The current vehicles fleet configuration was overestimated, causing higher holding costs of the trucks. The proposed framework allows the decision makers to choose solution from the pareto-optimal solutions and simulate the chosen scenario to finally adjust their decisions in case of a major change in the distribution network environment.

Table 3: comparison of parameter's value before and after optimization

	Current operating parameter	After optimization experiment	After simulation
Trucks number	8	5	5
Utilization rate	37%	< 70%	64%

5. Conclusion

In this paper, our aim was to answer the research questions: How to design an optimal sustainable distribution network? To answer this problematic, the authors contributed in the following way:

- A Mixed integer Linear Problem was formulated to solve a multi-objective optimization problem and location-allocation problem when it comes to decisions related to the opening/closing of regional distribution centers;
- The environmental impacts evaluation in a more comprehensive way using ReCiPe 2008 as a LCIA method;
- A social benefits objective function was formulated and added to the Analytical model;

- A simulation model combining both GIS and an Agent Model using the Anylogic software was introduced to take decisions related to the size of the vehicle fleet and especially optimize the trucks load.

From the obtained results, it appears that the total costs and environmental impacts minimization have the same effects on the network configuration. Social benefits maximization comes, however, with higher costs and impossible to achieve for decision makers. Hence, a set of solutions of compromise must be offered in order to design a more sustainable distribution network.

The proposed methodology, in order to answer properly the research question, need to explore more research avenues such as:

- Using the Social Life Cycle Assessment (S-LCA) to model the social objective function, since the social aspect of logistics is difficult to quantify and no standard measure exist in literature yet;
- Incorporating uncertainty in the model;
- Using metaheuristics for the resolution of the optimization problem.

References

Chopra, S., Sodhi, M.S., 2004. Managing risk to avoid supply-chain breakdown. MIT Sloan Management Review 46, pp 52–61.

SAVY, M. (2006). Logistique et territoire. Paris : La documentation Française, DIACT, Coll. Travaux 1.

Seuring and Muller, «From a literature review to a conceptual framework for sustainable suply chain management» journal of cleaner production, vol. 16, pp. 1699-1710, 2008.

S. Seuring, «A review of modeling approaches for sustainable supply chain management,» Decision Support Systems, vol. 54, p. 1513–1520, 2013.

M. Brandenburg, K. Govindan, J. Sarkis and S. Seuring, «Quantitative models for sustainable supply chain management: Developments and directions» European Journal of Operational Research, vol. 233, n°12, p. 299–312, 2014

M. Eskandarpour, P. Dejax and J. Miemczyk, «Sustainable supply chain network design: an optimization-oriented review, » OMEGA, vol. 54, pp. 11-32, 2015 tseng et al 2014

H.Deqqaq, A. Abouabdellah, 2016. Design of a green distribution network with multiple transportation modes ARPN Journal of Engineering and Applied Sciences. VOL. 11, NO. 21, ISSN 1819-6608**.**

Lam, Jasmine Siu Lee. (2015). designing a sustainable maritime supply chain: A hybrid QFD–ANP approach. Transportation Research Part E: Logistics and Transportation Review. 78. 70–81. 10.1016/j.tre.2014.10.003.

H.Deqqaq, A. Abouabdellah. Proceedings of Computer and Industrial Engineering conference CIE47, 11-13 October 2017, Lisbon / Portugal.

G. Figueira, B. Almada-Lobo. Hybrid simulation–optimization methods: A taxonomy and discussion. Simulation Modelling Practice and Theory 46. Pp 118–134, 2014.

J. Y Jung, G. Blau, J. F. Pekny, G.V. Reklaitis, D. Eversdyk. A simulation-based optimization approach to supply chain management under demand uncertainty. Computers & Chemical Engineering Volume 28, Issue 10, 15 September 2004, Pages 2087-2106.

X. Wan, J.F. Pekny, G.V. Reklaitis. Simulation-based optimization with surrogate models: Application to supply chain management . Computers & Chemical Engineering Volume 29, Issue 6, 15 May 2005, Pages 1317-1328

Qingqi Long, An agent-based distributed computational experiment framework for virtual supply chain network development. Expert Systems with Applications Volume 41, Issue 9, July 2014, Pages 4094-4112.

Qingqi Long and Wenyu Zhang. An integrated framework for agent based inventory–production–transportation modeling and distributed simulation of supply chains, Information Sciences
Volume 277, 1 September 2014, Pages 567-581.

Wikarek J., Sitek P. (2016) A Multi-level and Multi-agent Approach to Modeling and Solving Supply Chain Problems. In: Bajo J. et al. (eds) Highlights of Practical Applications of Scalable Multi-Agent Systems. The PAAMS Collection. PAAMS 2016. Communications in Computer and Information Science, vol 616. Springer, Cham.

B. Mota, M. I. Gomes, A. Carvalho and A. P. Barbosa-Povoa. 2015. towards supply chain sustainability: economic, environmental and social design and planning. Journal of Cleaner Production. 105: 14-27.

A. Brennan, et al. A taxonomy of model structures for economic evaluation of health technologies Health Economics, 15 (2006), pp. 1295-1310.
Mark Goedkoop, Reinout Heijungs, Mark Huijbregts, An De Schryver,Jaap Struijs and Rosalie van Zelm. 2009. ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition.

Biographies

Hajar DEQQAQ a PH. D student attached to laboratory of System Engineering, research Team of Modelling, Optimization of Industrial Systems and Logistics (MOSIL) at the University of Ibn Tofail, Kenitra (Morocco). She obtained a Master's Degree in Industrial Engineering at the National School of Applied Sciences of Agadir in 2013.

Abdellah ABOUABDELLAH Doctor of Applied-Science, member of the intelligent energy team, attached to laboratory of System Engineering and head of Team of Modelling, Optimization of Industrial Systems and Logistics (MOSIL) at the University IbnTofail, Kenitra. Mr Abouabdellah is a research professor and the coordinator of the Industrial Engineering and logistics Department at the National School of Applied Sciences of Kenitra. Mr Abouabdellah is the author and co-author of several papers published in indexed journals. And has participated in national and international conferences. His research concerns the modeling of business processes, industrial engineering, predictions systems and logistics.