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► **To cite this version:**

Nassim Mrabti, Nadia Hamani, Laurent Delahoche. Sustainability indicators for a pooled logistics chain. 7th International Conference on Advanced Logistics and Transport (IEEE ICALT 2019), IEEE, Jun 2019, Marrakech, Morocco. halshs-03321058

HAL Id: halshs-03321058

<https://shs.hal.science/halshs-03321058>

Submitted on 17 Aug 2021

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Sustainability indicators for a pooled logistics chain

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Abstract—Logistics pooling is an important solution for companies to improve the different aspects of sustainability. The lack of a complete study that addresses the impact of pooled on sustainability prompted us to do this work. The aim of this paper is to propose a formulation of indicators for three aspects of sustainability: namely, in the economic level, we formulate the different logistics cost and the transportation fill rate, in the environmental level, we establish the different types of CO₂ emissions and finally in the social/societal level, we estimate the accident rates and the noise level.

Keywords—sustainability indicators, freight transport, pooling, mathematical approach

I. INTRODUCTION

In addition to the strong competition and the requirements of customers, sustainability presents a major issue for companies. Indeed, they have some responsible behavior, since they become concerned about the problems of it. This allows them to reduce the various costs, reduce their environmental impact and improve their brand images in front of people who are becoming more and more sensitive to sustainability. On the other hand, it is difficult for companies to confront all these issues alone, hence the need to collaborate with each other. According to the literature review, there are two main types of collaboration, namely: vertical and horizontal collaborations. The first type is predominantly limited to the exchange of information between partners that belong to the same supply chain. The second type focuses on the sharing of resources and goods between competing and non-competing partners that do not belong to the same supply chain. Most cases of horizontal collaboration are focused on the pooling of resources or structures whose purpose is to massify flows in order to minimize costs. The combination of the previous types gives lateral collaboration that aims to improve flexibility.

The following section of this paper is dedicated to the state of the art, the third section is intended for the indicators formulation and finally, we finish with a conclusion and prospects.

II. STATE OF THE ART

According to Rakotonarivo [1], the notion of pooling appeared in the 1990s in the field of distribution. Pooling is considered as one of the innovative solutions to address logistical challenges and improve the different aspects of sustainability. The main objective of the pooling is to massify the flows to improves the fill rate of vehicles, this is guaranteed since there is a grouping of goods and a sharing logistics resources. Many existing research in the scientific literature dealt the pooling. We cite some examples that used different indicators to evaluate the performance of pooling. Tuzkaya [2] evaluated the logistics costs due to transport, storage and penalty because of late delivery. Pan [3]

evaluated the economic and environmental indicators, namely: the transportation cost, the storage cost and the CO₂ emissions due to transport. Abdesslem [4] modeled logistics costs and CO₂ emissions from transport and warehouses by mathematical modeling. He modeled the different economic and environmental indicators. Indeed, the author evaluated the different logistical costs (transport, installation, storage, etc.) as well as the CO₂ emissions that are due to vehicles (their uses and their manufacturing) and to warehouses (their exploitation and their construction) by referring in ADEME. Morana [5] produced a table to evaluate the sustainability of pooling at the economic and environmental levels. An empirical study done by Makaci [6] on the pooled warehouses management conducted to several interviews with companies. Referring to dashboard of Morana [5], the authors proposed a number of indicators to evaluate the performance of pooled logistics (fill rate of vehicle and performance of pooled warehouse, benefits of pooling, etc.). Moutaoukil [7] consists of comparing the performance of a traditional logistics network with different scenarios in terms of logistics costs, CO₂ emissions and the accident rate caused by the transport vehicles.

We noticed that most approaches handled only both aspects of sustainability; the economic and/or the environmental. However, sustainability must be both economically efficient, socially equitable and ecologically tolerable. For this reason, we present in this paper several sustainability indicators to evaluate a pooled logistics chain.

III. FORMULATION OF INDICATORS

In this section, we formulate the sustainable indicators. The “Fig. 1” shows the horizontal collaboration between suppliers.

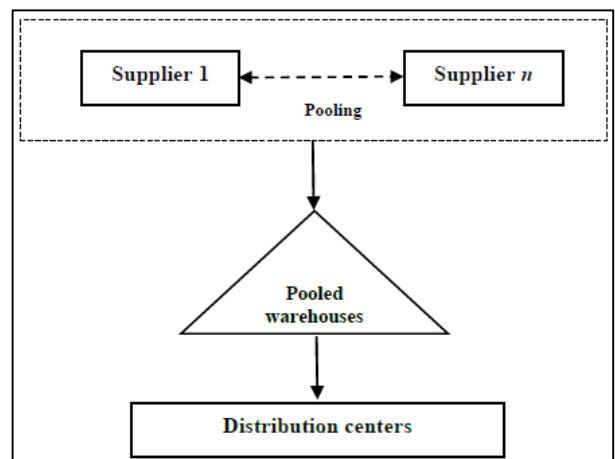


Fig. 1. Pooled logistics chain

The different indicators evaluated in our study are presented in “Fig. 2”.

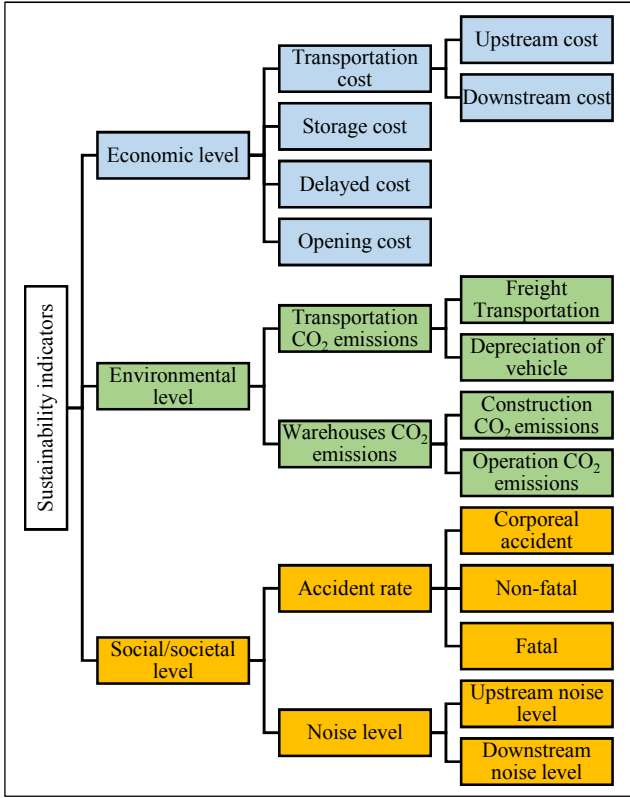


Fig. 2. The various estimated indicators

In our study, we consider the following index:

T : set of periods, $t=1..T$,

N : set of originating nodes, $i=1..N$,

M : Set of pooled warehouses, $m=1..M$,

D : Set of destination nodes, $j=1..D$,

P : Set of products, $p=1..P$,

A. The economic indicators

To formulate the indicators, we consider the following parameters in the table "TABLE I".

TABLE I. PARAMETERS USED FOR THE ECONOMIC FORMULATION

Parameter	Designation	Unity
CT_{ijt}	Transportation cost from location i to location j at the period t	€
q_{ijt}^p	Quantity of product p transported from location i to location j at the period t	pallets
Q	Vehicle capacity	pallets
d_{ij}	Distance between the location i and the location j	Km
d_{ji}	Distance between the location j and the location i	Km
C_q	Unit transportation cost when the vehicle is in charge	€/km.pallets
C_o	Unit cost of empty transportation	€/km
Nv_{ijt}	Number of vehicles required to transport from location i to location j at the period t	Vehicles
P_m^p	Inventory level of product p in warehouse m at the period t	pallets
CS_m^p	Unit storage cost of the product p in the warehouse m	€/pallet
CS_{mt}^p	The storage cost of the product p in the warehouse m at the period t	€
CD_t^p	Unit penalty cost due to late delivery of the product p at the period t	€/pallet
CD_t^p	The penalty cost due to late delivery of the product p at the period t	€
W_{jt}^p	Requested quantity of the product p by the node j at the period t	pallets
Wd_t^p	Delayed quantity of the product p at the period t	pallets
Cw_m	Unit opening cost of warehouse m	€/m ²

A_m	Area of warehouse m	m ²
Cw_m	The opening cost of warehouse m	€
F_{ijt}	The vehicle fill rate (from location i to location j) to period t .	%

1) *The transportation cost:* There are several mathematical formulas that can be used to model the transportation cost. This indicator can be modeled either according to the distance traveled, the quantity of goods transported or both simultaneously. In our work, we chose the formula proposed by Pan [3] who modeled the transportation cost according to the distance traveled and the quantity transported. This modeling done by Pan is the result of a project with industrial partners (*Association du Club Déméter Environnement et Logistique* and *Fédération des Entreprises et Entrepreneurs de France*). Indeed, Pan used a fee schedule provided by their study partners to propose the following formula:

$$CT_{ijt} = d_{ij} \left(\frac{Q \cdot C_q - C_o}{Q} \cdot \sum_{p \in P} q_{ijt}^p + C_o \cdot Nv_{ijt} \right) \quad (1)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

In order, to take into account the empty return we add the following extra term:

$$CT_{jit} = d_{ji} \cdot C_o \cdot Nv_{ijt} ; \forall i \in N, j \in D \text{ and } t \in T \quad (2)$$

The number of vehicles is the whole part of the ratio between the quantity transported and the vehicle capacity.

The following formulas will be used to model the transportation cost, taking into account the cost of empty return:

- In the case where the delivery distance is different to that for return ($d_{ij} \neq d_{ji}$)

$$CT_{ijt} = d_{ij} \left(\frac{Q \cdot C_q - C_o}{Q} \cdot \sum_{p \in P} q_{ijt}^p \right) + C_o \cdot Nv_{ijt} (d_{ij} + d_{ji}) \quad (3)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

- In the case where the delivery distance is equal to that for return ($d_{ij} = d_{ji}$)

$$CT_{ijt} = d_{ij} \left(\frac{Q \cdot C_q - C_o}{Q} \cdot \sum_{p \in P} q_{ijt}^p + 2 \cdot C_o \cdot Nv_{ijt} \right) \quad (4)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

2) *Storage cost:* Stock level assessment in pooled warehouses is important to optimize incoming and outgoing flows as well as the storage cost. According to the 3 M method, a high level of inventory (overstocking) generates unnecessary costs of storage (Muri) and a low stock level (under-storage), in turn generates unnecessary costs (Mura). Irregularities in this context are diverse: poor exploitation of resources (personnel, equipment and space), with an impact that can spread along the downstream supply chain (disruption of sales, stockouts, loss of customers).

According to [6], a pooled warehouse consists of three processes (operational, control/management and support). The storage cost can be defined as all the costs due to the presence of inventory in the store. These charges are counted from the goods receipt transaction to the exit transaction. The storage of goods therefore leads to the main lines of

expenditure which essentially belong to the two processes (operational and support). The storage costs increase in proportion to the quantities in stock as well as depending on the characteristics of the products. For this reason, we can conclude that the storage cost depend according to two main parameters, namely: date and quantity. We chose the model of [2], adopting it to our situation which includes a more generalized logistic chain with many pooled warehouses. In each warehouse, the storage cost of product p at period t is the multiplication of the inventory level by the unit storage cost. The inventory level of the product p is equal to the sum of the inventory level in the previous period and the difference between the quantity transported by the location i to the warehouse m and the quantity output by the latter to the location j . We assume that the unit cost is the same for all periods.

$$CS_{mt}^p = I_{mt}^p \cdot Cs_m^p; \forall p \in P, m \in M \text{ and } t \in T \quad (5)$$

$$I_{mt}^p = \sum_{i \in N} q_{imt}^p - \sum_{j \in D} q_{mjt}^p + I_{m(t-1)}^p; \forall p \in P, m \in M \text{ and } t \in T \quad (6)$$

3) *Penalty cost due to late delivery*: There are cases where companies delay delivery. It is interesting to get closer to this reality when designing pooled logistics chain. For this reason, we considered the penalty cost among our economic indicators. It is true that pooling showed its performance to reduce costs. However, this evaluation must take into account the penalty cost to see the impact of pooling on the relationship with customers who have the objective of having deliveries on time. In order to formulate this indicator, we adapted the formula given by [2] to our situation. The penalty cost of product p at the period t is the multiplication of unit penalty cost by the quantity delayed at the same period. The quantity delayed at period t is equal to the sum of quantity delayed at the preceding period and the difference between the quantity demanded by location j and the quantity delivered at period t by the pooled warehouse m .

We assume that the unit penalty cost depends on the type of product and the period because distribution centers may be more demanding in some periods than others due to high customers' demand or when it concerns seasonal products that are highly consumed during a given season.

$$CD_t^p = Wd_t^p \cdot Cd_t^p; \forall p \in P \text{ and } t \in T \quad (7)$$

$$Wd_t^p = \sum_{j \in D} W_{jt}^p - \sum_{m \in M, j \in D} q_{mjt}^p + Wd_{(t-1)}^p; \forall p \in P \text{ and } t \in T \quad (8)$$

4) *The warehouses opening cost*: The opening cost of the pooled warehouses depend on different factors (storage capacity, storage materials and empty space for the transfer of goods). For this reason, this cost is determined according to the area desired during the construction of the warehouse. The opening cost is the multiplication of the unit cost of opening by the area of the warehouse m . The unit cost may vary depending on the various parameters, including the location of the warehouse, size, and equipment, etc.

$$CW_m = A_m \cdot Cw_m; \forall m \in M \quad (9)$$

5) *The vehicle fill rate*: The objective of the pooling is the concentration of the flows by grouping the freight which makes it possible to improve the vehicle fill rate. This

indicator affects the supply chain sustainability, namely, its improvement makes it possible to minimize the number of vehicles hence the minimization of logistics costs and CO₂ emissions. According to [5] the fill rate is the ratio between the quantity of goods of all products (transported from location i to location j) and the vehicle capacity multiplied by the number of trips or vehicles needed.

$$F_{ijt} = \frac{\sum_{p \in P} q_{ijt}^p}{Q \cdot Nv_{ijt}}; \forall i \in N, j \in D \text{ and } t \in T \quad (10)$$

B. The environmental indicators

Before their participation to the pooling, companies must be aware of the collaboration impact on the environmental. This is only possible through an exhaustive evaluation of different environmental indicators. For this reason, we modeled the main types of CO₂ emissions generated during the design of a pooled logistics chain. Namely, CO₂ emissions from vehicles (transport and manufacturing) and those due to warehouses (operations and constructions).

According to the literature review, there are several methods to evaluate CO₂ emissions:

- Distance-based approach,
- Approach-based on energy consumption,
- Activity-based approach.

To formulate the environmental indicators, we consider the following parameters in the table "TABLE II".

TABLE II. PARAMETERS USED FOR THE ENVIRONMENTAL FORMULATION

Parameters	Designation	Unit
E_q	CO ₂ emissions for a loaded vehicle	g/km
E_o	CO ₂ emissions for an empty vehicle	g/km
a, b, c, d, e, f	Coefficients of emissions functions	
k	Constant	
C_{load}	The correction of the load factor	
r, s, t, u	Coefficients of the load correction functions	
E_v	CO ₂ emissions dues to manufacturing of vehicle without depreciation	tons CO ₂
T	The vehicle service life	km
W_o	The empty vehicle weight	tons
W	The GVWR (Gross Vehicle Weight Rating)	tons
EM	CO ₂ emissions dues to manufacturing of vehicle with depreciation	tons CO ₂ /km
E_{ijt}	CO ₂ emissions released during the freight transport from location i to location j at the period t	g/km
EO_{mt}	Unit CO ₂ emissions dues to the operation of the warehouse m at the period t	g CO ₂ /kwh
W_{mt}	Energy consumed in the warehouse m at the period t	kwh
EO_{mt}	CO ₂ emissions dues to the operation of the warehouse m at the period t	g CO ₂
EC_m	Unit CO ₂ emissions dues to the construction of the warehouse m	g CO ₂ /m ²
EC_m	CO ₂ emissions dues to the construction of the warehouse m	g CO ₂

1) *CO₂ emissions from vehicle*: There are two types of CO₂ emissions from vehicles, namely: emissions from their uses (freight transport) and others due to their depreciation (manufacturing processes).

a) *Transportation emissions*: Concerning the modeling of this first type of emissions, we used the activity-based approach that takes into account the quantity of goods transported and the distance traveled. For this reason, we are interested by the CO₂ emission function used in ([3] ; [7]). This formulation is the result of the COST (European Cooperation in the Field of Scientific Research) and MEET projects (Methodologies for Estimating Air Pollutant Emissions from Transport) ([8]; [9]). These projects produce the fundamental results for the COPERT software (Computer Program to Calculate Emissions from Road Transport). The general formula obtained is:

$$E_{ijt} = d_{ij} \cdot \left[\left(\frac{E_q - E_o}{Q} \right) \cdot \sum_{p \in P} q_{ijt}^p + E_o \cdot Nv_{ijt} \right] \quad (11)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

E_o depends on vehicle type according to the GVWR (*Gross Vehicle Weight Rating*) and speed. Referring to [9], the formula linking the speed and the CO₂ emissions of an empty vehicle is:

$$E_o(v) = K + a \cdot v + b \cdot v^2 + c \cdot v^3 + d/v + e/v^2 + f/v^3 \quad (12)$$

The fully loaded vehicle emission rate is obtained by multiplying the empty vehicle emission rate by the load factor correction.

$$E_q = E_o \cdot C_{load}(\delta, v) \quad (13)$$

The correction of the load factor depends on the percentage of gradient of the road and the vehicle speed. However, we neglected the gradient percentage because it is difficult to know each time. After this hypothesis, the correction of the load factor is given by the following formula:

$$C_{load}(v) = k + r \cdot v + s \cdot v^2 + t \cdot v^3 + u/v \quad (14)$$

The general emission formula does not take into account the amount of CO₂ released during vehicle empty return which we can estimate by the next formula:

$$E_{jit} = d_{ji} \cdot E_o \cdot Nv_{ijt}; \forall i \in N, j \in D \text{ and } t \in T \quad (15)$$

Finally, we can conclude that the formula of the CO₂ emissions due to freight transport from location i to location j at the period t becomes:

- If ($d_{ij} \neq d_{ji}$)

$$E_{ijt} = d_{ij} \cdot \left(\frac{E_q - E_o}{Q} \cdot \sum_{p \in P} q_{ijt}^p \right) + E_o \cdot Nv_{ijt} \cdot (d_{ij} + d_{ji}) \quad (16)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

- If ($d_{ij} = d_{ji}$)

$$E_{ijt} = d_{ij} \cdot \left(\frac{E_q - E_o}{Q} \cdot \sum_{p \in P} q_{ijt}^p + 2 \cdot E_o \cdot Nv_{ijt} \right) \quad (17)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

b) *CO₂ emissions from vehicle manufacturing*: There are two methods to model these emissions.

- **First method**

The CO₂ emissions from vehicle manufacturing are composed of CO₂ emissions from materials and emissions from the various workstation used during manufacturing. The first method is to model separately each type of emission.

- CO₂ emissions from materials

A transport vehicle consists essentially of steel, plastic, aluminum, flat glass, rubber and liquids, etc. The CO₂ emissions of these different materials vary according to the vehicle weight. The table “TABLE III” extracted from ADEME [10] represents the average of the percentages of the different materials of a vehicle:

TABLE III. VEHICLE CONSTITUTION AND CO₂ EMISSIONS OF EACH MATERIAL [10]

Material	p_i (percent in weight)	E_i (CO ₂ emissions)
steel	50 %	2.15
aluminum	7 %	9.84
plastic	10 %	2.39
flat glass	4 %	1.52
rubber	5 %	2.39
liquids	7 %	1.84
other	17 %	3.67

We can conclude that the CO₂ emissions of materials are equal to:

$$CO_2 \text{ emissions from materials} = W_o \cdot \sum_i p_i \cdot E_i \quad (18)$$

$$CO_2 \text{ emissions from materials} = 2,94 \cdot W_o \quad (19)$$

- CO₂ emissions from various workstation

According to [4] and the report [10], all workstation CO₂ emissions are of the order of 2.569 tons CO₂ for a particular vehicle of 1.19 tons. By dividing these emissions by the vehicle weight, we can conclude that:

$$CO_2 \text{ emissions workstation} = 2,158 \cdot W_o \quad (20)$$

The total of these two CO₂ emissions types gives the CO₂ emissions due to vehicle manufacturing. According to [10], it is necessary to add 10 % which correspond to other items (such as freight and waste) producing additional emissions during vehicle manufacturing.

$$Ev = 5,1 \cdot W_o + 10\% \cdot 5,1 \cdot W_o \quad (21)$$

$$Ev = 5,6 \cdot W_o \quad (22)$$

- **Second method**

This second method consists to evaluate the total manufacturing emissions of the two types mentioned above using the emission factors “Table IV” extracted from the OET [11] (Observatory Energy Environment of Transport).

TABLE IV. MANUFACTURING CO₂ EMISSIONS ACCORDING TO EMPTY WEIGHT [11]

Ev	2.2	4.5	6	9	10.5	14	15	18	20
W_o	12.1	24.5	33	49.5	57.8	77	82.5	99	110

If the table does not contain the vehicle weight used, it is possible to make a contribution by plotting the manufacturing emissions curve based on curb weight “Fig. 3” and determining the trend line.

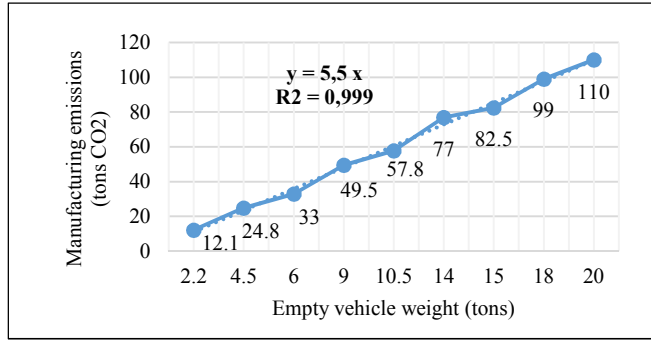


Fig. 3. Manufacturing CO₂ emissions according to empty weight

The coefficient of determination R^2 of the regression is relatively high. These two methods gave approximately the same result. This formula applies only to the vehicles built in Europe:

$$E_v = 5,55 \cdot W_o \quad (23)$$

In order, to take into account the depreciation of each vehicle, it is essential to divide this formula by the lifetime of the vehicle. We were guided on [10] to determine the lifetime formula as a function of the GVWR.

$$T = -242,02 \cdot W^2 + 24135 \cdot W + 171683 \quad (24)$$

The CO₂ emissions due to vehicle manufacturing is given by the following formula:

$$EM = \frac{E_v}{T} \quad (25)$$

The total CO₂ emissions is the sum of both types of emissions from the vehicle (its manufacture and operation) due to freight transport from location i to location j at the period t .

- If ($d_{ij} \neq d_{ji}$)

$$E_{ijt} = d_{ij} \cdot \left(\frac{E_q - E_o}{Q} \cdot \sum_{p \in P} q_{ijt}^p \right) + (E_o + EM) \cdot Nv_{ijt} \cdot (d_{ij} + d_{ji}) \quad (26)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

- If ($d_{ij} = d_{ji}$)

$$E_{ijt} = d_{ij} \cdot \left(\frac{E_q - E_o}{Q} \cdot \sum_{p \in P} q_{ijt}^p + 2 \cdot (E_o + EM) \cdot Nv_{ijt} \right) \quad (27)$$

$;\forall i \in N, j \in D \text{ and } t \in T$

2) CO₂ emissions from warehouses: The design of pooled logistics chain requires the installation of warehouses to massify the flow. However, these buildings are an important consumers of energy, therefore significant emitters of GHG emissions.

a) Emissions due to warehouse operations: These emissions are mainly due to operations and the necessary storage conditions (heating, cooling, ventilation, lighting and maintenance). We used the second approach, which consists of converting the number of kwh consumed in the warehouse to the equivalent of CO₂ emissions. In our work, we took into account the CO₂ emissions due to the production of the

necessary energy used as well as the online losses known as joule loss. According to the report ADEME [10], the production of a kwh of electricity in France generates 23 g C, or 85 g CO₂. This emission factor does not take into account online losses (joule losses) that are due to the transport and distribution of electricity from the power station to the consumer. These losses represent on average 3% of the final electricity consumed lost in the transmission network.

Finally, we concluded that CO₂ emissions from the operation of the warehouse m at the period t are equals to:

$$EO_{mt} = Eo_{mt} \cdot W_{mt} ; \forall m \in M \text{ and } t \in T \quad (28)$$

$$Eo_{mt} = 87,5 \text{ g CO}_2/\text{kwh} ; \forall m \in M \text{ and } t \in T \quad (29)$$

b) Emissions due to warehouse constructions: We used a detailed approach by quantity of materials used, which makes reduction in the error percentage. According to the report [10], buildings intended for storage (warehouses) are characterized by a steel structure and a cladding steel facade. Referring to [10] et [4], we determined the CO₂ emission of each element, then we have taken the average value. The results are summarized in the table in “Table V”.

TABLE V. DISTRIBUTION OF EMISSIONS DUE TO WAREHOUSE CONSTRUCTION

Element	Element's emission (E_i)	Percentage (P_i)	Construction's emission ($E_c = E_i / P_i$)
Structural steel	90 Kg CO ₂ /m ²	45 %	200 Kg CO ₂ /m ²
Cladding steel	60 Kg CO ₂ /m ²	30 %	200 Kg CO ₂ /m ²
Concrete	50 Kg CO ₂ /m ²	25 %	200 Kg CO ₂ /m ²
Average value			200 Kg CO₂/m²

The CO₂ emissions due to the construction of the warehouse m are the multiplication of the unit CO₂ emissions by the its area:

$$EC_m = E_{c_m} \cdot A_m ; \forall m \in M \quad (30)$$

C. The social/societal indicators

It is necessary to evaluate the impact of the design of a pooled logistics chain on residents and citizens. We evaluated indicators that focus on the social/societal, namely: the noise level of vehicles and the level of safety of people on roads by calculating accident rates generated by HW (*Heavy Weight*). To formulate the social/societal indicators, we consider the following parameters in the table “TABLE VI”.

TABLE VI. PARAMETERS USED FOR THE SOCIAL/SOCIETAL FORMULATION

Parameters	Designation	Unit
D	Distance traveled	Km
Rc	Risk of a corporeal accident	%
Ac	Number of accidents involving a heavy vehicle per year	accidents
pm	Percentage of mortality	%
Rn	Non-fatal corporeal accident rate	%
Rf	Fatal corporeal accident rate	%
l	Width between facade of buildings	m
E	Acoustic equivalence factor between light and heavy vehicles	%
V	Speed	km/h
d	Distance to the platform edge	m
lr	Width of the road	m
Q^{HW}_{ijt}	Flow of heavy weight vehicle that flows	vehicles

	between location i and location j at period t	
NL_{ijt}	Noise level when transporting goods from location i to location j at the period t	dB

1) *The accident rates:* The United Nations 2030 Agenda for Sustainability has set a road safety of halving the total number of road traffic fatalities and injuries by 2020. Referring to [14], we estimated this indicator. An accident is measured by unit of time (*accident/year*) or space (*accident/vehicle-kilometer*). The following formula gives the accident rate (compared to a thousand kilometers depends on a number of heavy vehicle accidents per year and the distance traveled).

$$Rc = \frac{Ac \cdot 1000}{365 \cdot D} \quad (31)$$

The distance traveled during all periods from all locations i to all locations j is equal to:

- If ($d_{ij} \neq d_{ji}$)

$$D = \sum_{i \in N, j \in D, t \in T} Nv_{ijt} \cdot (d_{ij} + d_{ji}) \quad (32)$$

- If ($d_{ij} = d_{ji}$)

$$D = 2 \cdot \sum_{i \in N, j \in D, t \in T} Nv_{ijt} \cdot d_{ij} \quad (33)$$

According to the road safety report, a bodily injury is any accident involving at least one road vehicle in motion, occurring on a lane open to public traffic, and in which at least one person is injured or killed. Confirming to this definition we find that a bodily injury can be fatal or non-fatal, for this reason in our study, we evaluated the three levels of accident (corporeal, non-fatal corporeal and fatal corporeal).

$$Rf = pm \cdot Rc \quad (34)$$

$$Rn = Rc - Rf \quad (35)$$

2) *The noise level:* Noise level assessment, when designing logistics networks, provides an idea of the adverse effects on the comfort of the inhabitants. We estimated this indicator by referring to land transport noise guide that designed by the CETU [15] (*Centre d'Études des Transports Urbains*). There are two types of fabric.

a) « *U* » *shaped closed fabric:* This fabric has low noise permeability, it is used in urban areas with a speed below 60 km/h. The following formula is used to determine this first type due to the freight transportation between two points i and j at a period t . The acoustic equivalence factor is equal to 10 for a ramp less than or equal to 2 %.

$$NL_{ijt} = 2 \cdot [55 + 10 \cdot \log(E \cdot Q_{ijt}^{HW}) - 10 \cdot \log(l)] \quad (36)$$

$$; \forall i \in N, j \in D \text{ and } t \in T$$

b) « *Open* » *fabric:* This type can be easily penetrated by noise. It consists of buildings distant from each other, which emit spaces very permeable to noise. Considering that the road is a motorway, The following formula is used to determine this second type due to the freight transportation between two nodes i and j at the period t .

$$NL_{ijt} = 2 \cdot [58 + 10 \cdot \log(E \cdot Q_{ijt}^{HW}) + 20 \cdot \log(V) - 12 \cdot \log\left(d + \frac{br}{3}\right)] \quad (37)$$

$$; \forall i \in N, j \in D \text{ and } t \in T$$

The angle is equal to 180° that is to say the source line is infinitely long. The acoustic equivalence factor between light and heavy vehicles is taken directly from the table indicated in the noise guide, the value is equal to four for a highway.

The flow rate of heavy weight vehicle is equal to the number of vehicle and the multiplication by two in the two formulas is done to count the return.

IV. CONCLUSION

We noted through the analysis of the literature that the majority of the work dealing logistic pooling, does not take into account the three aspects of sustainability. For this reason, we proposed different indicators to evaluate the sustainable performance of pooling: namely, the logistic costs, the vehicle fill rate, the CO₂ emissions, the accident rates and the noise level. This indicators formulation is only a first structuring that will be complemented by a mathematical model for the design problem of a sustainable pooled logistics chain.

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