Impacts of replenishment practices on sustainability

E. Baumann-Chardine*, V. Botta-Genoulaz.**

Université de Lyon, France
INSA-Lyon DISP, F-69621, Villeurbanne, France
*(Tel: +33 4 72 43 62 34; e-mail: emilie.baumann@insa-lyon.fr)
**(e-mail : valerie.botta@insa-lyon.fr)

Abstract: This paper proposes a model to study and analyze the sustainability of the impacts of replenishment practices. Ten sustainability indicators have been selected to characterize the sustainability performance. Two replenishment strategies (individual and joint) and three replenishment rules are studied. A mathematical model is developed to measure sustainability performance. The model is applied on a single-supplier, multi-distributor supply chain for a single product to comparatively assess the two strategies.

Keywords: Supply chain, performance evaluation, sustainable development, joint replenishment, simulation

1. INTRODUCTION

Increasing political momentum around issues such as resource scarcity, climate change, security and new regulations highlight critical challenges that our industry will face in the coming years. The 2007 Bali Treaty and other political initiatives are driving industry to come up with breakthrough solutions requiring new thinking, new approaches and new collaboration on infrastructures. For example, the first step in “the logistically distinct business” proposed by Fuller et al. (1993) is to group together products or customers based on their logistic needs and characteristics.

In this paper we study a joint replenishment problem on a two-echelon supply chain, with one supplier and several distributors, facing a random demand.

Current studies show that joint replenishment is beneficial to economic performance. In their review of joint replenishment problems in the literature over the period 1989 to 2005, Khouja & Goyal (2008) highlight the large number of papers that have analyzed this issue. The majority of published papers have dealt with the problem of finding the optimal solution, and have suggested various approaches and algorithms. The objective of these models is usually to minimize the total cost while satisfying demand. In the scientific literature, we have not found any contributions concerning the impacts of joint replenishment on sustainability indicators. We have found several articles dealing with the introduction of the notion of sustainability in the relation between suppliers and distributors (Su & Ang, 2010, Massol & Tschung-Ming, 2010 and Harris et al., 2010). However, all these contributions focus on CO2 emissions. When it comes to sustainable development, other criteria, such as quality, lead-time, and environmental and social criteria are required to define an optimized replenishment strategy. The aim of this paper is to evaluate the impacts of the joint replenishment strategy on economic, environmental and social performances. We call the combination of these three performances “sustainability performance”. To analyze the sustainability of the impacts of these practices, we develop a Sustainability Performance Replenishment Model (SPRM). The problem statement and mathematical model are presented in Sections 2 and 3 respectively. This model is applied to an industrial case, and enables us to evaluate six scenarios according to ten sustainability indicators (See Section 4). Section 5 concludes and proposes some research perspectives.

2. PROBLEM STATEMENT

In this section, we focus on the replenishment process and identify two replenishment strategies: “individual replenishment”, and “joint replenishment”. In each strategy, we apply three replenishment rules:

A: the order quantity is calculated according to the replenishment lead-time and the average product demand;

B: the order quantity is calculated according to the economic optimal order quantity (i.e. Wilson formula);

C: the order quantity is calculated according to the environmental optimal replenishment quantity (i.e. full truck).

An order point, a fixed order quantity and a variable periodicity characterize the two strategies. In the individual strategy, when the order point is reached, a replenishment of a fixed order quantity is launched. Each distributor orders products when its order point is reached. The order point depends on the demand, the inventory level and the safety stock level. When several distributors choose the joint replenishment strategy, products will be ordered when the order point of one of distributors is reached.

These two strategies are evaluated using ten indicators:

- NbRupt\text{TOT}: Total number of stock outs
- CA\text{TOT}: Total acquisition cost
- CS\text{TOT}: Total holding cost
- NbT\text{TOT}: Total (whole) number of trucks
- EF\text{TOT}: Total quantity of emitted CO2
Empty $^{TOT}$ Total quantity of lost transport of trucks

$^{TOT}$ E Total number of employments

$^{TOT}$ Dif Total difficulty of the work

$^{TOT}$ Acc Total number of working accidents

$^{TOT}$ PSon Total quantity of emitted decibels

The supply chain network includes: one supplier, several distributors (W), and several customers modelled by their demand of products (P) to distributors.

The supplier ensures the procurement of products, which is characterized by a lead-time ($D_{pw}$) and by a rate of faulty products ($I_{pw}$). The supplier offers a price discount to entice distributors to accept the joint strategy.

Distributors obtain a fixed order quantity ($Q_{pw}^{base}$) of supplies from the supplier for each product when their order point ($t_{pw}^{alert}$) is reached for that product. The global quantity of replenishment in case of joint replenishment is $Q_{pw}^{base}$. The order cost for a given product is characterized by its unit acquisition cost ($C_{pw}^0$) and by its order cost ($CP_{pw}$). The joint cost of a joint order is $CP_{pw}^J$. The stocking at distributors is defined by an average unit holding cost of a given product ($CS_{pw}$). Handling operations (I) at distributors are determined by a pallet capacity ($Cap_{Pal}$), a number of worked hours for operation $j$ for handling a pallet ($h_{jw}^{palm}$), a degree of difficulty of the work ($dd_{jw}$), a rate of occupational accidents ($ta_{jw}$), and a number of decibels due to the use of a pallet truck ($Dec_{TP}$). As the distributors and suppliers are geographically distant, transport between the two entities is defined by a distance ($Dist_{pw}^j$) in the individual replenishment, $Dist_{pw}^jo$ and $Dist_{pw}^{R}$ in the joint replenishment), a truck capacity ($Cap_{T}$), an average quantity of emitted CO2 by km for a loaded vehicle ($EFCO2_{full}$) and for an empty vehicle ($EFCO2_{empty}$), and by a number of decibels when the truck starts up ($Dec_{T}$).

Hypothesis:

Customers’ demand for each product is random and follows a normal probability of distribution around a known mean.

Delivered products in period $t$ are available to satisfy the received demand by the distributor in the same period.

Unmet customers’ demands are transferred to postpone to a later date. Partial deliveries are refused.

Entry variable.

$C_{pw}(t)$ Demand of product $p$ at distributor $w$ in period $t$

In every period, distributors have to satisfy the demand $C_{pw}(t)$. They activate a need for replenishment if their inventory level is less than their order point. If a need for replenishment is activated, the supplier restocks for a fixed quantity $Q_{pw}(t)$, in the case of individual replenishment; and for a fixed quantity $Q_{pw}(t)$ in the case of joint strategy. The mathematical model for individual replenishment is given for the equations below, from (1) to (24):

Minimize $NbRupt^{TOT}$ $= \sum_{t=1}^{W} \sum_{w=1}^{P} \sum_{p=1}^{N} NbRupt_{pw}(t)$

Minimize $CA^{TOT} = \sum_{t=1}^{W} \sum_{w=1}^{P} CA_{pw}(t)$

Minimize $CS^{TOT} = \sum_{t=1}^{W} \sum_{w=1}^{P} CS_{pw}(t)$

Minimize $Nbt^{TOT} = \sum_{t=1}^{W} NbT_{w}(t)$

Minimize $Empty^{TOT} = \sum_{t=1}^{W} \sum_{w=1}^{P} Empty_{w}(t)$

Minimize $EF^{TOT} = \sum_{t=1}^{W} EF_{w}(t)$

Maximize $ET^{TOT} = \sum_{t=1}^{W} E_{w}(t)$

Minimize $Dif^{TOT} = \sum_{t=1}^{W} P_{en}(t)$

Minimize $PSon^{TOT} = \sum_{t=1}^{W} PSon_{w}(t)$

Minimize $Acc^{TOT} = \sum_{t=1}^{W} Acc_{w}(t)$

We consider several constraints:

$Q_{pw}(t) = \begin{cases} Q_{pw}^{base} & \text{if } I_{pw}(t) \leq t_{pw}^{alert} \\ 0 & \text{otherwise} \end{cases}$

At each period $t$, the quantity ordered by distributor $w$ from the supplier for each product $p$ is the fixed order quantity when the order point in period $t$ is reached, or zero when the order point is not reached.

$QDisp_{pw}(t) = I_{pw}(t-1) + Q_{pw}(t) \times \frac{1 - f_{pw}}{100}$

The available quantity of product $p$ at distributor $w$ in the beginning of period $t$ depends on the stock level of product $p$ at distributor $w$ at the beginning of period $t$, on the fixed
quantity of product $p$ ordered by distributor $w$ in period $t$, and
on the rate of faulty product $p$ at distributor $w$ in period $t$.

$$N\text{R}upt_{pw}(t) = \begin{cases} 
1 & \text{if } C_{pw}(t) > Q\text{Disp}_{pw}(t) > 0 \\
0 & \text{otherwise}
\end{cases}$$  \hspace{1cm} (13)

The number of stock outs for product $p$ at distributor $w$ at the end of period $t$ is 1 if the available quantity of product $p$ at distributor $w$ is not enough to match the demand in period $t$, and 0 if the available quantity of product $p$ at distributor $w$ is enough.

$$I_{pw}(t) = Q\text{Disp}_{pw}(t) - C_{pw}(t) \times [1 - N\text{R}upt_{pw}(t)]$$  \hspace{1cm} (14)

The stock level of product $p$ at distributor $w$ at the end of period $t$ matches the average unit holding cost of product $p$ at distributor $w$ during period $t$. Otherwise, it is equal of the available quantity of product $p$ at distributor $w$ in period $t$ decreased by the demand of product $p$ served by distributor $w$ in period $t$.

$$N\text{bPal}_{w}(t) = \frac{\sum_{p=1}^{P} Q_{pw}(t)}{\text{CapPal}}$$  \hspace{1cm} (15)

The number of handling pallets at distributor $w$ during period $t$ matches the ratio of order quantities for all products by distributor $w$ in period $t$ over the capacity of a pallet.

$$C_{pw}(t) = Q_{pw}(t) \times \frac{\text{Ca}_{\text{base}}}{2000} + CP_{pw}$$  \hspace{1cm} (16)

The acquisition cost of product $p$ for distributor $w$ in period $t$ depends on the order cost of product $p$ for distributor $w$, on the unit acquisition cost of product $p$ for distributor $w$, and on the given discount in period $t$. A discount of 10% is given for each 2000 products ordered from the supplier.

$$C_{pw}(t) = I_{pw}(t) \times C_{s \text{ pw}}$$  \hspace{1cm} (17)

The selling cost of product $p$ at distributor $w$ at the end of period $t$ matches the average unit selling cost of product $p$ at distributor $w$, combined with the number of stocked products $p$ at distributor $w$ in period $t$.

$$N\text{bT}_{w}(t) = \begin{cases} 
N\text{bT}_{w}^{\text{int}}(t) & \text{if } N\text{bT}_{w}^{\text{int}}(t) > N\text{bT}_{w}^{\text{int}}(t) \\
N\text{bT}_{w}^{\text{int}}(t) + 1 & \text{otherwise}
\end{cases}$$

with

$$N\text{bT}_{w}^{\text{int}}(t) = \frac{Q_{pw}(t)}{\text{CapT}}$$  \hspace{1cm} (18)

The number of trucks to replenish distributor $w$ in period $t$ is the ratio of order quantities for all products by distributor $w$ at period $t$ over the capacity of the truck.

$$E\text{mpty}_{w}(t) = N\text{bT}_{w}(t) - N\text{bT}_{w}^{\text{int}}(t)$$  \hspace{1cm} (19)

The quantity of lost transport to replenish distributor $w$ in period $t$ is evaluated by the difference between the optimal quantity of transport to replenish distributor $w$ in period $t$ and the used quantity of transport to replenish distributor $w$ in period $t$.

$$EF_{w}(t) = N\text{bT}_{w}(t) \times \frac{\text{Dist}_{w} \times E\text{FCO}_{\text{full}}}{2} + \frac{\text{Dist}_{w} \times E\text{FCO}_{\text{empty}}}{2}$$  \hspace{1cm} (20)

The quantity of CO$_2$ emitted to replenish distributor $w$ in period $t$ is based on the ADEME$^1$ scale according to the load and the kind of truck. It is evaluated by the number of units of emitted CO$_2$ for each kilometre in period $t$ to replenish distributor $w$.

$$E_{w}(t) = \sum_{j=1}^{J} \frac{\text{NhPal}_{w}(t) \times h_{jw}}{\text{ETP}}$$  \hspace{1cm} (21)

The number of employees to replenish distributor $w$ in period $t$ matches the ratio of working hours (based on handling standards) to achieve handling operation $j$ for a pallet at distributor $w$ at period $t$ over the number of working hours of a full-time employee at distributor $w$.

$$D\text{iff}_{w}(t) = \sum_{j=1}^{J} d\text{pen}_{wj} \times \text{NhPal}_{w}(t)$$  \hspace{1cm} (22)

The difficulty of the work at distributor $w$ for handling operation $j$ for a pallet is based on the scale of the Research and Security Institute$^2$. It is evaluated in terms of degrees of difficulty at distributor $w$ for all handling operations and all handling pallets during period $t$.

$$P\text{Son}_{w}(t) = N\text{bT}_{w}(t) \times \text{DecT} + \text{NhPal}_{w}(t) \times \text{DecTP}$$  \hspace{1cm} (23)

The number of emitted decibels to replenish distributor $w$ in period $t$ is based on the scale of the Information and Documentation on Noise Centre$^3$. It is evaluated according to the emitted decibels of each handling pallet at distributor $w$ in period $t$, and for each truck starting up at distributor $w$ in period $t$.

$$A\text{cc}_{w}(t) = \sum_{j=1}^{J} t\text{aw}_{wj} \times \text{NhPal}_{w}(t)$$  \hspace{1cm} (24)

The number of occupational accidents at distributor $w$ in period $t$ is evaluated by the average rate of occupational accidents at distributor $w$ in period $t$ for each handling pallet.

---

2. www.inrs.fr
In the case of the joint strategy, the model is the same except for equations (11), (18), (19) and (20), which are respectively replaced with equations (25), (26), (27) and (28).

\[ Q_p(t) = \begin{cases} Q_p^{\text{base}} & \text{if } \exists w \text{ such that } t_{pw}(t) \leq I_{\text{alert}}^{pw} \\ 0 & \text{otherwise} \end{cases} \]

with

\[ Q_p^{\text{base}} = \sum_{w=1}^{W} Q_p^{\text{base}}(t) \quad (25) \]

In the joint strategy, order quantity for all distributors is launched when one of the distributors has reached its order point.

Equation (18) is replaced by equation (26), which integrates the joint order quantity. Consequently, equation (19) is replaced by equation (27).

\[ NbT(t) = \begin{cases} NbT^{\text{int}}(t) & \text{if } NbT^{\text{int}}(t) = NbT^{\text{int}}(t) \\ NbT^{\text{int}}(t) + 1 & \text{otherwise} \end{cases} \]

with

\[ NbT^{\text{int}}(t) = \frac{Q_p(t)}{\text{CapT}} \quad (26) \]

\[ \text{Empty}(t) = NbT(t) - NbT^{\text{int}}(t) \quad (27) \]

Equation (20) is replaced by equation (28), which integrates the new distances of the joint round between distributors.

\[ EF(t) = \frac{\text{Dist}_{\text{joint}}}{S} \times \text{EFCO}_2^{\text{full}} + \frac{\text{Dist}_{\text{joint}}}{R} \times \text{EFCO}_2^{\text{empty}} \times Nbt(t) \quad (28) \]

Decision variables linked to number of trucks (4), number of lost transport (5) and number of emitted CO\(_2\) (6) are evaluated in the joint replenishment model with equations (25), (26), (27) et (28).

4. APPLICATION

In this section, we apply the Sustainability Performance Replenishment Model to a real supply chain composed of two distributors (\(w_1\) and \(w_2\)) in the area of Lyon (France). These distributors are supplied with the same product \(p\) from the same supplier, based in the area of Lille (France). We focus on a product \(p\), which is small, light and used in large quantities. The simulation is performed using the ARIS Toolset simulator.

4.1 Data

The parameters of the case study are described in Table 1. Simulation covers single days over a period of one year. The supplier and distributors are open 365 days a year and work 24h/24h. Customers’ demand is generated daily and randomly from an average demand \(\mu=260\) with a standard deviation \(\sigma=36\) for distributor \(w_1\), and an average demand \(\mu=100\) with a standard deviation \(\sigma=23,25\) for distributor \(w_2\).

<table>
<thead>
<tr>
<th>Data for simulation</th>
<th>Distributor (w_1)</th>
<th>Distributor (w_2)</th>
<th>Joint replenishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I_{\text{alert}}^{pw}) (order point)</td>
<td>4,219</td>
<td>1,660</td>
<td></td>
</tr>
<tr>
<td>(C_{pw}(t)) (daily average demand of product)</td>
<td>260</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>(\sigma_{pw}) (standard deviation of demand)</td>
<td>50</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>(\text{Del}_{pw}) (replenishment lead time)</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>(\text{SS}_{pw}) (safety stock)</td>
<td>319</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>(f_{\text{pr}}) (average rate of faulty product)</td>
<td>0 to 20%</td>
<td>0 to 20%</td>
<td></td>
</tr>
<tr>
<td>(\text{CapPal}) (capacity of pallet)</td>
<td>1,000</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>(\text{Cap}_{pw}) (initial unit acquisition cost)</td>
<td>6.5€</td>
<td>6.5€</td>
<td>6.5€</td>
</tr>
<tr>
<td>(\text{CS}_{pw}) (order cost)</td>
<td>10€</td>
<td>14€</td>
<td></td>
</tr>
<tr>
<td>(\text{CS}_{\text{mpr}}) (unit holding cost)</td>
<td>0.005€</td>
<td>0.01€</td>
<td></td>
</tr>
<tr>
<td>(\text{CapT}) (capacity of truck)</td>
<td>11,600</td>
<td>11,600</td>
<td></td>
</tr>
<tr>
<td>(\text{Dist}_{pw}) (distance from supplier to distributor (w))</td>
<td>720km</td>
<td>800km</td>
<td></td>
</tr>
<tr>
<td>(\text{EFCO}_2^{\text{CO2}}) (emitted CO2 for a loaded truck)</td>
<td>0.1114/km</td>
<td>0.1114/km</td>
<td></td>
</tr>
<tr>
<td>(\text{EFCO}_2^{\text{empty}}) (emitted CO2 for a empty truck)</td>
<td>0.101/km</td>
<td>0.101/km</td>
<td></td>
</tr>
<tr>
<td>(\text{ETP}) (full-time equivalent)</td>
<td>7h</td>
<td>7h</td>
<td></td>
</tr>
<tr>
<td>(h_{\text{pr}}) (time/pallet/operation: check in/control/stock)</td>
<td>5min/17min/90min</td>
<td>5min/17min/90min</td>
<td></td>
</tr>
<tr>
<td>(\text{ddif}_{\text{pr}}) (difficulty of the work/pallet/operation: check/Control/Stock)</td>
<td>1.1/0.6/2.3</td>
<td>1.1/0.6/2.3</td>
<td></td>
</tr>
<tr>
<td>(\text{ta}_{\text{pr}}) (accidents/pallet/operation: check/Control/Stock)</td>
<td>0.1/0.1/0.1</td>
<td>0.1/0.1/0.1</td>
<td></td>
</tr>
<tr>
<td>(\text{DecT}) (decibels at truck starting up)</td>
<td>80</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>(\text{DecTP}) (decibels due to the use of a pallet truck)</td>
<td>70</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>(\text{Dist}_{\text{joint}}) (single distance of round)</td>
<td>900km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\text{Dist}_{\text{joint}}) (return distance of round)</td>
<td>850km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(I_{pw}^{\text{int}}) (initial inventory level)</td>
<td>4,219</td>
<td>1,660</td>
<td></td>
</tr>
</tbody>
</table>
For scenarios w1-A, w2-A and J-AA:

$$q_{pw}^{base} (A) = \text{Del}_{pw} \times C_{pw}$$

(29)

For scenarios w1-B, w2-B (considering a rate of holding of 0.05):

$$q_{pw}^{base} (B) = \frac{2 \times C_{pw}^{base} \times C_{pw}}{C_{pw}^{base} \times 0.05}$$

(30)

And for J-BB:

$$q_{pw}^{base} (B) = \frac{q_{pw1}^{base} (B) + q_{pw2}^{base} (B)}{2}$$

(31)

For scenarios w1-C, w2-C and J-CC

$$q_{pw}^{base} (C) = \text{CapT}$$

(32)

4.2 Simulation results

The simulation takes around 30min for the individual strategy and 1h for the joint strategy on a Core 2 Duo T7700, 2.4 Ghz. The simulation results in Table 2 are derived from the mean of 15 replications generated around a random demand.

Unsurprisingly, joint replenishments enable distributors to save (acquisition and holding costs). Acquisition costs in replenishment rules A are reduced by around 20% in the individual strategy compared to the joint strategy: 40% in rule B and 10% in rule C. Also unsurprisingly, the replenishment rule that obtains the best acquisition cost is rule C because the order quantity is the biggest. The holding costs of joint replenishments are weaker than individual replenishments. The holding costs in replenishment rule B are reduced to 15% in the individual strategy compared to the joint strategy, and to 10% in rule C. Concerning rule A, there is the same number of replenishments and the same order quantities between the individual replenishments scenario and the joint scenario. Holding costs increase with order quantities (€986 for individual replenishments in rule C against €759 for individual replenishments in rule A). Stock outs occur far more with the joint strategy, due to the order point system. In fact, if distributor w1 has reached its order point, it should wait for distributor w2 to have reached it as well, before ordering. This generates more stock outs than individual stock management. It is most frequently the case for rule B, because order quantity (optimal economic quantity) does not cover the replenishment lead-time (35 stock outs in individual replenishment and 109 in joint replenishments).

Table 2: Simulation results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CA TOT</td>
<td>668,382</td>
<td>580,932</td>
<td>743,623</td>
<td>529,916</td>
<td>527,800</td>
<td>487,200</td>
</tr>
<tr>
<td>CS TOT</td>
<td>759</td>
<td>759</td>
<td>905</td>
<td>791</td>
<td>986</td>
<td>893</td>
</tr>
<tr>
<td>NbRupt TOT</td>
<td>112</td>
<td>130</td>
<td>35</td>
<td>109</td>
<td>13</td>
<td>37</td>
</tr>
<tr>
<td>EF TOT</td>
<td>7,429</td>
<td>4,416</td>
<td>6,409</td>
<td>3,456</td>
<td>2,057</td>
<td>2,496</td>
</tr>
<tr>
<td>NbTI TOT</td>
<td>46</td>
<td>23</td>
<td>40</td>
<td>18</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Empty TOT</td>
<td>36</td>
<td>13</td>
<td>28</td>
<td>8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>E TOT</td>
<td>38</td>
<td>37</td>
<td>46</td>
<td>36</td>
<td>39</td>
<td>37</td>
</tr>
<tr>
<td>Dif TOT</td>
<td>17</td>
<td>13</td>
<td>10</td>
<td>13</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Acc TOT</td>
<td>552</td>
<td>552</td>
<td>664</td>
<td>504</td>
<td>624</td>
<td>624</td>
</tr>
<tr>
<td>PsOn TOT</td>
<td>13,340</td>
<td>11,500</td>
<td>14,820</td>
<td>10,260</td>
<td>11,960</td>
<td>11,960</td>
</tr>
</tbody>
</table>

As they are linked, number of trucks and emitted CO2 can be analyzed together. Number of trucks and quantities of emitted CO2 are reduced by means of a joint strategy. In rule A, 46 trucks are necessary to transport replenishments in the individual strategy, against only 23 in the joint strategy, and in rule B, 40 trucks in the individual strategy against 18 in the joint strategy. However, concerning emitted CO2 for rule C, we note that the joint strategy generates more emitted CO2 than the individual strategy. This is because the joint and individual strategies require the same number of trucks but the joint strategy involves a longer transportation loop, which generates more CO2. Another indicator is interesting: the number of lost trucks. This is the difference between the real number of used trucks and the optimal number trucks (i.e. number of equivalent full trucks) to replenish in the same period. For example, in scenario “individual strategy rule A”, 46 trucks have been used to replenish the two distributors but, if replenishments had been optimized, only 10 trucks would have been enough: 36 excess trucks have thus been used. Clearly, the joint strategy is better, and rule C is the best, because the trucks used are full.

Regarding social performances, the number of jobs is reduced in the case of joint replenishments. Even if it is better for the distributor’s economic performance, this is negative for the community. In fact, in rule B, 10 jobs are lost between the two strategies (this result must be put into perspective, given the number of stock outs). We note that joint replenishments have neutral or positive effects on the difficulty of the work, yet the rate of occupational accidents increases (except for rule A). Risks of occupational accidents are the highest under rule B because this rule generates more replenishments and more pallets (more handling), than do the
other two. Joint replenishments generate fewer decibels than do individual replenishments. For example, in rule B, emitted decibels are reduced by more than 45% between the two scenarios.

4.3 Ranking scenarios

In this sub-section, we focus on the comparison of scenario results. Table 3 details the rank of each scenario. For example, scenario $w_1\cdot A + w_2\cdot A$ obtains the rank n°1 on holding costs and n°6 on the number of trucks. The two last columns serve to rank scenarios. The former sums up rank n°1 (best scenario) and the latter sums up rank n°6 (the worth). With this calculation we obtain the best scenario, scenario “$w_1\cdot C + w_2\cdot C$”, which is ranked first six times. The scenario “$w_1\cdot A + w_2\cdot A$” is the worst one; it is ranked sixth five times. More precisely, “$w_1\cdot C + w_2\cdot C$” obtains the best results on economic and environmental performances. Nevertheless, scenario J-CC obtains the best compromise between the three performances. Table 3 shows the position of each strategy (individual and joint) for each replenishment rule (A, B and C), according to ten sustainability indicators. From Table 3, taken as a whole, we see that the joint strategy is the best one in the case of replenishment rules A and B. In replenishment rule C, the individual strategy is better than the joint strategy.

Table 3: Ranking of scenarios

<table>
<thead>
<tr>
<th>Indicators/Scenarios</th>
<th>CA Tot</th>
<th>CS Tot</th>
<th>NRupt Tot</th>
<th>NStop Tot</th>
<th>Effort</th>
<th>Empty Tot</th>
<th>E Tot</th>
<th>Dif Tot</th>
<th>Acc Tot</th>
<th>PSon Tot</th>
<th>Number of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>w_1\cdot A + w_2\cdot A</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>J-AA</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>w_1\cdot B + w_2\cdot B</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J-BB</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>w_1\cdot C + w_2\cdot C</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>J-CC</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

5. CONCLUSION

We have looked at the impacts of replenishment strategies on sustainability performance within a multi-level, multi-product, multi-entity and multi-period framework. We have presented a Sustainability Performance Replenishment Model for two strategies: individual versus joint replenishment. To characterize the impacts of the two strategies for each replenishment rule, defined by ten sustainability indicators, we have based this model on a simulation platform. Experimentation results in the case study limit to one supplier/two distributors show that a joint replenishment strategy is better than individual replenishment in cases of lead-time replenishment, rule (A), and economic optimal order quantity, (B). In the case of full-truck replenishment (C), we saw that it is better to replenish individually. These results must be moderated. Indeed, some of our hypotheses affect results; it is the case of low unit costs of storage or application of customers, whose average is known. It would be interesting to analyze the impacts of the same supply chain with higher storage costs. This conclusion for one supplier/two distributors can of course not be generalized, as it is, for N distributors. Further research and experiments are required in order to determine the minimal number of distributors required to generate benefits.

Acknowledgements

This work has been carried out as part of the French research project COPILOTES 2 supported by the Rhône-Alpes Region (France) under the research cluster GOSPI.

REFERENCES