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**Abstract**

We consider a supply chain consisting of n locations replenished at the beginning of each period by a supplier. These locations may coordinate in order to balance their inventory level through *transshipment*. Transshipment is the items transfer from location having an inventory excess to another in need. The transshipment problem consists to determine the initial inventory level where a transshipment policy is practiced. In this work, we consider the transshipment problem characterized by a non-negligible transshipment lead times and a limited transportation mean capacity. Our aim is to find a transshipment policy that reduces the inventory costs and improve the customer fill-rates. To realize this aim, we proposed a new formal transshipment model in which the period is divided into a set of sub-periods and the transshipment decision is made at the end of one of them. We also introduced a multi-agent model allowing to simulate the cooperated behavior of the inventory locations.

## 1 Introduction

The inventory management is a crucial activity in the supply chain. It allows the regulation of the inventory level to face the unexpected fluctuation of customer demands. In fact, a reduced inventory level causes the non satisfaction of customer requirements witch presents a shortage cost. An inventory excess generates a holding cost. The challenge facing the inventory managers is to minimize the total inventory cost and to improve the customer fill-rates. This task becomes more complex when it concerns several locations. The transshipment is an inventory collaboration method consisting to transfer items between locations. It has been widely used in practice to reduce inventory costs and to improve the customer fill-rates. It provides an effective mechanism for correcting discrepancies between the locations observed customer demands and their available inventories. The transshipment problem is defined as the determination of two target parameters. The first is the replenishment quantity for each location and the second is the transshipment policy [Kris65]. The transshipment problem is extensively studied, where several parameters are considered. We identify three parameter types. The first is the *replenishment parameters* such as the replenishment lead times [Taga89] and the replenishment fixed costs [Here99]. The second is the *transfer parameters* such as the transshipment mean capacity [Ozde03] and the transshipment lead times [Taga02]. The third type of parameter is the *environment parameters* such as the number of locations [Robi90], [Taga92], [Week05] and the number of periods [Taga99]. We can classify the studies on the transshipment problem into two categories: (1) in the first category, exact methods are adopted to resolve the problem. This kind of research is interested in inventory system restricted to two non-identical locations or multi-identical locations [Week05, Kris65, Taga89]. (2) In the second category, meta-heuristics or simulations are adopted to find an approximate solution or to choose between several strategies. This kind of research is interested in inventory system composed by multi non-identical locations [Robi90, Ozde03, Taga99].

In this work, we investigate the two following parameter configurations: (1) a non-negligible transshipment lead times and (2) a limited transportation mean capacity. Our aim is to propose a transshipment policy that reduces the total inventory cost and improves the customer fill-rates under these considerations. The contribution of this paper is twofold. First, it introduces a formal model that takes into account the two parameters mentioned above. In this model, we propose to divide the period into a set of sub-periods at the end of one of them the transshipment decision is made. Second, it defines a multi-agent model that simulates the cooperative behavior of the locations.

The rest of the paper is organized as follows. The second section presents a description of the transshipment problem. The third section introduces our formal transshipment model. The fourth section presents the proposed multi-agent model and describes the global dynamics of the system based on this model. The fifth section describes the realized experimentation and comments the obtained results. Finally, we discuss the future works.

## 2 Problem description

In our work, we consider the transshipment problem characterized by a set of locations having non-identical cost structures[1]. These locations are replenished by a supplier at the beginning of each period. We assume that the inventory review is periodic for each location and the replenishment quantity is fixed. We consider also that the transshipment lead times between locations are non-negligible. In addition, we consider a limited capacity of the transportation mean. In the next sections, we adopt the following notations [Taga99] :

- $U_i$ : excess quantity at the location $L_i$
- $Z_i$ : in need quantity at the location $L_i$
- $D_i$ : customer demands at the location $L_i$
- $C_i$ : replenishment unit cost at the location $L_i$
- $CS_i$ : shortage unit cost at the location $L_i$
- $CH_i$ : holding unit cost at the location $L_i$
- $C_{ij}$ : transshipment unit cost from the locations $L_i$ to the location $L_j$. It is supported by $L_i$
- $Q_i$ : initial inventory quantity at location $L_i$
- $X_{ij}$ : transshipped quantity from the location $L_i$ to the location $L_j$

The objective function is the minimization of the total inventory cost noted *C(Q)*:

$$C(Q) = \sum_{i=1}^{n} \left[ C_i Q_i + \sum_{j=1}^{n} C_{ij} * X_{ij} + CH_i * U_i + CS_i * Z_i \right].$$

n is the number of locations and $U_i$ is the excess quantity at the location $L_i$. This quantity is calculated after the satisfaction of the customer demands and the achievement of the transshipment actions to the other locations ($\Sigma X_{ij}$ ). $Z_i$ is the needed quantity at the location $L_i$. This quantity is calculated after the partial satisfaction of the customer demands and the realization of the transshipment actions from the other locations to $L_i$ ($\Sigma X_{ji}$ ).

[1] Cost structures designs the holding, shortage and transshipment cost

$$U_i = \max\left(0, Q_i - (D_i + \sum_{\substack{j=1 \\ j \neq i}} X_{ij})\right)$$

$$Z_i = \max\left(0, D_i - (Q_i + \sum_{\substack{j=1 \\ j \neq i}} X_{ji})\right)$$

# 3 Transshipment policy

In this work, we are interested to find a transshipment policy that takes into account a non-negligible transshipment lead times and a limited transportation mean capacity. It should contribute to minimize the inventory costs and it should also insure good customer fill-rates. To define such policy, the two following questions should be discussed: (1) what's the transshipment decision moment ? (2) What's the transshipment quantity that should be transferred from a location $L_i$ in excess to a location $L_j$ in need ?

## 3.1 Decision transshipment moment

Let $L_1$, $L_2$, $L_3$ and $L_4$ four locations buying the same item. At the beginning of each period, these locations are replenished by the same supplier. We consider in this example that a period corresponds to seven days. We assume that the transshipment from a location $L_i$ in excess to $L_j$ in need takes a non-negligible lead time noted $t_{ij}$. We assume also that $t_{ij} = t_{ji}$. Figure 1 presents the different possible transshipment actions and their respective lead times.

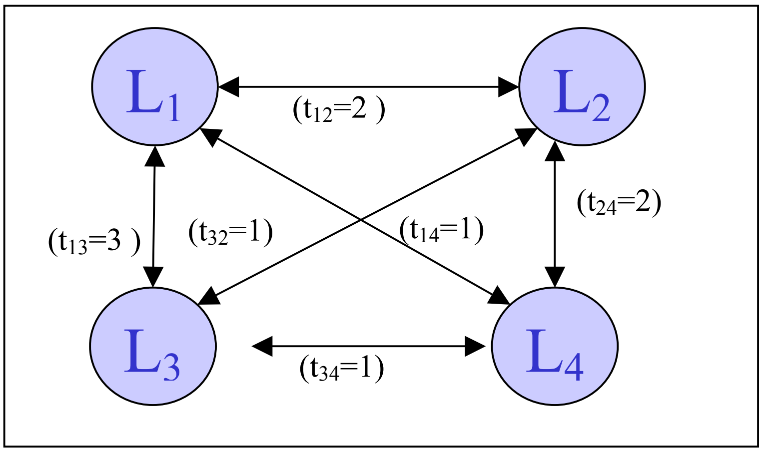


Figure 1. : transshipment actions and their Lead times.

Suppose that the location $L_1$ is in need at the end of the period. Its shortage could be satisfied by transshipment actions from the other locations. The transshipment action must be launched at a precise moment called the transshipment decision moment. This moment must consider the different transshipment lead times that is $t_{12}$, $t_{13}$ and $t_{14}$. In fact, in order to satisfy the cumulated observed demand during the period, the transshipped quantity must arrive to the location $L_1$ before the end of the period. Thus, $L_1$ must evaluate its inventory at an appropriate moment within the period in order to take the transshipment decision. Let $T_1$ be this particular moment. The figure 2 illustrates the different transshipment possibilities and their lead times from locations $L_2$, $L_3$ and $L_4$ to the location $L_1$.

Three cases could be identified :

- If the supplier location is eventually $L_4$ then the transshipment decision must be taken by the location $L_1$ before the end of the period by a lead time equals to 1 day ($t_{14}$).
- If the supplier location is eventually $L_2$ then the transshipment decision must be taken by the location $L_1$ before the end of the period by a lead time equals to 2 days ($t_{12}$).
- If the supplier location is eventually $L_3$ then the transshipment decision must be taken by the location $L_1$ before the end of the period by a lead time equals to 3 days ($t_{13}$).

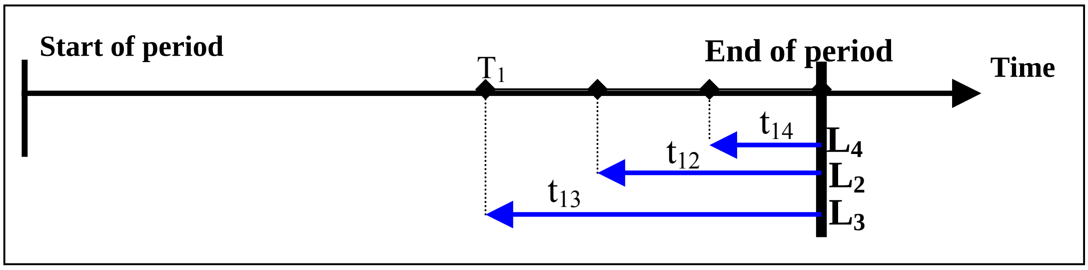


Figure 2 : Transshipment possible actions and their lead times.

In the worst case, the location $L_1$ is supplied by the location $L_3$ having the maximum lead time. In fact, the location $L_1$ must insure that its transshipment request could be processed by all the other locations and eventually served by at least one of them. Consequently, $T_1 = L_p - \max(t_{1j})$, $j \in \{2,3,4\}$ and $L_p$ is the period length (7 days ). In the general case for a location $L_i$ : $T_i = L_p - \max(t_{ij})$, $j \in \{1,2,\ldots,n\}$, $j \neq i$ and n is the number of locations.

In the majority of the research works concerning the transshipment problem, the inventory review is assumed to be periodic [Kris65, Taga99, Ozde03, Here01]. This means that the inventory situation is known only at the end of the period. However, as we proposed to evaluate the inventory situation at $T_i$ within the period, it is necessary to divide the period into several equal sub-periods. Thus, the transshipment decision is made at the end of a sub-period and the transfer lead time $t_{ij}$ between locations $L_i$ and $L_j$ is expressed as a number of sub-periods.

### 3.2 Transshipment quantity

The transshipment quantity depends on the transshipment lead times witch determines the transshipment decision moment. Consequently, this quantity depends on the inventory evaluation moment. Intuitively, it depends also on the transportation mean capacity of the sending locations. To determine the transshipment quantity to the location $L_i$ in need, it is necessary to know the $L_i$ inventory situation at the transshipment decision moment $T_i$.

Figure 3 illustrates the transshipment decision moment $T_1$ (identified for the example of the pervious section) and both realized and provisional customer demands. We note $D_{obs}(T_1)$ as the observed customer demands during the four first sub-periods and $D_{prov}(T_1)$ the provisional customer demands for the rest of a period (the last three sub-periods). $L_1$ inventory level at $T_1$ noted $IL_1(T_1)$ depends on $D_{obs}(T_1)$, $D_{prov}(T_1)$ and the initial inventory level $Q_1$. We obtain : $IL_1(T_1) = Q_1 - (D_{obs}(T_1) + D_{prov}(T_1))$.

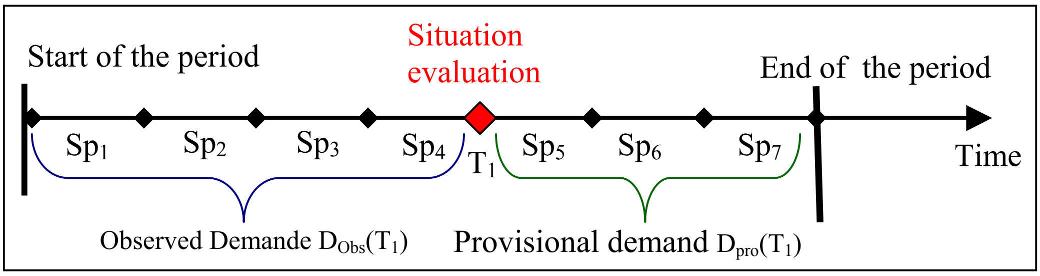


Figure 3: Inventory situation at $T_1$ moment.

In the general case, we obtain : $IL_i(T_i) = Q_i - (D_{obs}(T_i) + D_{prov}(T_i))$. If $IL_i(T_i)$ is positive then the location $L_i$ is in excess else it is in need. Now, we define the quantity that must be transferred from $L_i$ in excess to $L_j$ in need noted $X_{ij}$ at moment $T_j$. This quantity is equal to the minimum between : (1) the location sender $L_i$ transportation mean capacity noted $TC_i$, (2) the excess quantity in the location $L_i$ and (3) the needed quantity in the location $L_j$. We obtain : $X_{ij} = \min(TC_i, IL_i(T_j), | IL_j(T_j) |)$.

We note that this quantity depends on the provisional customer demands. In this research, we distinguish two kinds of inventory locations: *cooperative* and *egoist*. We suppose that a sub-period customer demands follows a normal distribution N ($\mu$, $\sigma$). A cooperative location favorites the global benefit by forecasting a mean sub-period customer demands evaluated to $\mu$. An egoist location favorites its own benefit by forecasting a maximum sub-periods customer demands evaluated to $\mu + 3\sigma$[2].

# 4 Multi-agent model

Our model contains two types of agents: the *Interface agent* (IA) and the *Location agent* (LA) described in the next sections.

## 4.1 Interface agent

The Interface agent is defined by the following static knowledge:

- IAident : IA identifier.
- NbrLA : Number of Location agents.
- NbrPeriod : Number of periods.
- NbrSubPeriod : Number of sub-periods.
- PcentageEgoist : The percentage of the egoist LA.

The dynamic knowledge of the Interface agent is represented by a list called *LEvaluationParamters* containing total inventory cost and fill-rates.

The interface agent permits to :

(1) Create the different Location agents.
(2) Construct the initial Location agents coalitions.
(3) Trigger the resolution process.
(4) Recuperate the values of the evaluation parameters at the end of each period.
(5) Detect the end of the simulation process and display the results.

## 4.2 Location agent

The Location agent represents an inventory location and it communicates with the other location agents and the Interface agent. It is defined by the following static knowledge :

[2] The probability that the customer demands is between $\mu - 3\sigma$ and $\mu + 3\sigma$ is equal to 0.997 [Will71]. This is valid if the customer demands is normally distributed.

- $S_i$ : location agent i identifier
- $TypeS_i$ : location agent $S_i$ type: cooperative or egoist.
- $CH_i$ : holding unit cost for the Location agent $L_i$.
- $CS_i$ : shortage unit cost for the Location agent $L_i$.
- $Q_i$ : renplishment quantity for the Location agent $L_i$.
- $\mu_i$ : sub-period's demand mean for Location agent $L_i$.
- $\sigma_i$ : sub-period's demand standard deviation for the Location agent $L_i$.
- $TC_i$ : the capacity of the transportation mean used by Location agent $L_i$.
- $T_i$ : transshipment decision sub-period for the Location agent $L_i$.
- $LCoal_i$ : a list containing the Location agents that $L_i$ can communicate with them.
- $LCostLead_i$ : a list that contains the transshipment costs and the lead times for the Location agent $L_i$.

The dynamic knowledge is:

- $Status_i$ : the location $L_i$ status (in need or in excess)
- $LRecevedDemand_i$ : a list containing the transshipment requests received by $L_i$ from the other Location agents.
- $LAcceptedDemand_i$ : a list containing the transshipment requests that can be served by the Location agent $L_i$.
- *LOffers* : a list containing offers sent by locations as response to the $L_i$ transshipment request.
- $LRestrainedOffer_i$ : a list that contains the offers restrained by $L_i$.
- $LTransshipment_i$ : a list containing the $L_i$ realized transshipment.

The Location agent behavior depends on two criteria: the location inventory level and the current sub-period. During each sub-period, the Location agent executes some operations. The figure 4 illustrates the inventory level variation of the Location agent $L_i$ during one period divided into seven sub-periods ($Sp_1$, $Sp_2$,..., $Sp_7$). It enumerates the different operations executed by this Location agent during the period.

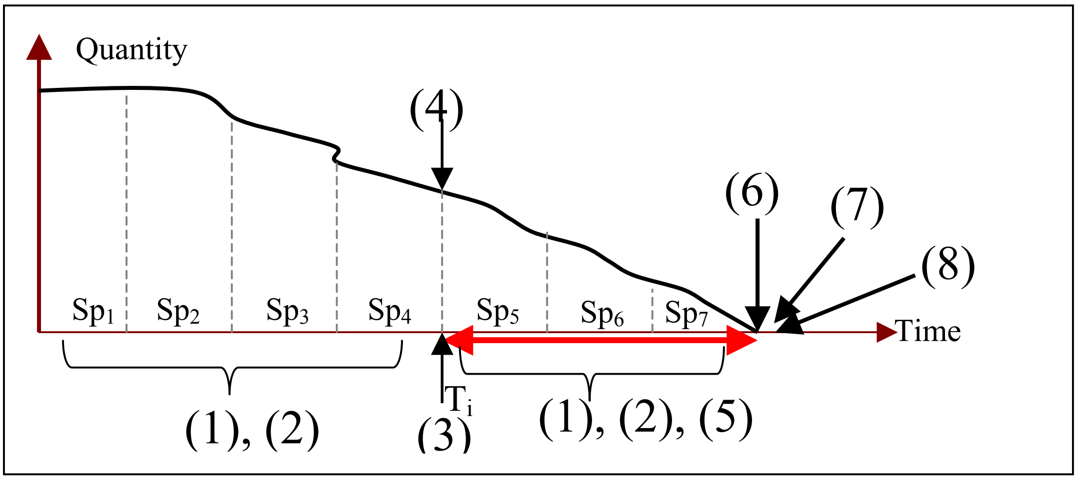

Figure 4. : Operations executed by a Location agent during one period.

The Location agent $L_i$ executes two operations before the transshipment decision moment $T_i$ :

(1) *Demand observation* : this operation is executed at each sub-period.

(2) *Transshipment request processing* : it is possible during these sub-periods that an other Location agent $L_j$ in need had sent a transshipment request to the Location agent $L_i$.

At the $T_i$ moment two other operations are executed by the Location agent $L_i$ :

(3) *Inventory status evaluation* : this operation consists to calculate the inventory level $IL_i(T_i)$. If this level is positive then the Location agent is in excess otherwise it is in need.

(4) *Transshipment request launching* : in the case where the Location agent $L_i$ is in need, it launches a transshipment request to the other Location agents.

During the rest of sub-periods (after $T_i$) the location $L_i$ executes operations (1) and eventually (2). Besides these operations, it executes the operation (5) if the operation (4) was executed.

(5) *Transshipment quantity updating* : this operation consists to execute one of the following actions :

a- To cancel the transshipment request : this operation is executed if the Location agent in the current sub-period is in excess and the surplus quantity can cover the shortage ones realized at the previous sub-period.

b- To modify the quantity to transship : this operation is executed in the case where the Location agent notes after the inventory level evaluation that the quantity to transship must be updated (increased or decreased).

Finally, at the end of the period, the Location agent $L_i$ executes the three following operations:

(6) *Customer demands satisfaction* : this operation consists to serve the customer demands observed during the period.
(7) *Situation evaluation* : calculate the values of the total inventory cost and the customer fill- rates.
(8) *Backlogging the unsatisfied customer demands* : this operation consists to backlog the unsatisfied customer demands ( if ever exists) to the next period.

## 4.3 Global dynamics

The simulation process for identifying the best transshipment strategy is composed by the following three steps :

- Simulation initialization
- Negotiation and transshipment
- Simulation stop

### *4.3.1 Step 1 : Simulation initialization*

This step consists to execute the following actions:

- *Creation of the Location agents* : this operation is realized by the interface agent. It consists to create and initialize the knowledge for each Location agent.
- *Creation of Location agents list accountancies* : each Location agent forms his list accountancy containing the other Location agents identifiers
- *Sorting of the Location agents list accountancies* : each Location agent sorts its list of accountancies according to their lead time.
- *Calculating the transshipment decision moment for each Location agent.*
- *Starting the simulation*.

### *4.3.2 Step 2 : Negotiations and transshipment*

During this step, the different Location agents cooperate to determine the necessary transshipments in order to reduce the total inventory cost and to improve the customer fill-rates. The negotiation protocol between the Location agents adopted is the contract net [Davi83]. We assume that the Location agents in need are the *managers* and the Location agents in excess are the *contractors*.

The actions executed during this step by the Location agents are the following :

- *Status evaluation* : it consists to evaluate the Location agent status.

- *Transshipment request* : the Location agent in need send a message to the other Location agents belonging to its coalition.
- *Processing of received requests* : it consists to response to the transshipment requests sent by the other Location agents in need.
- *Selection of offers :* it consists to select the best offers sent by the Location agents in excess.
- *Updating of the offers* : it consists to modify the requested transshipment quantity or cancel the offers.
- *Realization of transshipment* : it consists to update the inventory level of the Location agents in need and the others in excess that participate in the transshipment operation.

In order to achieve the negotiation described above through the executed actions the following messages are exchanged between Location agents ($L_i$ designs Location agent in need and $L_j$ designs Location agent in excess):

- *TransshipmentRequest* ($L_i$ , $L_j$ , $id_{Req}$ , $Q_{req}$) : this transshipment request message identified by $id_{Req}$ is sent by the Location agent $L_i$ to the Location agent $L_j$ belonging to its coalition to ask for $Q_{req}$ items.
- *TransshipmentOffer* ($L_j$ , $L_i$ , $id_{Req}$ , $Q_{off}$) : this transshipment offer message is sent by the Location agent $L_j$ (contractor agent) proposing $Q_{off}$ to the Location agent $L_i$ as a response to the transshipment request launched identified by $id_{Req}$.
- *Apology* ($L_j$ , $L_i$ , $id_{Req}$) : this apology message is sent by Location agent $L_j$ to the Location agent $L_i$ for the latter request identified by $id_{Req}$.
- *AcceptedOffer*($L_i$, $L_j$, $id_{Req}$, $Q_{acc}$): this message is sent by the Location agent $L_i$ to inform the Location agent $L_j$ that its request identified by $id_{Req}$ is accepted and the accepted quantity is $Q_{acc}$ .
- *RefusedOffer*($L_i$ , $L_j$ , $id_{Req}$) : this message is sent by a Location agent $L_i$ to inform the Location agent $L_j$ that its offer corresponding to the request identified by $id_{Req}$ is refused.
- *CanceledOffer*($L_i$ , $L_j$ , $id_{Req}$) : this message is sent by Location agent $L_i$ to inform the Location agent $L_j$ that its transshipment offer corresponding to the request identified by $id_{Req}$ is cancelled.

- *ModifiedOffer($L_i$ , $L_j$ , $id_{Req}$ , $Q_{mod}$)* : this message is sent by the Location agent $L_i$ to inform the Location agent $L_j$ that its offer is modified and the new requested quantity is $Q_{mod}$.
- *RealizedTransshipment ($L_j$ , $L_i$, $id_{Req}$)* : this message is sent by the Location agent $L_j$ to the Location agent $L_i$ to inform it that the transshipment is realized.

#### *4.3.3 Step 3: Simulation stop*

This step is executed at the end the period. The Interface agent recuperates the total inventory cost and the customer fill-rates for each Location agent. Then, it displays the global results relative to these evaluation parameters.

## 5 Experimentations and results

We realized Multi-Agent Simulation tool for the TRAnsshipment problem (MASTRA) based on the above presented model. MASTRA have been realized with swarm multi-agent platform. It is a simulation environment realized in objective-C [Bene02]. In this section, we are interested to show the effects of differents parameters on our inventory model.

The evaluation parameters considered during our experimentation study are : the average total inventory costs, noted $C_{avg}$ and the average customer fill-rate, noted $F_{avg}$. These evaluation parameters are calculated through the following formula using the notations presented in the section 2:

$$C_{avg} = (1/n)\left[\sum_{i=1}^{n}\left(CS_i * Z_i + CH_i * U_i + \sum_{j=1}^{n} C_{ij} * X_{ij}\right)\right]$$

$$F_{avg} = (1/n)\left[1 - \left(\sum_{i=1}^{n} Z_i \Big/ \sum_{i=1}^{n} D_i\right)\right].$$

To construct the following experimentation configurations, data relative to the cost structure are randomly generated. This choice is justified by the absence of the transshipment benchmark.

Our first experimentation study is designed to compare between a cooperative inventory management adopting our transshipment model and inventory management without transshipment. 10 inventory locations are considered. The results described in the figures 5 and 6 show that our transshipment policy contributes simultaneously to reduce consequently the inventory costs and to improve the customer fill-rates.

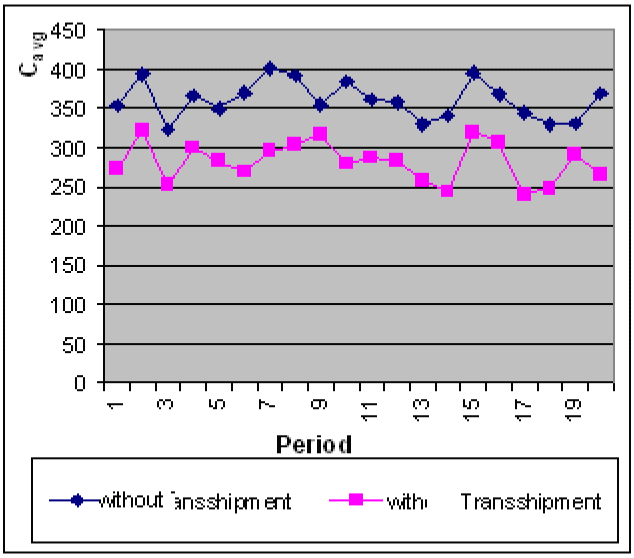


Figure 5 : Variation of $C_{avg}$ .

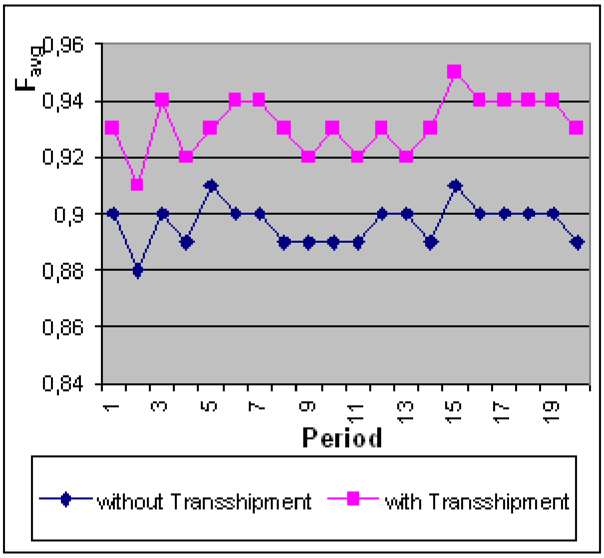


Figure 6 : Variation of $F_{avg}$ .

The next sections describe the experimental results relative to the following parameters :

- Number of Location agents and their types
- Transshipment lead times
- Transshipment mean capacity

## 5.1 Number of Location agents and their types

We have compared between three inventory systems. The first includes 5 cooperatives Location agents. The second contains 10 cooperative Location agents. The third contains 20 cooperatives Locations agents. The results of this experimentation illustrated in figures 7 and 8 show that we obtain good results with the third system. We conclude that we obtain good results if the number of the Location agents participating in the transshipment actions is important. This is explained of a higher probability of cooperative interaction

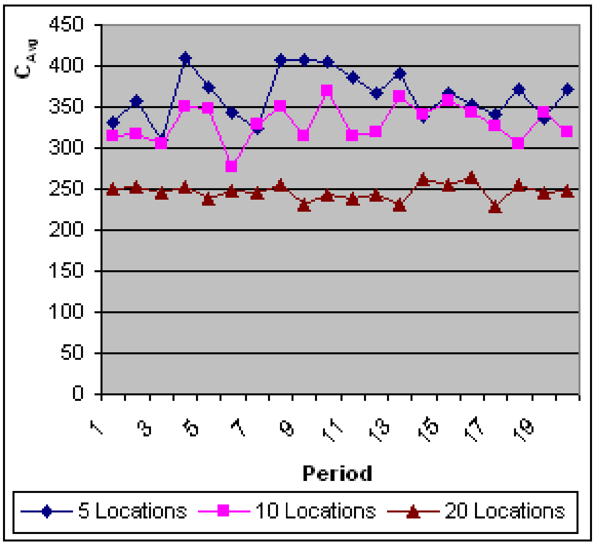


Figure 7 : Variation of $C_{avg}$

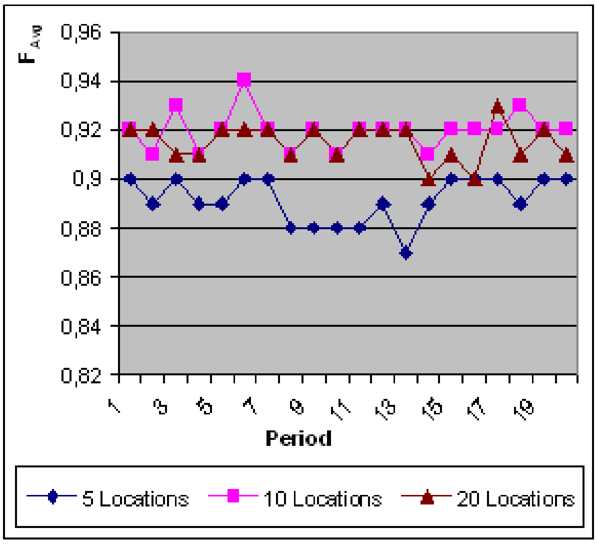


Figure 8 : Variation of $F_{avg}$

A second experimentation is realized to show the influence of the different Location agents types participating in the transshipment actions on the evaluation parameters. We compared between three inventory systems. The first includes only a cooperatives Location agents. The second contains only egoists Location agents. The third contains cooperatives and egoists Locations agents. The results of this experimentation illustrated in figures 9 and 10 show that we obtain good results with the third system. We conclude that we obtain good results if the population of Location agents participating in the transshipment actions is mixed.

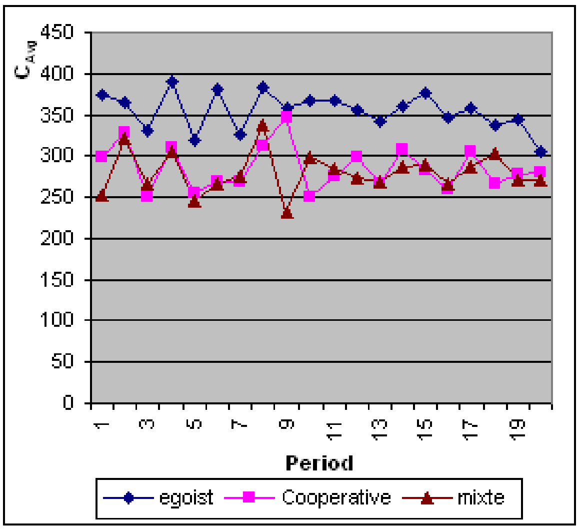


Figure 9 : Variation of $C_{Avg}$

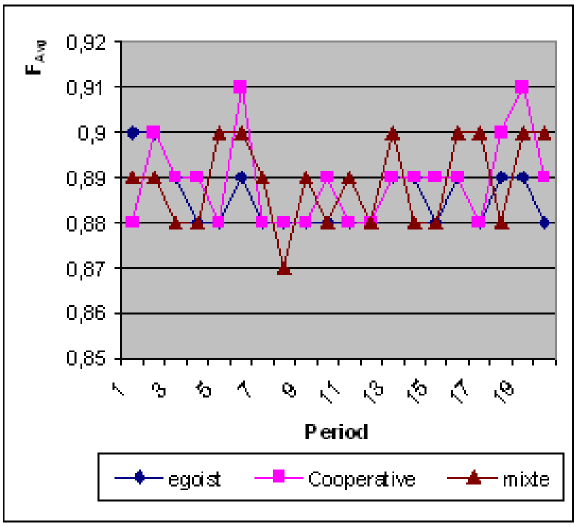


Figure 10 : Variation of $F_{Avg}$

### 5.2 Transshipment leads time

This experimentation is realized to show the influence of the transfer leads time on the evaluation parameters. We compared between two inventory systems. In the first system the transfer lead time $t_{ij}$ is belonging to the set of days {1, 2}. However, in the second inventory system $t_{ij}$ is belonging to the set of days {3, 4}. The results of this experimentation illustrated in figures 11 and 12 show that we obtain good results with the first system. We conclude that we obtain good results if the transfer lead time is reduced.

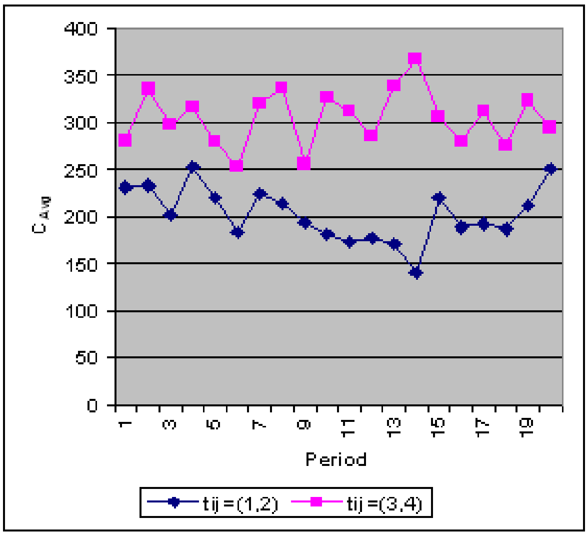


Figure 11: Variation of $C_{avg}$

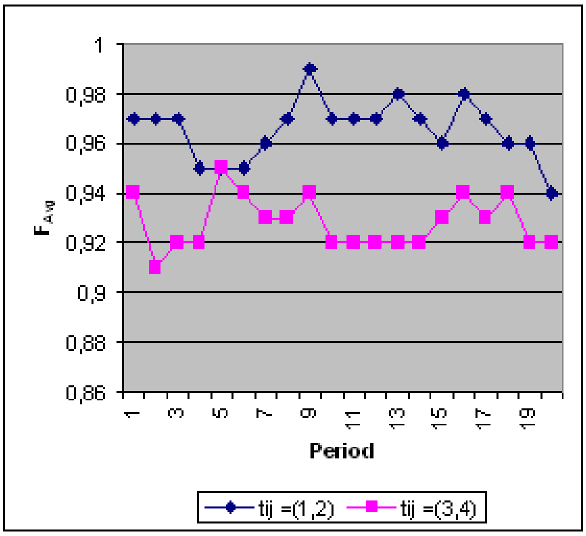


Figure 12 : Variation of $F_{avg}$

### 5.3 Transportation mean capacity

This experimentation is realized to show the influence of the transportation mean capacity on the evaluation' parameters. We are compared between two inventory systems. The first system uses a transportation mean having a capacity equal to 20 item units. However, the capacity of the transportation mean used by the second system is 50 item units. The results of this experimentation illustrated in figures 13 and 14 show that we obtain good results with the second system. We conclude that we obtain good results if the capacity of the transportation mean used is large.

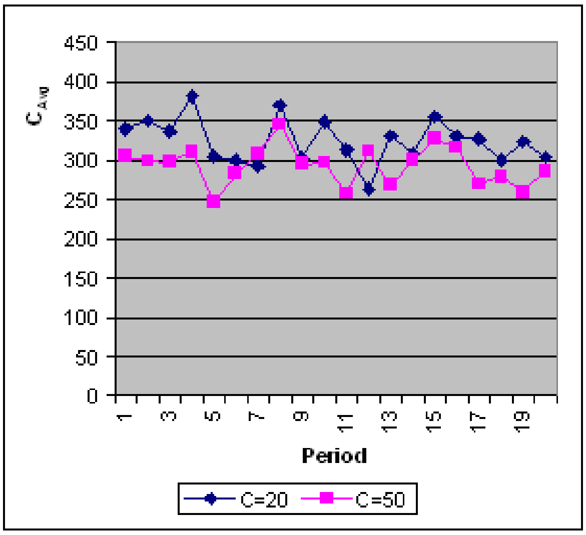


Figure 13 : Variation of $C_{Avg}$

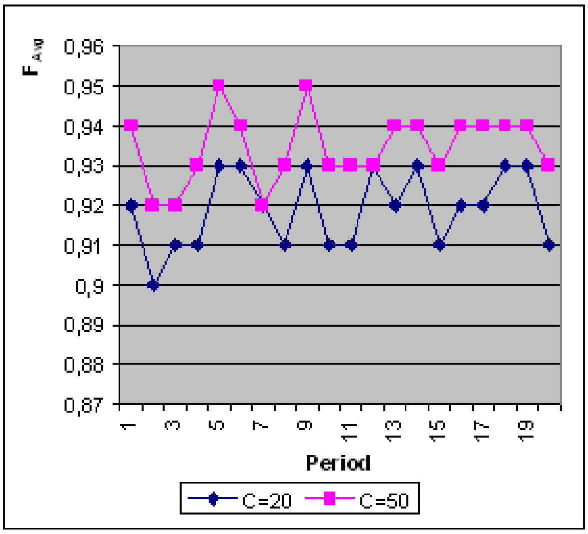


Figure 14 : Variation of $F_{Avg}$

# 6 Conclusion

In this paper we have proposed a new transshipment policy that takes in account a non-negligible transshipment lead times and a limited transportation mean capacity. In order to satisfy the maximum of the customer demands, we have required that the transshipped items participate to satisfy the demands of the current period. So, we have proposed to divide the period into several sub-periods and at the end of one of them the transshipment decision is made. We have introduced a multi-agent model that simulates the behavior of the collaborative network locations. Our experimental results demonstrate that: (1) the number of locations influences the total inventory cost. In fact, we obtain a good result if the number of locations is important, (2) We obtain a good result if the population of the Location agents is mixed, composite of egoist Location agents and cooperatives ones, (3) The transshipment lead times affect the total inventory cost. With a reduced transshipment lead times we obtain better results, (4) the transportation capacity influence the total inventory cost. In fact, with a large capacity we obtain a good result.

Our future works are to determine the initial inventory level, where the transshipment strategy described above is practiced and to use the learning techniques to evaluate the risk caused by the participating in the transshipment operations.

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