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Intermodal transport and distribution patterns in ports relationship to hinterland

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Abstract. It is of great importance to examine all interactions between ports, terminals, intermodal transport and logistic actors of distribution channels, as their optimization can lead to operational improvement. Proposed paper starts with a brief overview of different goods types and allocation of their logistic costs, with emphasis on storage component. Present trend is to optimize storage costs by means of port storage area buffer function, by making the best use of free storage time available, most of the ports offer. As a research methodology, starting point is to consider the cost structure of a generic intermodal transport (storage, handling and transport costs) and to link this to intermodal distribution patterns most frequently cast-off in port relationship to hinterland. The next step is to evaluate storage costs impact on distribution pattern selection. For a given value of port free storage time, a corresponding value of total storage time in the distribution channel can be identified, in order to substantiate a distribution pattern shift. Different scenarios for transport and handling costs variation, recorded when distribution pattern shift, are integrated in order to establish the reaction of the actors involved in port related logistic and intermodal transport costs evolution is analysed in order to optimize distribution pattern selection.

1. Introduction

Specific goods types can be differentiated on their value and package density in four different categories as follows: first - low value bulk cargo, second - high-value bulk goods or outsized general cargo, third - relative small goods with high value and fourth - low value, relative small goods. Necessity of their movement imposes an appropriate logistic concept that recommends specific intermodal transport and a particular distribution pattern. Port related cargo types; mostly from first and second category, derived from value and package density, have different breakdown of logistic costs (storage, handling and transport costs). According to literature [1], low value bulk cargo, e.g.: crude oil, cereals etc., has a share of logistic cost distributed 10% storage costs, 10% handling costs and 80% transport costs while high-value bulk goods or outsized general cargo, e.g.: chemical by-products, machines etc., have a share of logistic cost distributed 40% storage costs, 10% handling costs and 50% transport costs. This is the reason why actors playing a role in the logistic chain that integrates port and inland distribution tend to optimize storage costs by means of port storage area buffer function, by making the best use of free storage time available, most of the ports offer. Literature [2], [3] shows a declining trend of the value of this time interval by reason of pricing strategies that consists in additional increased taxes applied when free storage time available is



overdue. Present data indicates [2], [3], in most of European ports, for container traffic, an average dwell time of four to seven days and a free average storage available in port of seven days.

In spite of this, dwell port time charges remain of low value, smaller than the ones in consignees warehouses or on factory premises, leading to bottle necks in port storage area, creating stocks that exceed capacity. In order to solve this problem, storage areas increased substantially and led to geographical modifications of port layout in terms of relocation of terminals to marginal areas, as presented in different studies [4],[5]. When large capacity storage areas are available, there is no problem to sustain increased dwell times in ports. However, European sites record high problems concerning lack of space and, therefore, logistic terminal operators make sense that high values of free storage time can lead to port system capacity fall and can decrease the access to hinterland efficiency [6]. As an example, Port of Los Angeles reduced free storage time at six days for import and five days for export, in order to augment port storage capacity.

The logical alternative is to transfer ports buffer stacking function further in the distribution channel [7], to other nodes from intermodal network, namely to freight distribution centres (FDC).

2. Selected inland distribution patterns

Port related transport system can be perceived as a series of reservoirs connected one by one and, each time one is full, the taps that allow traffic flows from each other must be shut down. If port storage area, inland distribution centers or final user storage areas exceed capacity, then, the immediate solution is to stop transit flows through it. As a result, chain reactions emerge inside the system as the blockage perpetuates from one subsystem to another till it reaches the port and causes overload. On long term time frame, a possible solution is to enlarge inland distribution centers storage capacity [8] but this measure could only be viable if final user consumption would grow and that is not a transport solution. In a simplified manner, local, regional freight distribution centers (FDC) and transport network must work together [9] to clear the port storage area.

For pattern presented in this paper as direct distribution one, exemplified in a simplified manner in Figure 1(a), stacking areas available in terminal play a buffer role and insure the storage for cargo borne from water operations and going through land transport operations further in the distribution channel. Expected change of traffic through port, inland area industry evolution, urban areas spread and, last but not least, pricing strategies, determine, most likely, changes in the pattern of inland distribution. One of the major consequences, which also influence port logistics and basic direct distribution pattern is the necessity of intermediate storage areas and split-up of trunk road transport and local distribution.

As direct distribution pattern changes into freight centres distribution pattern, as characterized in Figure 1 (b) and Figure 1(c), adjustments register not only in transport characteristics of vehicle fleet (in sense of increased size/capacity) but also in port stacking areas, in activity scheduling in order to insure handling cycle times concordant to vehicle cycles, that are compulsory for unit cost reduction. Different solutions can be adopted, for example long routes tend to justify rail transport distribution - appropriate cargo can be transported in a combined rail – road system, by means of rail flatcars from railhead to inland freight distribution centre as. This combined rail road distribution pattern lowers the pressure on rail transport network and, by combining road short-haul and rail long-haul characteristics alleviates port logistics as it only had to deal with road vehicle which are easier to manage.

In order to assure a good inland distribution, various conditions must be cumulated: transport capacity (appropriate inland transport fleet selection and appropriate transport network capacity), handling capacity (loading/ unloading) and storage capacity. All these attributes are directly dependent on inland distribution patterns. Therefore it is not sufficient to calculate the number of vehicles that is necessary for daily transport to/ from the port to inland only as a function of quantities to be transferred. Correct transport problem imposes the appraisal of vehicle journey times because the distance between inland distribution centre and port regulates the size and structure of vehicle transport fleet.

Concluding, distribution pattern and transport network (route) capacity are some of the core factors that determine the correct size of inland vehicle fleet and type of handling facilities inside port.

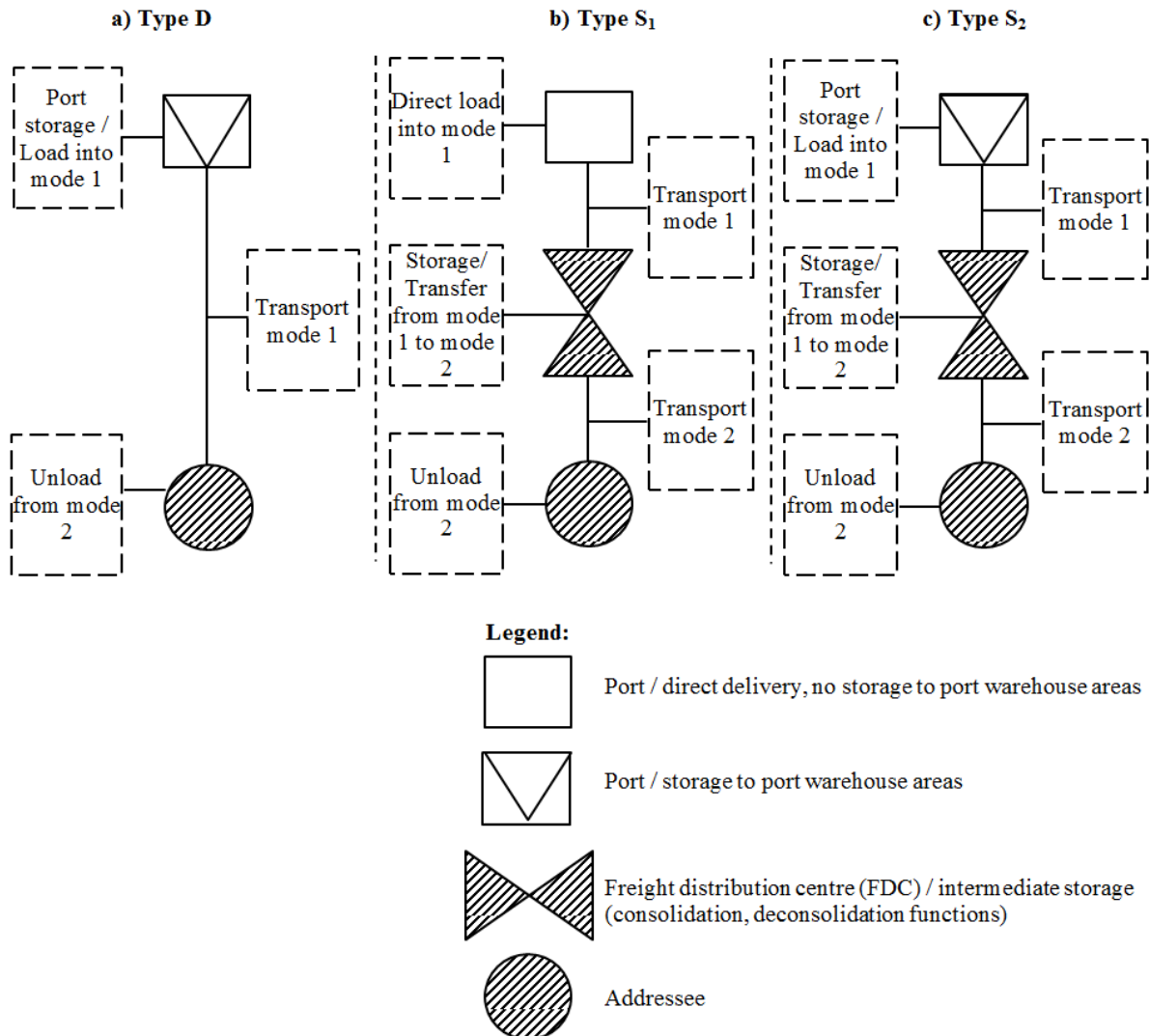


Figure 1. Taxonomy of physical distribution from port corresponding to proposed patterns.

3. Appraisal of distribution patterns

3.1. Costs of intermodal transport

With respect to the cost analysis of the distribution pattern further down discussed, some simplifying hypothesis are made: cargo is homogeneous, the time period that goods are stored in the distribution channel, before arriving to the addressee, is t_{mt} and the port free time storage is t_{mt0} .

Cost categories considered in present analysis are: storage costs including handling costs for storage, handling costs for loading and unloading transport means of different modes, transfer costs from one mode to another and transport costs.

A simplified general formula for intermodal transport [1] from port to addressee, using M modes, is shown in equation (3.1):

$$C = C(\text{storage}, P) + C(\text{load}, 1) + \sum_{m=1}^M (C(\text{transport}, m) + C(\text{storage}, FDC_m) + C(\text{transfer}, [m, m+1])) + C(\text{unload}, M) \quad (3.1)$$

with:

$$C(\text{transfer}, [m, m + 1]) = 0 \text{ for } m = M$$

When only one mode is used:

$$C(\text{transport}, m) = C(\text{transportmeans}, m) + C(\text{trafficmeans}, m) + C(\text{inframeans}, m)$$

and:

C - the total cost for distribution;

$C(\text{storage}, P)$ - costs of storage in ports;

$C(\text{load}, 1)$ - costs of loading goods in transport means, $m = 1$;

$C(\text{transfer}, [m, m + 1])$ - costs of transferring goods from mode m to mode $m + 1$, except for $m = M$;

$C(\text{storage}, FDC_m)$ - costs of storage in FDC corresponding to mode m ;

$C(\text{unload}, M)$ - costs of unloading goods from transport means corresponding to mode M ;

$C(\text{transportmeans}, m)$ - costs with the transport means for mode m ;

$C(\text{trafficmeans}, m)$ - operating costs of mode m ;

$C(\text{inframeans}, m)$ - costs of using the infrastructure for mode m .

3.2. Storage costs impact on distribution pattern selection

For type D distribution pattern, as illustrated in Figure 1(a), input cargo is stored in port warehouse areas for a given period of time t_{mt} (time period that we assumed that goods are stored in the distribution channel). At the end of storage interval, cargo is loaded into transport means of mode 1 and transported directly to the addressee, where unloading operations take place. The cost formula in this case of direct distribution can be expressed as in equation (3.2).

$$C^D = C(\text{storage}, P) + C(\text{load}, 1) + C(\text{transport}, 1) + C(\text{unload}, 1) \quad (3.2)$$

with:

$$C(\text{storage}, P) = c(\text{storage}, P) \cdot t_{mt}$$

and:

$c(\text{storage}, P)$ - costs per day of storage in ports warehouse ;

t_{mt} - time period that goods are stored expressed in days.

And port storage costs depend on a time period that goods are stored, t_{mt}

For type S₁ distribution pattern, as illustrated in Figure 1(b), input cargo is loaded directly to transport means of transport mode 1 and carried to freight distribution centre (FDC) where it is stored for the same period of time t_{mt} (time period that we assumed that goods are warehoused in the distribution channel). From this FDC's storage facility goods are then transferred to transport means corresponding to mode 2, transported to the addressee, where unloading operations take place. The cost formula in this case of direct distribution can be expressed as in equation (3.3).

$$C^{S1} = C(\text{load}, 1) + C(\text{transport}, 1) + C(\text{storage}, FDC) + C(\text{transfer}, [1, 2]) + C(\text{transport}, 2) + C(\text{unload}, 2) \quad (3.3)$$

with:

$$C(\text{storage}, FDC) = c(\text{storage}, FDC) \cdot t_{mt}$$

and:

$c(\text{storage}, FDC)$ - costs per day of storage in Freight Distribution Centre (FDC) warehouse

An actor a , consigner in the logistic chain corresponding to nominated distribution patterns, must select the alternative less expensive from the point of view of costs involved. In many situations,

when port storage costs are low or when ports offer a free time storage for a limited amount of time, t_{mt0} , type D distribution pattern is preferred to type S₁ distribution pattern, leading to bottle necks in port storage area, creating stocks that exceed capacity. This situation can be formulated as in equation (3.4) as an inequality [10] of each distribution characteristic costs:

$$c(\text{storage}, P) \cdot (t_{mt} - t_{mto}) \leq \left(\Delta C_{(S1,D)}^{\text{transport}} + \Delta C_{(S1,D)}^{\text{handling}} \right) + c(\text{storage}, FDC) \cdot t_{mt} \quad (3.4)$$

with:

t_{mto} - port free storage time expressed in days;

$\Delta C_{(S1,D)}^{\text{transport}}$ - transport cost difference between distribution pattern S₁ and distribution pattern D;

$\Delta C_{(S1,D)}^{\text{handling}}$ - handling (loading, unloading, transfer) cost difference between distribution pattern S₁ and distribution pattern D;

Alleged facility of port free storage for a limited amount of time, t_{mto} , can be significant for distribution pattern split. If $\alpha_{t_{mt}}$ represents of the proportion of port free storage time from the total amount of storage in the logistic channel as in equation (3.5):

$$\alpha_{t_{mt}} = \frac{t_{mto}}{t_{mt}}, \quad t_{mt} > t_{mto} \quad (3.5)$$

Assuming that

$$0 < \alpha_{t_{mt}} < 1$$

Inequality (3.4) becomes:

$$c(\text{storage}, P) \leq \frac{c(\text{storage}, FDC)}{1 - \alpha_{t_{mt}}} + \frac{\alpha_{t_{mt}} \left(\Delta C_{(S1,D)}^{\text{transport}} + \Delta C_{(S1,D)}^{\text{handling}} \right)}{(1 - \alpha_{t_{mt}}) \cdot t_{mto}} \quad (3.6)$$

Equation (3.7) indicates the limit of port storage costs per day beyond which type S₁ distribution pattern becomes more attractive than type D distribution pattern, for a certain actor a, consigner in the logistic chain.

Considering that β_{ta} represents the ratio between port unitary costs of storage and FDC costs of storage per day, than equation (3.6) leads to:

$$\beta_{ta} = \frac{c(\text{storage}, P)}{c(\text{storage}, FDC)} \leq \frac{1}{1 - \alpha_{t_{mt}}} + \frac{\alpha_{t_{mt}} \cdot \left(\Delta C_{(S1,D)}^{\text{transport}} + \Delta C_{(S1,D)}^{\text{handling}} \right)}{(1 - \alpha_{t_{mt}}) \cdot t_{mto} \cdot c(\text{storage}, FDC)} \quad (3.7)$$

Equation (3.7) is not satisfied in the case depicted in equation (3.8).

$$c(\text{storage}, P) > \bar{\beta}_{ta} \cdot c(\text{storage}, FDC) \quad (3.8)$$

where:

$$\bar{\beta}_{ta} = \frac{1}{1 - \alpha_{t_{mt}}} + \frac{\alpha_{t_{mt}} \cdot \left(\Delta C_{(S1,D)}^{\text{transport}} + \Delta C_{(S1,D)}^{\text{handling}} \right)}{(1 - \alpha_{t_{mt}}) \cdot t_{mto} \cdot c(\text{storage}, FDC)} \quad (3.9)$$

If $\bar{\beta}_{ta}$ is high positive then port storage costs per day are relatively high and is obvious that type S₁ distribution pattern becomes more attractive than type D distribution pattern.

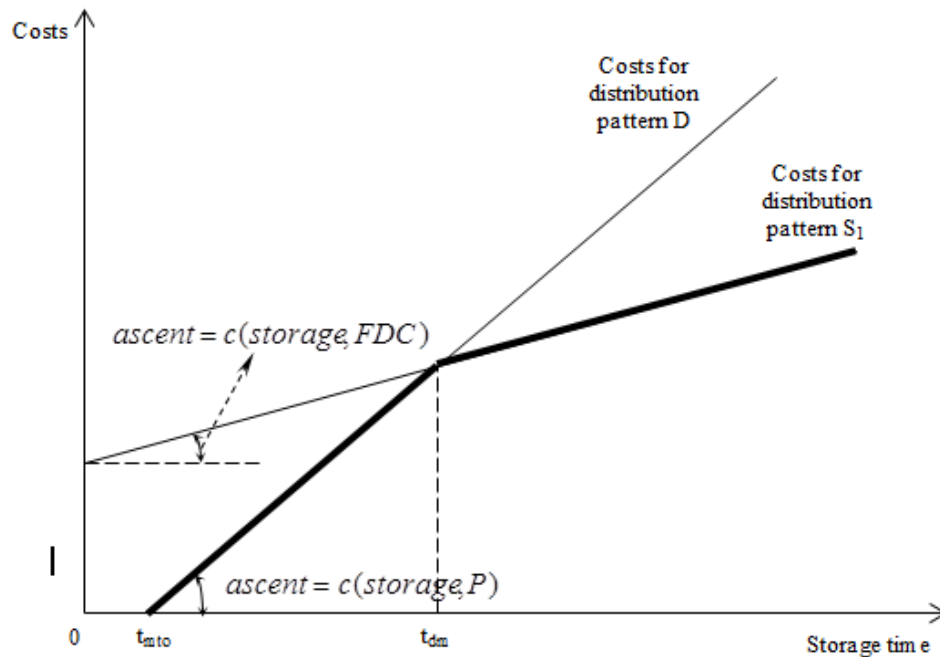


Figure 2. Distribution pattern selection dependence with storage period and costs for situation depicted in equation (3.10).

A negative value of $\bar{\beta}_{ta}$ suggests that, even if port storage costs per day are lower than costs per day of storage in Freight Distribution Centre (FDC) warehouse, distribution pattern D is not preferred to distribution pattern S₁. In order to solve the ambiguity of this assertion, presented mathematical analysis implications are examined through graphic representation in Figure 2.

For a given port free storage time, a corresponding value of time that goods are stored in the distribution channel can be identified in order to substantiate distribution pattern shift. Concluding, a distribution pattern selection in relation to costs involved can be, in a simplified manner, interpreted from the point of view of time period that goods are stored in the distribution channel.

The third distribution pattern S₂ presented in Figure 1(c), comprises storage of input cargo in port for the period of free storage time and after transfers the storage function to the intermodal Freight Distribution Centre (FDC), cargo is loaded from port storage area to transport means of transport mode 1 and carried to freight distribution centre (FDC) where is stored for the period of time $t_{mt} - t_{mt0}$. From FDCs storage facility goods are then transferred to transport means corresponding to mode 2, transported to the addressee, where unloading operations take place. The cost formula in this case of direct distribution can be expressed as in equation (3.10).

$$C^{S1} = C(storage, P) + C(load, 1) + C(transport, 1) + C(storage, FDC) + C(transfer, [1, 2]) + C(transport, 2) + C(unload, 2) \tag{3.10}$$

with:

$$C(storage, P) = c(storage, P) \cdot t_{mt}$$

$$C(storage, FDC) = c(storage, FDC) \cdot (t_{mt} - t_{mt0})$$

4. Scenarios of transport and handling costs variation and distribution pattern shift

A. Additionally to the study in paragraph 3.2, if the difference of cumulated transport and handling costs registered when distribution pattern D shifts to distribution pattern S₁ is positive as in equation (4.1), then distribution pattern D is preferred to distribution pattern S₁, for port storage costs per day

lower than costs per day of storage in Fright Distribution Centre (FDC) warehouse, no matter the storage time period in distribution system. For situations according to port storage costs per day higher than costs per day of storage in Fright Distribution Centre, distribution pattern D is preferred to distribution pattern S₁ for storage periods shorter than t_{dm} , level of storage time that recommends the shift between distribution patterns, as in Figure 2.

$$\Delta C_{(S1,D)}^{transport} + \Delta C_{(S1,D)}^{handling} \geq 0 \quad (4.1)$$

$$t_{dm} = \frac{(\Delta C_{(S1,D)}^{transport} + \Delta C_{(S1,D)}^{handling}) + c(storage, P) \cdot t_{mto}}{c(storage, P) - c(storage, FDC)} \quad (4.2)$$

where:

t_{dm} represents the level of storage time that recommends the shift between distribution pattern D and distribution pattern S₁

B. If the difference of cumulated transport and handling costs registered when distribution pattern D shifts to distribution pattern S₁ is negative than two different cases can be outlined, as in equation (4.3) or as in equation (4.5).

First case, if

$$\Delta C_{(S1,D)}^{transport} + \Delta C_{(S1,D)}^{handling} < 0 \text{ and } c(storage, P) < c(storage, FDC) \quad (4.3)$$

then the costs can be represented according to Figure 3 and distribution pattern D is preferred to distribution pattern S₁ for goods that have a period of storage higher than t_{dm} and t_{mt1} is the inferior limit of storage time distribution pattern S₁ starts to be pertinent from.

$$t_{mt1} = \frac{-\left(\Delta C_{(S1,D)}^{transport} + \Delta C_{(S1,D)}^{handling}\right)}{c(storage, FDC)} \geq t_{mto} \quad (4.4)$$

Second case, if

$$\Delta C_{(S1,D)}^{transport} + \Delta C_{(S1,D)}^{handling} < 0 \text{ and } c(storage, P) > c(storage, FDC) \quad (4.5)$$

then the costs can be represented according to Figure 4 and t_{mt1} is the inferior limit of storage time distribution pattern S₁ starts to be pertinent from:

$$t_{mt1} = \frac{-\left(\Delta C_{(S1,D)}^{transport} + \Delta C_{(S1,D)}^{handling}\right)}{t_{adm}} < t_{mto} \quad (4.6)$$

For goods that storage time in distribution channel is longer than t_{mto} but shorter than t_{dm} distribution pattern of type D is preferred to distribution pattern S₁ and for goods that have a period of storage higher than t_{dm} , distribution pattern S₁ is preferred to distribution pattern D as in Figure 4.

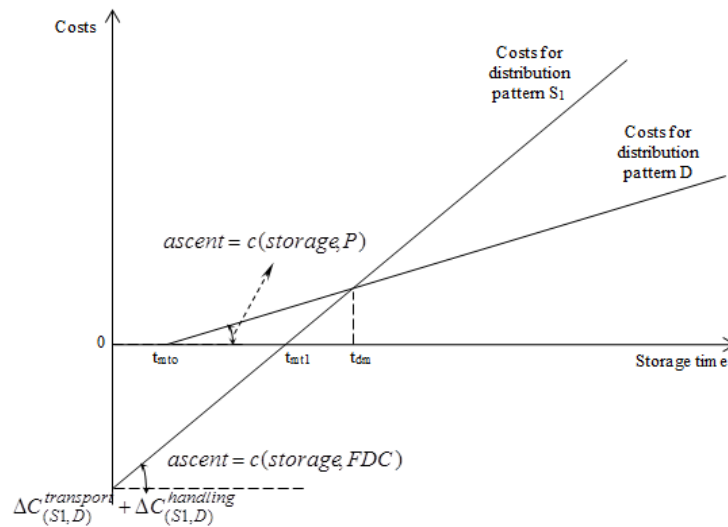


Figure 3. Distribution pattern selection dependence with storage period and costs for situation depicted in equation (4.3).

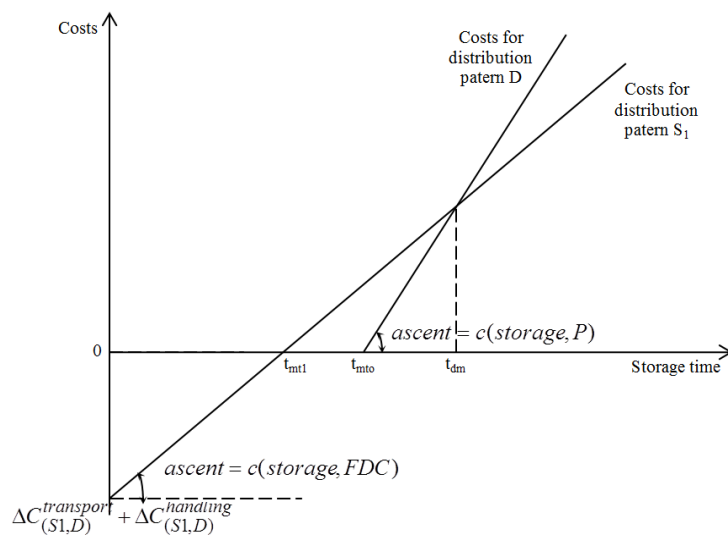


Figure 4. Distribution pattern selection dependence with storage period and costs for situation depicted in equation (4.5).

5. Conclusion

Storage system component of every distribution pattern can, in a certain amount, to adjust its capacity by means of variant time period, t_{mt} , that goods are stored in the distribution channel, before arriving to the addressee. More precisely, this can be done through break down of t_{mt} between different intermodal storage areas (located in port or in FDCs). Storage cost alteration has a direct influence on time period that goods are stored in different warehouses of the distribution channel. Indeed, as shown in present paper, bigger cost of one or the other stacking areas can determine shifts from one distribution pattern to another and, as a result, lead to operational improvement. In most of the cases, cost variations generate prompt reactions from ports users, sensitive to costs elasticity.

If the structure of intermodal transport costs is presented to all actors involved in port related logistic chains [7] and they become conscious of all components, their response fits the cost function presented in different situations studied in Figure 2, Figure 3 or Figure 4. Port storage time take on

new attributes in nowadays logistic operations. Unlike conventional port productivity measures [11], [12], [13], [14] actors of recent logistic chains deliberately increase port dwell times in order to achieve low-cost storage [6]. As a result, elevated dwell times in terminals can no longer be considered a sign of reduced connectivity or lack of interconnection between seaborne traffic flows and inland transport.

It is very likely that ports, through their storage policy in terminals to play an active role in distribution channels by imposing increased dwell time charges and diminished free time storage.

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