Synchromodality as a solution to improve the efficiency in freight transportation

Joana Cunha[1]

[1]Instituto Superior Técnico, University of Lisbon

Av. Rovisco Pais, 1049-001, Lisboa, Portugal

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Abstract: In the last decades, several solutions have emerged in the context of freight transport, proposing the use of other transport modes in alternative to road transport during the main-haulage of the transport of the freight from its origin to its destination, and employing the road transportation only in the pre- and end-haulage. These are called multimodal solutions, the most recent concept being Synchromodality, that allows real-time switching of modes. The purpose of this work is to investigate the potential benefits of Synchromodality in relation to Intermodality in the improvement of the network's performance, as well as their limitations.

The literature review showed that Synchromodality's main innovation is the introduction of the possibility of real-time switching as well as increased sharing of information, relying on the assumption that, by improving the quality of communication between agents and allowing modal flexibility, the planning process will be better able to adapt to new conditions in the network.

To fulfill this objective, a simulation model was developed, applying the methods of Discrete Events and Agent-Based Modeling, in order to simulate the operations executed by each agent in the freight transportation along the Atlantic Corridor, as well as the decision-making process of different logistic operators.

Confronting these operators with distinct conditions in the system, with varying degrees of flexibility and transport demand, it was concluded that Synchromodality shows some performance improvement with respect to Intermodality, namely in the timely delivery of orders, but its advantages only show when the system operates under more adverse circumstances.

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[1] e-mail: joanafrcunha@ist.utl.pt

1. Introduction

Freight transport is a key element in the efficient and timely movement of raw materials and products through space, allowing the link between producers and consumers.

In the search for efficient logistic solutions, able to maintain acceptable costs, several transportation concepts appeared, the most recent being Synchromodality, which comprises of a transport chain which uses multiple modes, and in each transportation step it is possible to select the next mode to be used. This allows for the optimization of the chain according to transport influencing factors, producing solutions that are flexible and adapted to each case, improving efficiency and reducing costs, when compared to previous solutions. Since this is a new concept, and still in a maturing phase, literature is scarce; in addition, there are few examples of practical application of this solution in Europe, most implemented in the Netherlands. Under these circumstances, not only the potential of Synchromodal systems has not been fully exploited, as some aspects of this solution are still to be determined, namely a consensus on its definition.

As such, this work aims to identify the innovations introduced by the Synchromodal transportation concept, and assess what benefits this solution may bring to the performance of a transportation chain.

To achieve this, a model will be developd to simulate the behavior of Synchromodal and Intermodal transport solutions in the same transport chain and under different system conditions. The comparison of the results of each transportation concept will be the basis for the assessment of the existence of performance improvements with the implementation of Synchromodality.

2. Literature Review

Over the years, different concepts have emerged, their definitions presented bellow.

- **Multimodality:** "the transportation of goods by two or more different modes of transport (such as road, rail, air or inland waterway, and short- or deep-sea shipping) as part of the contract where often a multimodal transport operator is responsible for the performance of the entire haulage contract from shipping to destination" [1]
- **Intermodality:** " the movement of goods in one and the same loading unit or vehicle by successive modes of transport without handling of the goods themselves when changing modes" [2]–[8]
- **Co-modality:** "the efficient use of different modes on their own and in combination"[9]
- **Combined transport:** "intermodal transport where the major part of the journey is by rail, inland waterways or sea and any initial and/or final leg carried out by road are as short as possible" [10]

As noted by Reis [11], these concepts are an evolution of the same basic principle first introduced by multimodal transportation, which introduced the idea of using more than one mode of transport, creating a more complex transport chain, in comparison to "door-to-door" road transportation, where the most appropriate modes are selected in each leg of the route from the origin to the destination.

The concept of Intermodal transportation then introduced the idea of integrating the various modes in the transport chain, by coordinating the operations carried out by each one, and reducing frictions during transhipment operations. To do so, it introduced the practice of cargo consolidation, which can take advantage of the maximum capacity of vehicles to include smaller flows in the intermodal network, by using load units, compatible with all transport modes, which in turn reduce the risk of damage during transhipment operations, and lead to a increase in efficiency of the latter; thus resulting in a solution that allows the creation of a single door-to-door service.

The co-modal transportation concept focuses on maximizing efficiency, aiming to achieve an optimal and sustainable use of available resources. In turn, combined transportation adds a concern with the external impacts of the transport process, prioritizing the use of rail, maritime and inland waterway modes, so as to minimize the use of the truck, and achieve environmentally sustainable transport solutions.

In this context, emerges **Synchromodality**:

- "positioned as the next step after intermodal and co-modal transportation, (it) involves a structured, efficient and synchronized combination of two or more transportation modes" [9]

- “can be achieved by making modality choices according to the latest logistics information, e.g., transport demands, traffic information, etc.” [2]
- “an innovative, promising idea of flexible and sustainable utilization of transport resources based on the co-operation of carriers representing various transport modes, adjusted to customer requirements and current transport capacities.” [12]
- “the continual synchronization of chains of goods, chains of transport and infrastructure in such a way that the best modal choice can be made at any moment for the aggregated demand for transport” [13]

Deriving from the previous concepts, Synchromodality presents three main innovations: the introduction of a logistic operator, a Synchromodal network manager, which oversees the transport of all orders being transported in the system, and coordinates the operations of every agent in the network (carriers, terminal operators, etc.) to produce a seamless transport; collection (monitoring), and sharing of information in real time, which allow, at any given time, to access the system conditions (including infrastructure, operational services and freight processing) and thus permitting to quickly identify and respond to any disturbances; and the flexibility to change modes, either in response to disturbances or due to new customer specifications. As such, while there is a pre-establishment of services and an initial planning of the transport, these are continuously reviewed and optimized in accordance with the current conditions in system, seeking to achieve an efficient and balanced use of all available resources.

3. Methods and Case Study Application

3.1. Discrete-Event Modelling

In Discrete-Event Modelling, the system is described as a process, i.e. a sequence of operations performed on a set of entities that populate the system and using a set of available resources [14].

In this modeling method: **entities** are individuals, or objects, with their own attributes, these being the target of transformation during the process; **resources** constitute the elements necessary to perform the operations, these also having attributes, such as service hours, capacity, or speed; **operations** are the set of activities carried out during the processing of each entity.

3.2. Agent-Based Modeling

In Agent-Based Modeling, the system is modeled as a set of entities capable of making independent decisions [15], which is particularly suitable for situations where it is desired to simulate individuals whose actions result, not from a pre-defined sequence of activities, but rather are a flexible response to various occurrences in the systems, whether due to events that occur in the environment in which the entities are located, or in response to the behavior of other entities [16].

Thus the system is described as a populated environment, where a group of individuals, named **agents**, which have their own behavior, and the ability to communicate with each other, and perceive the conditions in the system. In this context, each agent has a number of specific objectives and a set of behaviors or actions, which are structured in accordance with an internal cycle and activated according to internal or external stimuli.

3.3. Case Study Modeling

The developed model aims to simulate the transport of orders along a transportation chain, which comprises of 15 terminals and 3 ports, and is served by road, rail and sea transportation services (Figure 1).

Figure 1- Transport Chain

This environment is populated by the following agents and processes:

- the **Order**, which consists of two process flows, simulates the arrival of a transport request, creating the corresponding entity to this Order, and, after the conclusion of the transportation to the final destination, eliminating it from model.
- The **Transport Services**, which consist of three process flows, each corresponding to one of the existing modes in the transport chain, that simulate the creation of vehicles (or services), the transport of orders between terminals, and the end of the service. Each of those flows comprises of service generation, loading and unloading of cargo, movement between terminals, and end of service. Since road and sea modes last only for one trip, i.e. the services are terminated after the motion between consecutive terminals, while the rail mode may make several stops during operation, the latter has additional objects of choice output and introduction of delays, and can run multiple cycles in the process flow.
- the **Terminal** appears as a hybrid of the Discrete-Events and Agent-Based modelling methods: the Terminal is considered as being an agent that switches between two states - active, inactive -, wherein the present state of the agent affects its internal process flow. When active, the orders are received at the Terminal and sent to the mode of transport that will transport them to the next terminal, or to the final delivery stage, if they have reached their destination. This agent is then composed by a flow of processes and a statechart: the process flows containing object entry, queues, hold, delays, and selection between multiple outputs; the statechart contains an initial state of inactivity, and turns active during the terminal's working hours.
- the **Operator** is an agent, its behaviour being modeled as a statechart that reflects the logical decision-making process during the the assignment, and revision of the Orders' itineraries. This statechart consists of an initial state of Stand By, the registration of Orders, route planning and revision of the planning; and the transfers between the various states are triggered by different events: the arrival of a message, timeout, or condition.

  The transition of the registration state to the planning is triggered by a timeout, i.e. the transition is made after a certain period of time has elapsed since the entry into the state, which was set to 12 hours in the developed model. The reason for the stipulation of a minimum time of permanece in the registration state, as opposed to the immediate initiation of the planning stage, is the need to allow the collection of several requests for transport, which will then be planned at the same time; the absence of this collection phase would imply that each new Order was planned immediately after its creation, not allowing for comparison with other Orders to assess priorities in the planning process, which (given the fact that a given order does not necessarily have a delivery date prior to a subsequently generated ordering) could lead to the impossibility of allocating priority Orders for services that fulfill the time window, because of their capacity's saturation with less urgent Orders.

  When in the state of planning, the operator sorts of all the recorded Orders in accordance with the priority criteria, and then proceeds to choose the best route for each Order, taking into account the available services and capacities.

  In the state of revision, the Operator sorts all Orders again, later planning the Orders that are unplanned or replanning the ones affected by the disorder.

  It's in this aspect the different the behavior of Intermodal and Synchromodal Operators is introduced: the Intermodal Operator can only reschedule the services reserved for orders directly affected by the disorder, looking for available services that meet the deadline, or if this is not possible, to minimize the delay, but being obliged to comply with the itinerary originally assigned; in turn, the Synchromodal Operator is free to change the schedule of services or the itinerary, not only orders directly affected by the disorder, with also the other orders, and may take advantage of possible releases in the capacity of modes (resulting from the replanning other orders) that provide more advantageous alternatives, in terms of time and price.

The interaction between these entities and agents is shown in Figure 2.

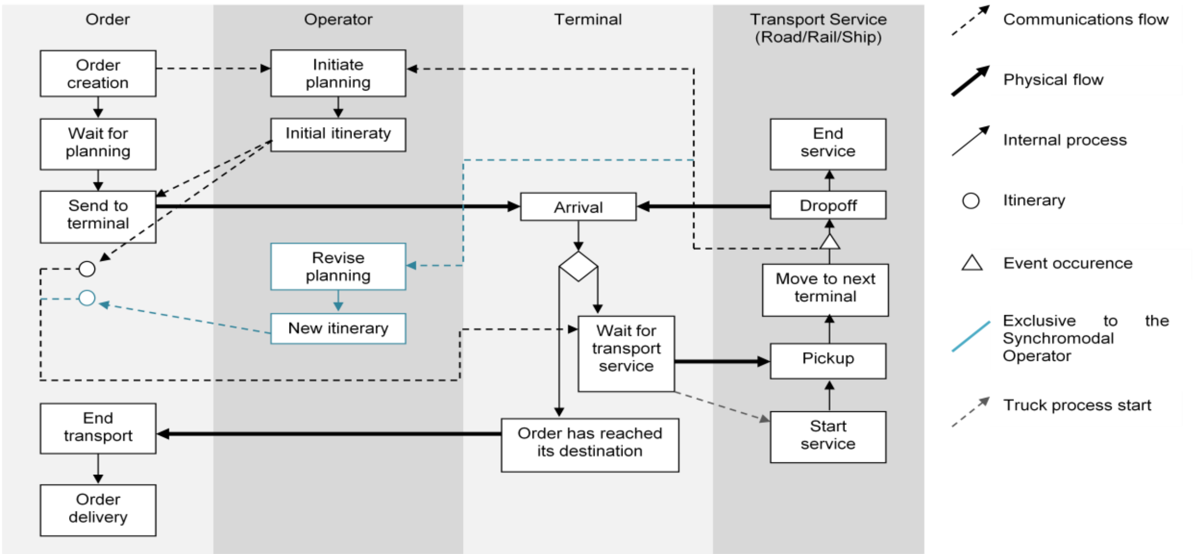

Figure 2 - Transportation process

Table 1 – System conditions cases

Altered parameters	Case 0	Case 1
Simulation period	01/01/16 – 01/01/17 (8684 h)	01/01/16 – 01/05/16 (2904 h)
Order generation	Normal(9; 0,5)	Normal(3; 0,5)
Request in advance	before = uniform_discr(0, 3) * day()	before = uniform_discr(0, 1) * day()
Time window	after = uniform_discr(4, 7) * day()	after = uniform_discr(0, 2) * day()
Truck speed	Triangular(45; 70;85)	Normal(70; 6)
Ship speed	Triangular(15; 30; 50)	Normal(30; 7)
Train transit time	Triangular(0,97t; t; 1,1t)	Triangular(0,9t; t; 1,2t)

4. Results

4.1. Scenarios

The application of the developed model for the comparison of Intermodal and Synchromodal transportations will be based on three different scenarios, each reflecting the behaviors of the Operator according to each concept:

- **Intermodal (I0):** this Operator will be notified whenever disturbances are identified; upon the arrival of a Delay message, the operator will then perform a re-scheduling of the orders directly affected by the occurrence, allocating them to the next available service, without introducing any changes to the itinerary.
- **Synchromodal 1 (S1):** this Operator is a hybrid between the two concepts, adopting the behavior of a Synchromodal operator in the event of disturbances, not only re-planning directly affected orders, but also reviewing the planning of others, but being this process of re-planning conditioned by the occurrence of these disturbances, as with the Intermodal Operator.
- **Synchromodal 2 (S2):** this Operator performs the procedure previously described for the re-planning and revision of all Orders' transport plans when a disturbance is identified; in addition, when a request arrives to the terminal, the operator is forwarded to the state of re-planning and revises the planning of all existing orders, thus increasing the frequency in which the operator actively looks for opportunities to improve the service.

Each of these Operators will be confronted with two possible cases that simulate different conditions in the system (Table 1):

- **Case 0** presents more flexibility during the operation of the transport chain, with a less frequent generation of new Orders, each with rather extended deadlines, which can reach a week after the cargo's pickup at the origin; it also proposes less variation in the vehicles' circulation speed.
- **Case 1** introduces stricter conditions in the system, with a higher amount of Orders competing for the same resources in the network, and shorter deadlines coupled with

a lesser advance in the notification of the Operator; in addition, the transport times now have a larger breath.

4.2. Global results

Given that the objective of a manager of a transport chain is the transport of cargo within the deadline at the lowest possible price, it was considered that a first approach to assessing the degree of success of the adopted transport solution is to evaluate, on the one hand, the proportion of transport that meets the stated requirements and, secondly, the trade-offs that made it possible, both in terms of planning efforts, as well as monetary.

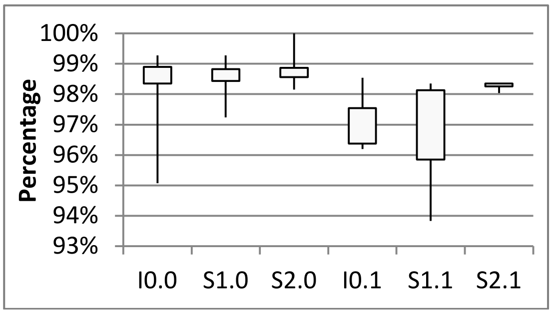

Figure 3 - Percentage of delivered orders

Based on Figure 3, it can be observed that around 97% to 99% of generated orders were delivered at the end of the simulation cycle. However, it is possible to note that the Synchromodal scenarios, particularly S2, have a higher amount of delivered orders: this difference, although very slight in Case 0, is more pronounced in Case 1, where the conditions in the system are more adverse. It should be noted that, in Case 1, S1's results show a remarkable discrepancy to others, which is due to the fact that in a few of the simulation runs, the number of generated orders was much lower than the norm.

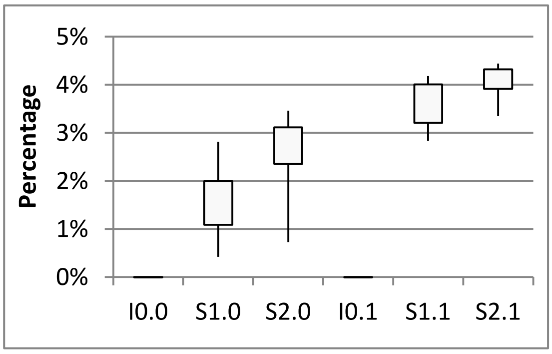

Figure 4 - Percentage of altered itineraries

Despite a high frequency of revisions and replannings, the number of orders to effectively change their itinerary is very low, ranging between 2% and 4.5% in the tested cases (Figure 4); it can be inferred that most of the changes made during the replanning and revision processes consist of services' scheduling, and itinerary changes. It is also interesting to note that, although the number of replannings and revisions decreased from Case 0 to Case 1, this situation is reversed in the case of itinerary changes, and S2 appears to be more likely to perform re-routing.

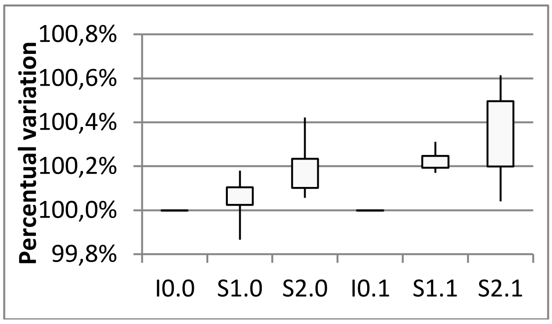

Figure 5 - Percentual deviation of transport prices

By analyzing the percentual deviation between the prices of the forecasted and real itineraries (Figure 5), it is clear transportation costs rise, not only with Synchromodality, but also with the worsening of system conditions. This indicates that, as expected, the introduction of adversity in the system will force the Synchromodal Operator to opt for more expensive routes to ensure the compliance with the deadlines. It is, however, important to notice that this increase is marginal, not reaching 0.7%; taking into account that the trnasportation prices include a 15% margin of profit on the operating costs of the services, it can be concluded that the discrepancy between actual and projected price is covered by this margin, maintaining the economic sustainability of the solution.

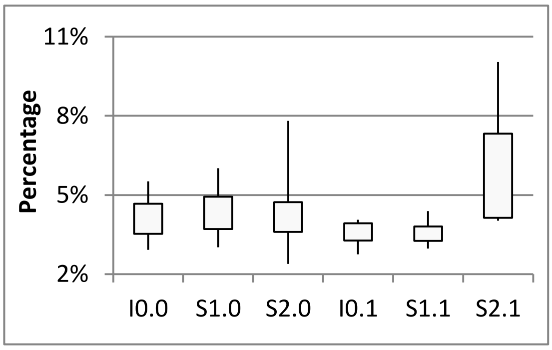

Figure 6 - Percentage of orders delivered within forecasted time

Regarding the fulfillment of transport the forecasts, it can be seen in Figure 6, that for good operating conditions in the system, there are no significant differences between each scenario, although it can be pointed out that Synchromodal scenarios, particularly S2, show greater dispersion; this may be due to the greater likelihood of itinerary alterations in these solutions, which introduce variations regarding the expected times. In Case 1, however, S2 distances itself from other scenarios, revealing a greater ability to comply with forecasts; this indicates that more frequent monitoring will give the Operator a greater control over the transport of orders, allowing it to maintain the level of service in more extreme operating conditions.

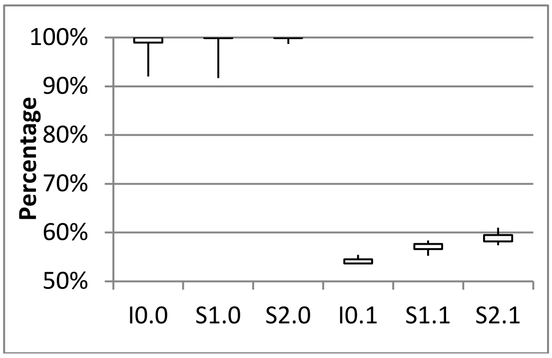

Figure 7 - Percentage of orders delivered within deadline

Finally, it remains to assess the compliance to the established deadlines. As seen in Figure 7, the changes between scenarios are relatively contained, meaning there is not enough discrepancy between scenarios to establish the superiority of one over another. However, it is possible to observe that the introduction of Synchromodal characteristics appears to produce more consistent results, noting the lesser dispersion of the results of S2 in Case 0, as well as more favorable performance, since with the introduction of adversity on the system in Case 1, a greater variation between scenarios is observed, with Synchromodality gaining dominance over Intermodality.

4.3. Deviation to forecast and deadline

The deviations from the expected transport time of each of the scenarios for the different test cases, are shown in Figure 8; it is important to note that during the treatment of the results the existence of some orders with uncharacteristic deviations, higher than those of other orders delivered, was found. Thus, to facilitate the reading of diagrams, the values corresponding to 99.75 percentile are presented (withdrawing 0.0025% of observations), instead of the maximum observed value.

Regarding the fulfillment of the forecasts, it is observed that between the 1st and 3rd quartiles, the deviation from the forecast remains relatively constant between the various cases and similar between scenarios, with half the observations concentrated between a 18%-49% delay in Case 0, whereas in Case 1 reduces values reduce to 11%-41%. These results show that the variation of the order parameters has no significant impact on the ability to comply with forecasts, although one can notice a slight increase in the dispersion of the maximum and minimum values of this deviation for Synchromodal scenarios, particularly S2, which may be due to its increased likelihood of applying changes to the transportation plan.

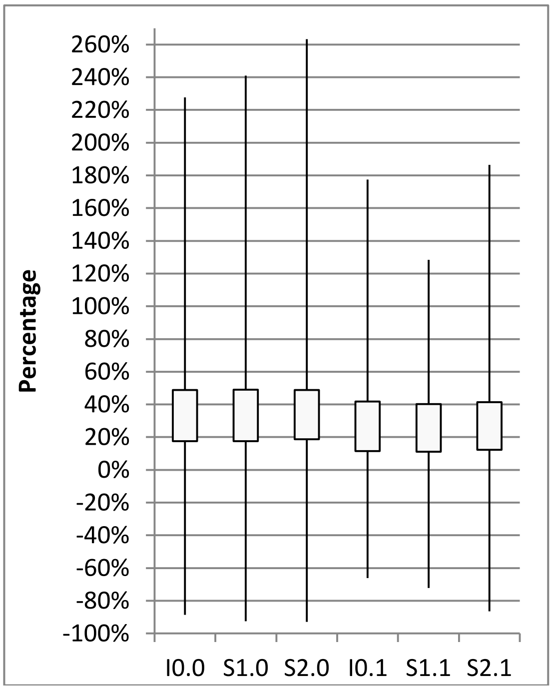

Figure 8 - Percentual deviation to the forecast

With regard to meeting the deadlines, it is remarkable the reaction of the various scenarios to varying sizes of the time window (Figure 9): with the reduction of deadlines there is a movement of deviations from the deadline for more positive values, signaling the greater difficulty in meeting the established limits. However, in Case 0, the scenarios do not differ significantly from each other and can only be noted that the S2 scenario presents more consistent results, as evidenced by the lower dispersion observed; only after reducing delays and increasing variation of speeds and modes of transport times in Case 1 does the divergence between the synchromodal and intermodal scenarios begin to show. This corroborates the conclusion reached in the previous section, whereby the theoretical advantages of Synchromodality, in comparison to Intermodality, will only show when the system is confronted with more extreme conditions. The evolution of the absolute and percentual deviations to the deadline for Case 1 is shown in Figures 10 and 11.

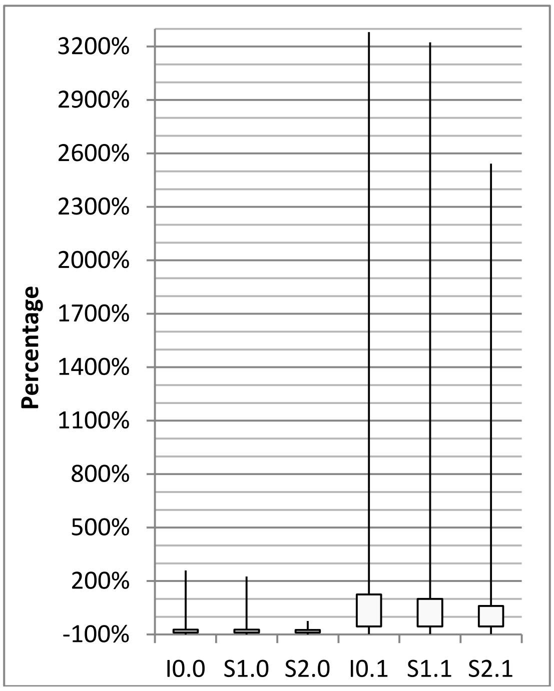

Figure 9 - Percentual deviation to the time window

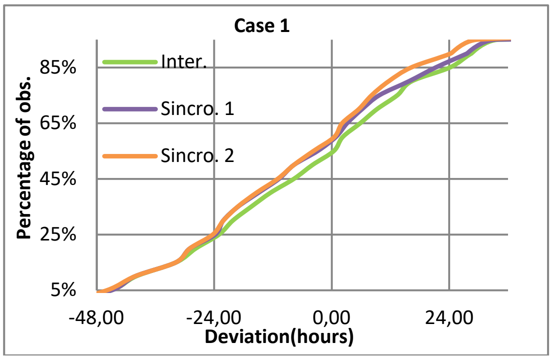

Figure 10 - Absolute deviation to the time window

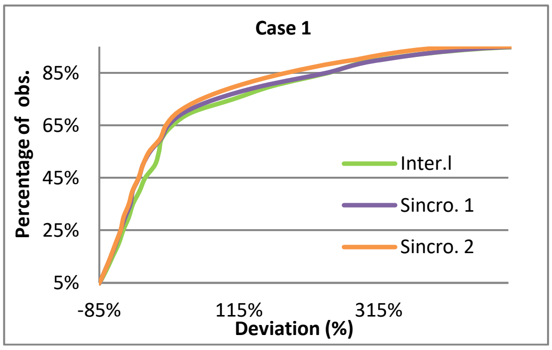

Figure 11 - Percentual deviation to the time window

5. Conclusions and Further Developments

5.1. Conclusions

The objective proposed for this work was to investigate the potential benefits of Synchromodality, as well as the limitations of these, by comparing its performance with the Intermodal solution. To achieve this objective, a methodology for assessing the success of freigth transport along a section of the Atlantic Corridor was developed, which confronts various types of logistics operator with different system operating conditions.

To this end, a simulation model was created, using both Discrete-Events and Agent-Based Modelling methods, which simulates the processes performed by each agent operating on the network, as well as the interactions between them, and the decision-making logic of the logistics operator when planning the transport, both reflecting the differences between each transportation concept.

A total of six model configurations were tested, simulating 3 possible logistic operator scenarios (one Intermodal, one Synchromodal, and a hybrid, with the ability to change modes, but no ability to monitor system conditions) and facing them with 2 possible cases of varying conditions in the system (one where the deadlines are flexible, and another where deadlines are more strict, and there is greater variability of transport times).

The results revealed that Synchromodality shows potential for an improved performance, since it was be able to produce a higher amount of deliveries during the simulation, as well as a larger percentage of deliveries within the forecasted transport time, and within deadline. In this aspect, the monitoring capacity seems to be what most differentiates the performance results of the Synchromodal and Intermodal solutions, by allowing the first to offer a more consistent and timely service.

However, the analysis of the deviations between the transport time's forecast and the transport time, as well as between the time window and the transport time, revealed that Synchromodality shows slight improvement only regarding the deadline. Importantly, these results show that although the Synchromodal solution has the potential to surpass Intermodality in terms of performance, its advantages are only revealed when the system is confronted with more adverse circumstances, as it was observed that the differences between each Operator became more pronounced when testing the situation of greater demand on the system.

5.2. Further Developments

Some future contributions to continue the work in analyzing the potential advantages of the Synchromodal transport solution could be:

- In order to enrich the model, the Operator could be provided with the ability to consolidate Orders, and to optimize this aggregation in order to save resources.
- Another variant is the possibility of the Operator, taking notice of the entry of new Orders in the system well in advance, being able to reschedule the services, in accordance with this information, and in order to optimize the use of resources.
- In addition, the model would become more realistic if the Operator would consider, in the Order priority assignment process, a set of criteria to assess, on the one hand, the frequency of services operating in the connection between the current position and destination, and, secondly, the distance between these two points. The addition of these criteria would allow the operator to affect to each order an urgency factor, not only based on the time window's flexibility, but also on the difficulty in fulfilling it.
- In a final consideration of the simplifications made during the development of the model, it would be extremely rewarding to provide the Synchromodal Operator with the ability to establish, at any given time, the location of each order circulating on the network, calculate the current speed of the vehicle transporting it, and thus predict time of arrival to the next terminal, thereby simulating the continuous monitoring of system conditions for which the concept is characterized.
- It would also be worthwhile to make the model more realistic by adding an agent to represent the client, providing each individual with its own set of characteristics and behaviors, and allowing them to make changes to the requirements of their orders. Some of these features could, for example, be a preference for certain modes of transport, the establishment of a maximum amount they're willing to pay for shipping, or a tolerance regarding delays in the deadline, or even the existence of a function to establish the relative importance of each of these factors to the individual and whether failure of any of these may be offset by an improvement in another.
- The existence of more or less flexible customers would give the Operator the opportunity to negotiate the transportation of their orders, allowing for the optimization of order consolidation.
- Finally, it would be interesting to take a different approach to the comparison of the performance of the Synchromodal and Intermodal solutions, by inserting both agents an environment in which they operate simultaneously in the same transport chain. By providing potential customers with a memory in which past experience with each of the Operators affect their "view" of the same, and hence their propensity to contact them in the future, it would be possible to observe the fluctuations in demand for each Operator and assess whether the theoretical advantages of Synchromodality are perceived by the customer as such, as well as the level of adherence to the Synchromodal solution in a context of competition.

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