TRANSPORT ITEMS AND PHYSICAL INTERNET HANDLING BOXES: A COMPARISON FRAMEWORK ACROSS SUPPLY CHAINS

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Abstract

Pallets, cardboard boxes, and plastic crates are widely used tools to operate supply chains. As such they have many impacts on handling effort, shipment protection, transport mean utilization as well as repositioning and recycling efforts and they represent billions of assets spread all over the world. The historical and local origins of the designs and the sharing among many stakeholders do not ensure at all any kind of global optimization. The purpose of this paper is to define and explain a research effort to better measure and evaluate the efficiencies and inefficiencies for supply chain stakeholders for themselves and globally. When validated the framework will be sued to evaluate new designs on a global scale especially for the design of the handling box related to the Physical Internet concept.

1 Introduction

Pallets and cardboard boxes for FMCG (Fast Moving Consumer Goods), plastic crates for vegetable or meat, plastic boxes in the automotive industry, individual cardboard boxes for express shipping are different examples of common logistics tools: transport items (TI) and returnable transport items (RTI). As such they have many impacts on handling effort, shipment protection, transport mean utilization as well as repositioning and recycling efforts. One may think that the best solution is used according to each specific need after a long historical selection process. This hypothesis is possibly valid in some cases. However the supply chain concept challenges local solutions as flows of many different origins are mixed together all the way down of supply chains.

With the just-in-time and e-commerce paradigms, goods are less and less shipped in big lots and ever more one by one. In less than two decades the median shipment size has diminished by a factor of 4.5 in France [1]. Shipment median weight diminished from 160 kg in 1988 to 30 kg in 2004. And at that time ecommerce shipping was marginal compared to its actual and growing market share. Massive convoy of raw materials represents less and less of the t.km (ton times kilometer). It implies many challenges and new stakes associated to packaging and returnable transport items, among them weight, heterogeneous load mixing, picking and repacking activity multiplicity, management, recycling or scraping. At the end, it may lead to several efficiency issues such as empty space, truck fill rate and waste [2,3].

As a response to the above mentioned supply chain trends, many other forms of collaboration have risen such as pooling and horizontal collaboration [4] and recently the Physical Internet [1,5]. These proposed logistics schemes have in common fading boundaries between previous dedicated supply chains activities, leading to more and more mixed shipments with an increasing importance of TI and RTI.

With the Physical Internet was introduced the concept of interconnection [6] of logistics services with three proposed types of encapsulation levels [7]. The transport container level deals mainly with transportation means interface and protects its content from the outside world. It conceptually extends the current cargo container (maritime containers and swap boxes). Replacing cases, totes and pallets, the handling container (box) level aims to improve filling rates through modularity and to increase handling productivity. The packaging container (pack) level deals with the product itself. Note that not all levels are always required. Two different prototypes of possible Physical Internet boxes are already available [8, 9]. They highlight several key features of Physical Internet handling boxes such as: modularity, block composition, etc.

The maritime 20ft and 40ft containers, the more used transport containers, seem "natural" nowadays, but the establishment of the solution we know took about a century [10] notwithstanding all advantages we see today. At the level of the TI and RTI or handling boxes, no solution was able to conquer the world so far. Even the well-known pallet comes in dozens of standardized sizes and grades! Please refer to ISO 6780 for details and Figure 1 as an example of the diversity of the pallets' sizes. Not to mention cardboard boxes which come in an almost infinite number of sizes and are sometimes very difficult to manage [11] even if there is also international standards about packaging, ISO 3394 and 3676.

Product Code	Product name	L x W x H (in millimetres)	Major Countries Available
B4840A	Timber Block Pallet North American Standard (48 x 40 inches)	1219 x 1016 x 141	USA, Italy, New Zealand
B1210A	Wooden Pallet	1200 x 1000 x 162	Most European countries, Latin America, United Kingdom, India, New Zealand
B0806A	Wooden & Metal Pallet	800 x 600 x 163	Most European countries, United Kingdom, South Africa
B1210M	Wooden Pallet - 3 Runner	1200 x 1200 x 154	India, China
160001	Wooden Pallet - New Zealand standard	1200 x 1000 x 140	New Zealand
B1210L	Perimeter Wooden Pallet	1200 x 1000 x 154	India, China
B4820A	Timber Half Pallet	1220 x 508 x 128	Canada
S1210A	Bearer Pallet	1200 x 1200 x 150	Namibia, South Africa
S1512A	Bearer Pallet	1500 x 1200 x 176	Namibia, South Africa
B1208A	Wooden Pallet	1200 x 800 x 144	Most European countries, United Kingdom, South Africa, India
S1165A	Wooden Pallet - Australian Standard	1165 x 1165 x 150	Australia, New Zealand
B1210C	Pallet Mercosur	1200 x 1000 x 145	USA, Argentina
B1060B	Wooden Pallet	1000 x 600 x 162	France
06040	Plastic Dolly	600 x 400 x 173	Austria, Switzerland
16517	Plastic Pallet - New Zealand standard	1219 x 1016 x 144	New Zealand
P0604A	Plastic Display Pallet	600 x 400 x 145	Most European countries
P1208B	Plastic Display Pallet	1200 x 800 x 160	Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, Portugal, Spain, Sweden, United Kingdom
P1210B	Plastic Pallet	1200 x 1000 x 160	Belgium, France, Germany, Ireland, Netherlands, Spain, United Kingdom
P1208A	Plastic Pallet	1200 x 800 x 160	Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, Portugal, Spain, Sweden, United Kingdom
P1210C	Blue Shield Plastic Pallet	1200 x 1000 x 150	China, Thailand, South Africa
P1210D	Plastic Pallet - 3 Runner	1200 x 1000 x 150	China
P1165A	Plastic Pallet	1165 x 1165 x 150	Australia
HHT06508	Automotive Pallet - US Standard	1166 x 1242 x 152	USA, Canada, Mexico

Figure 2: Excerpt of pallets sizes from Chep website
http://www.chep.com/pallets/pallet_sizes/

The challenge of establishing a new set of standard handling boxes is huge and beyond the scope of this contribution. But as a first step we propose a framework to measure the global performance of handling boxes vs. other solutions such as cardboard boxes loaded as bulk and handled individually on one side and cardboard boxes loaded on pallets on the other side.

1.1 Research questions

The proposed evaluation framework is global to overcome two main barriers usually faced by actors of the supply chain.

The first motivation is the lack of global assessment framework. At plant level the optimization often aims to minimize the cardboard boxes size around packaging for example. In the best case, the boxes will match the footprint of the most used pallet at that place but usually not of the other pallets with other sizes. At some point in the supply chain it implies the handling of all boxes to mix them with other boxes. The construction of a pallet with various sizes and the automation became an art. What is efficient in one part of a supply chain is then not necessarily efficient in another part.

The first question of this research is: what is the level of efficiency of RTI used in current supply chains?

As a consequence of local optimums, actors could be locked with their current practices because of a lack of collaboration mechanisms. For example a supplier will not invest in better boxes even if it avoids repacking all products for the retails if all benefits are for the retailer, etc. To move forward this way would imply a better knowledge of the whole supply chain and a collaboration mechanism between the supplier and the retailer. So where end-to-end supply chain value involving several players exists, sharing mechanisms should be implemented.

The second question of this research is: are collaboration mechanisms required to unlock investment in RTI and reach a new level of performance?

This paper focuses on performance measurement through a RTI lifecycle and claims for a global approach. It could be seen as an addition to the work done about modular boxes diversity and their fill rate [12] and work initiated in the Modulushca European project. It will not only assess the economic performance but also the environmental footprint left by all scenarios.

Nowadays most of supply chain environmental cost (accidents, global warming, air pollution, congestion, etc.) are almost exclusively external but can be assessed [13]. Accordingly the third research question is: what level of internalization for environmental costs unlocks new solutions?

1.2 Methodology

In the proposed framework of TI and RTI performances along the supply chains, we distinguish five different key characteristics that play at distinct supply chain stages:

- Investment: reflecting the cost per use either it is bought for a single usage (TI case) or rent by many during its lifecycle (RTI case).
- Space and payload utilization: according to the ability of a set of boxes to fill the available space, means will be used efficiently or not for a given amount of cargo. As a result more or less transport resources will be used.
- Product protection: result of the interaction of shipment, the box and handling.

As it is complex to assess, in this primer it is neglected, let for further research.

- Handling effort: the bundles built along the supply chain may impact significantly the handling effort. Here the notion of shipping unit is used as a proxy of the handling effort undertaken for each operation such as receiving and loading.
- Repositioning and disposal: three different cases can be distinguished here, single use (TI) with disposal at the end of usage, repositioning in a closed loop (the case of an automotive manufacturer where the RTI is shipped back to the supplier) and repositioning in an open loop (when RTI are pooled and proposed to the closest customer).

Figure 2: Excerpt of pallets sizes from Chep website

The proposed framework can be applied not only at the level of a participant of a supply chain but rather from "end-to-end" across a multi-echelon supply chain, as many inefficiencies remain at the interfaces as depicted in Figure 2.

2 The evaluation framework

The evaluation framework is based on a set of functions designed to evaluate each task undertaken by supply chains.

Basically two types of functions are identified at facilities (nodes of the supply chain) and between facilities (links of the supply chain). Two additional operations must be considered to represents the life cycle of an RTI: introduction (manufacturing) and removal (disposal or recycling).

At nodes level of the supply chain a focus is made on the handling effort required at each stage: unloading of a transportation mean, stock entry and exit, sorting, composing and decomposing of the unit load and loading of a transportation mean. If operations are automated, this information is included in the handling cost model. Fill rate of racks are also taken into account.

At link level of the supply chain (transportation) the main component is the fill rate. This fill rate is expressed in weight and in volume. The fill rate is defined as the amount of payload used for cargo (products) compared to the raw capacity of the transportation mean. This evaluation implies to solve knapsack problems [14] or the usage of a loading sheet, notably when parcels are loaded as bulk in a truck.

Supply chain operations are performed within different types of organizations when RTI are used more than once:

- Closed loop: this organization implies that RTI are shipped back to the origin point. This type of organization is usually found between a supplier and a manufacturer. Parts are packed in a specific RTI shipped and the empty RTI is shipped back to the supplier. This organization is the simplest but comes with a low efficiency.
- Semi-open loop or pooled: in this organization RTI are pooled among a set of customers by a service provider. The provider takes advantage of its economies of scale to ship a free RTI to the nearest demand point within its customers.
- Open loop or interconnected: in this organization RTI are available for all requests. This organization minimizes the repositioning effort but makes tracking much more challenging and loss rates are usually much higher than in the two previous cases.

The performance indicators are of two types:

- Physical performance indicators: weight, fill rate, number of box moved, etc.
- Cost indicators: they are based on physical performance indicators and they can vary according to the time, the technology and the country.

The framework and the performance indicator are shown in the next two Figures 4 and 5. They must be read as one figure too large to fill a single page as represented by Figure 3.

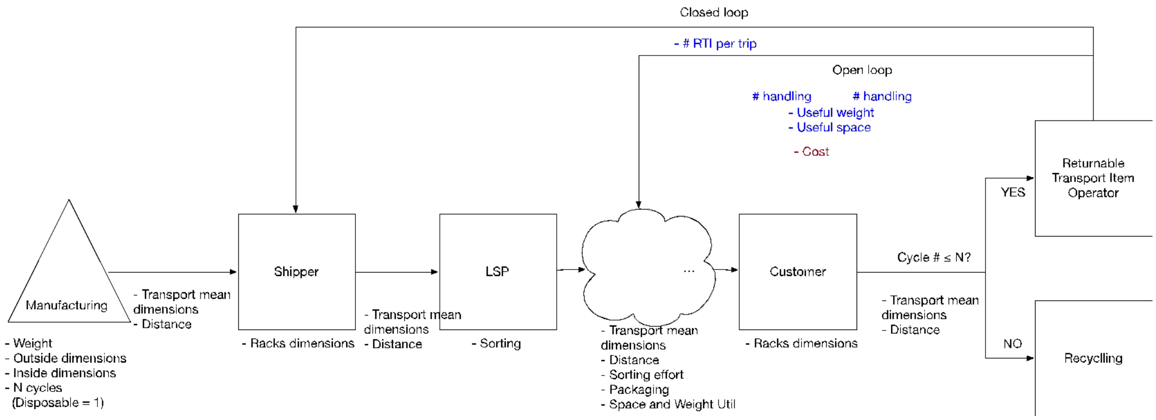

Figure 3: Evaluation framework - global view

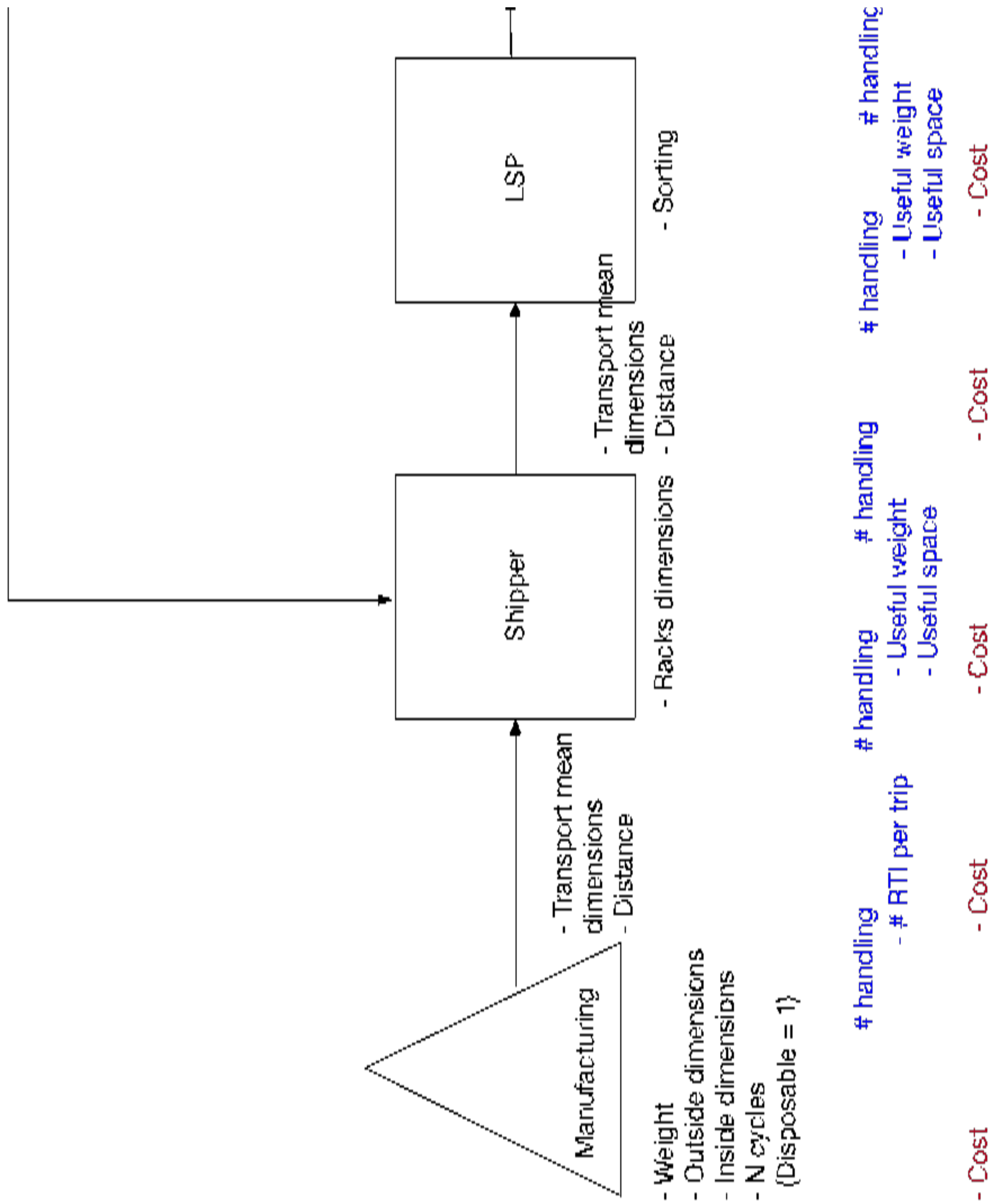

Figure 4: Evaluation framework part 1

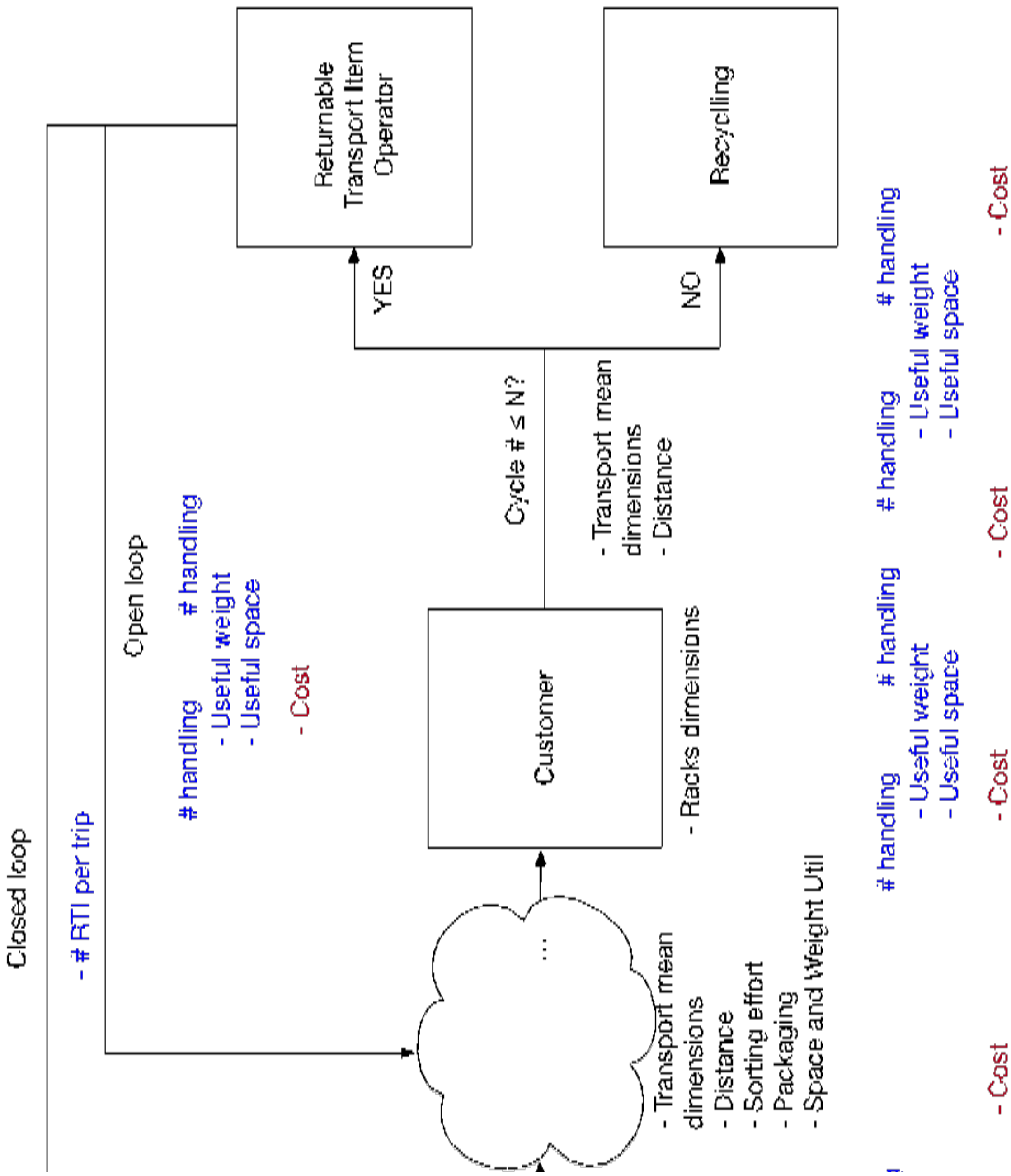

Figure 5: Evaluation framework part 2

The framework is implemented in *Mathematica*® where all kind of optimization tools and graphics are available as well as animation to perform cost sensitivity analysis for example.

One the framework implemented it will enable computations of cost sharing between players of a given supply chain. Cost sharing mechanism are required when the cost benefit analysis at the level of a single player is not enough to pay for an improvement while a gain exists in another part of the supply chain. This problem could be solved in many ways. Among them negotiation between the parties (easier when few parties are involved) is a practical approach, but cooperative game theory could also help to deal with more complex problems. In theses cases cost sharing will be based on Shapley value and extension of the concept as required according to the nature of each game.

Implementation of external costs (environmental footprint) is a direct implementation of external cost as defined by Delft report in 2011 and updated in 2014 [13]. They are for transportation but other costs could be included if available and necessary.

3 Data samples and partial results

Two cases will be used to illustrate possible uses of the framework. The first one compares classical cardboard boxes with or without pallets to a modular handling box of the same size on a single trip. The second one compares a cardboard and plastic box solution to a single modular box in a two echelons supply chain.

3.1 First use case: a single trip comparison

In this first case we compare a single trip with a maritime container at first and a road segment to follow with handling in between. The performance of load units is compared on a single size 0.6x0.4x0.4meter. This size is one size of the MODULUSHCA prototypes and a normalized dimension of cardboard boxes. On each transport segment several scenarios are possible, see table 1 for cardboard boxes and table 2 for handling boxes.

In both cases the container is filled without pallets, while pallets are used in the truck trailer. Table 1, second column, shows the number of manipulations required to move the cargo. For example, the 40’ container is loaded at its maximum capacity with 500 boxes. When boxes are on pallets in the trailer, the 924 boxes must be loaded first on 33 pallets and the 33 pallets are then moved. The third column indicates the maximum volume left inside all boxes and the fourth one indicates the weight left to comply with regulations. The volume ratio diminishes quite significantly when boxes are bigger and dimensions do not really fit with transportation mean dimensions or when pallets are used.

Table 1: Fill rates for cardboard boxes and pallets in two transportation means

Case studied	Handling moves Pal./Layer/Box	Useful volume left	Useful weight left
Boxes 0.6x0.4x0.4m in a 40' container	500	59%	86%
Boxes 0.3x0.4x0.3m in a 40'	1470	64%	85%
Boxes 0.6x0.4x0.4m on pallets in a 40'	25/400	48%	85%
Boxes 0.6x0.4x0.4m on 3 pallets (1+2) in a 40'	25/75/320	38%	82%
Boxes 0.6x0.4x0.4m on pallets in a trailer	33/924	72%	93%
Boxes 0.6x0.4x0.4m on (1+1) pallets in a trailer	33/66/924	72%	90%
Boxes 0.6x0.4x0.4m on (1+2) pallets in a trailer	33/99/792	62%	84%

The handling boxes results are based on respectively 15mm floor thickness; 10mm side and top envelop thickness and 3kg weight per box. The plastic handling box prototype is significantly heavier than its cardboard counterpart and could be improved. However the comparison of table 1 and 2 shows that both solutions are almost equivalent when floor pallets are used in a container or when a pallet and a layer pallet are used in a trailer.

Table 2: Fill rates for handling boxes in two transportation means

Case studied	Handling moves Block/Box	Useful volume left	Useful weight left
Hand. boxes 0.6x0.4x0.4m in a 40' container	8/500	54%	83%
Handling boxes 0.6x0.4x0.4m in a trailer	11/924	65%	89%

Capacity usage, volume and weight, are just two performance indicators. The handling effort to load boxes or pallet on transportation means and sort boxes between transportation means add cost. Figure 5 shows that from a total cost point of view it is less expensive to use modular boxes compared to the actual cardboard pallet combination. This example is based on several cost assumptions that could be changed to illustrate various situations according to cost fluctuations.

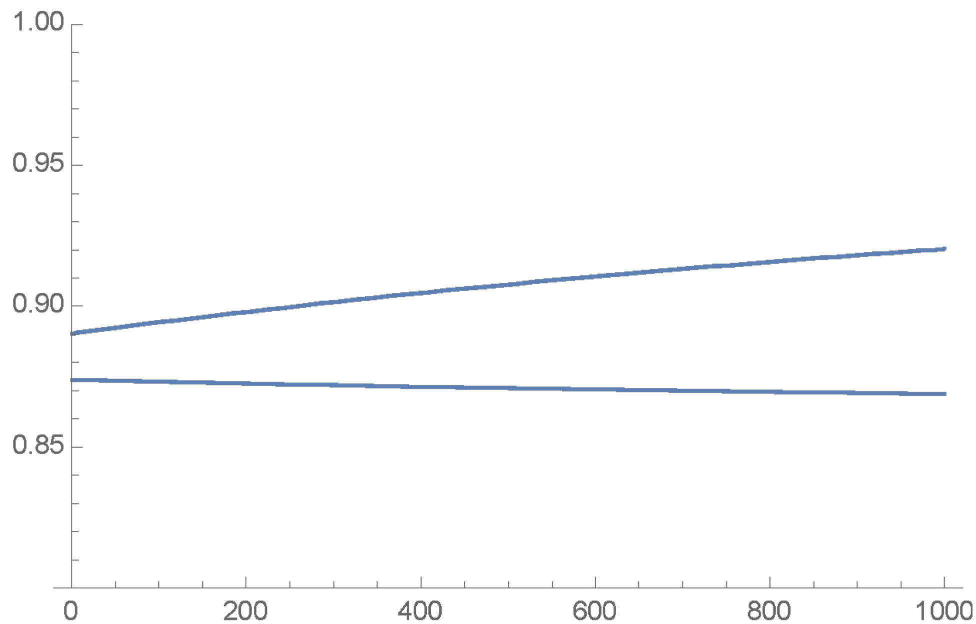

Figure 6: Handling box/cardboard box cost ratio according to travelled distance by truck in km. (Upper curve one pallet in the trailer, lower curve one floor pallet + 2 layer pallets)

In this particular case with pallet and handling boxes equivalent handling and sorting costs, Figure 6 points out a better cost for handling boxes thanks to less handling costs when cardboard boxes and transshipped one by one to pallets while blocks are recomposed to match with the dimensions of the trailer. In the case of layer pallets savings are better with handling boxed thanks to a better space utilization.

3.2 Second use case: impact of plastic boxes between a retailer and shops

In this second case we compare a set of cardboard boxes of different sizes toward shops. Again, and without generalizing, load units are compared to a single size 0.6x0.4x0.24meter. This size is one footprint of the MODULUSHCA prototypes with a lower height. We focus here only on two main points while others are also of interest. The height of shipping units (pallets and cardboard boxes on hand and dolly and plastic boxes on the other hand) and the productivity to fill shelves in store are compared.

When shipped a store, cardboard boxes of different sizes are staked to form a heterogeneous pallet. The pallet height is very limited because of stability issues. The following picture illustrates the case.

Figure 7: Pallets delivered to a store

In this particular case, useful weight is clearly not an issue. We have light products with a limited height available and a lot of empty space. The actual volume and weight fill rate are even lower. Table 3 shows typical numbers.

Table 3: Fill rates of cardboard boxes and pallet vs. modular units and dolly in a trailer

Case studied	Handling moves Pal./Layer/Box	Useful volume left	Useful weight left
Boxes of various size on pallets in a trailer	33/300	23%	95%
Boxes 0.6x0.4x0.4m on dolly in a trailer	33/400	48%	90%

We it comes to store productivity, it is not possible to share actual cost but the benefit are obvious. The in store handling cost is almost divided by two half compared to cardboard in picking productivity as all products are already sorted according to shelves localization and not stability constraints. But there are also other costs in favor or against of plastic boxes more difficult to assess: ergonomics, repositioning vs. recycling etc.

An Excel spreadsheet was developed to collect all costs when known. Buy

4 Conclusion and further work

The aim of the paper is to propose an evaluation framework to study industrial scenarios helping industry at large to identify the gains and the barriers against a more global approach. The framework was also used to compare handling box performance versus classical operations in a classical scenario.

The contribution of this framework is not in a new operation research method but rather a platform to gain insights from actual operations and use this knowledge to improve supply chain performances and help to design a new generation of RTI.

In this paper we have shown only partial answers to the first research question: what is the level of efficiency of RTI used in current supply chains? The answer will be more and more substantial as we will gather data from industrial partners. In a further work, to compare performances with a limited bias, an optimization procedure could take place to optimize boxes dimensions within the current framework.

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