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Ex ante sustainability improvement assessment of city logistics solutions: learning from a simple interlinked pooling case

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Abstract: Improving the sustainability of city logistics involves the design and implementation of solutions that lead to improvements from social, environmental and economic perspectives. In this paper we focus on the ex ante sustainability assessment of city logistics solutions. For demonstration purposes, we rely on a simple fictitious city and investigate the implementation of alternative logistics pooling solutions. Using sustainability key performance indices, we contrast a centralized pooling solution relying on a single Urban Consolidation Center (UCC) with an interlinked pooling solution rather relying on a network of distributed UCCs. Key learnings are (1) the importance of rigorous ex ante sustainability assessment of proposed city logistics solutions, as the assessment investigated solutions revealed counterintuitive results, and (2) the importance of designing city logistics solution using an open interconnected systemic approach rather than a piecemeal approach, as a fundamental root cause of the results with the proposed alternative solutions was revealed by contrasting the foundations of their design to those inherent interconnected city logistics as prescribed according to the Physical Internet concept. This work is the beginning of a core project aiming to enable and to investigate the ex ante assessment of city logistics solutions for actual cities.

Keywords: *City logistics, Pooling, Urban Consolidation Centers, Sustainability evaluation, Interlinked pooling, Interconnected logistics, Physical Internet.*

1 Introduction

City logistics is the last link of complex supply chains that involve numerous stakeholders such as carriers, inhabitants and the public administration. It is a small part of the total distance traveled by products across supply chains, nevertheless it can represent up to 28% of the total transport cost (Roca-Riu and Estrada, 2012). Moreover, urban freight transport is estimated to induce between 16% and 50% of the overall air pollution made by transport activities in a city (Albergel et al., 2006). These numbers emphasize the importance of addressing urban freight transport in the management and planning of the city (COST 321, 1998). Furthermore, designing

an efficient urban transportation system facilitates small businesses, shops and boutiques, therefore improving the livelihood and livability of cities (Taniguchi et al., 2013).

Unfortunately, most public decision-makers are not knowledgeable enough about city logistics to tackle the adaptation of local public policies so as to better face these hurdles (Dablanc, 2007). They may ignore urban freight transportation issues to concentrate their effort on issues they perceive as having more direct repercussions on the life of inhabitants, such as public people mobility.

Furthermore, city logistics solutions are based on two principles, transportation multimodality and resource pooling, either independently or concurrently (Allen et al., 2007; Boudouin, 2006). In the context of a specific city, such solutions are currently usually established without any sort of scientific study. Generally, the conclusions are relying on a try-and-see method whose results are only known ex post. That makes it difficult to collect rational behavior to provide sustainable models for city and town planners to install innovative collaborative systems for urban freight transportation.

This highlights the need to help public decision-makers and city logistics solutions designers improve their knowledge and their potentiality assessment so they contribute better to the quest toward providing sustainable city logistics solutions notably relieving city freight induced traffic congestion and reducing the negative environmental impact of urban freight transport.

In this paper, in line with the recommendations of Taniguchi et al. (2003) and Russo and Comi, (2011), we contribute to addressing this need by demonstrating the potential offered by enabling model-based ex ante assessment of proposed city logistics solutions using a decision support system. Such a system aims to provide pertinent information beforehand when designing a city logistics project where stakeholders must think about "What will happen to the city and its inhabitants if we make this choice?".

We focus on resource pooling centric solutions in order to demonstrate that using a rigorous and pragmatic "What if" model-based decision support system can help decision-makers assess the potential impact of proposed city logistics solutions. The pooling solutions addressed here are simple to conceptualize, being based on the implementation and exploitation of Urban Consolidation Centers (UCC), the most popular type of pooling solution in European cities to deal with city logistics issues (Chwesiuk et al., 2010). Other solutions like vehicle sharing have been studied by authors such as Thompson and Hassall (2012).

Using a simplified case study, we contrast the current situation first with a pooling solution exploiting a single UCC and then with a more elaborate interlinked pooling solution based on a network of distributed UCCs. We demonstrate that, even for such a simple case, assessing the relative sustainability impact of alternative solutions is not a trivial undertaking, yet does reveal intricate non-intuitive results. This emphasizes the critical importance of rigorous ex ante model based assessment capability, especially as the proposed solutions are to become more sophisticated in the future, such as those resulting from applying the Physical Internet concepts to enable smart interconnected city logistics (Montreuil, 2013). It also reveals the importance of tackling city logistics with an open interconnected systemic approach instead of relying on a piecemeal approach.

The paper is organized as follows. Section 2 introduces the simple fictitious city used in this paper. Then section 3 provides sustainability assessment of alternative centralized and

interlinked pooling solutions to city logistics. These are positioned relative to Physical Internet enables interconnected city logistics in section 4. Finally section 4 provides conclusive remarks and opportunities for further research.

2 A simple fictitious city

In order to get to the essence of our purpose without getting stuck with a specific city's peculiarities and details, we have selected to use a simplified fictitious city case, yet exhibiting basic characteristics of several cities around the world. We have studied several such cities, as Moscow and Paris depicted in **Erreur ! Source du renvoi introuvable.**.

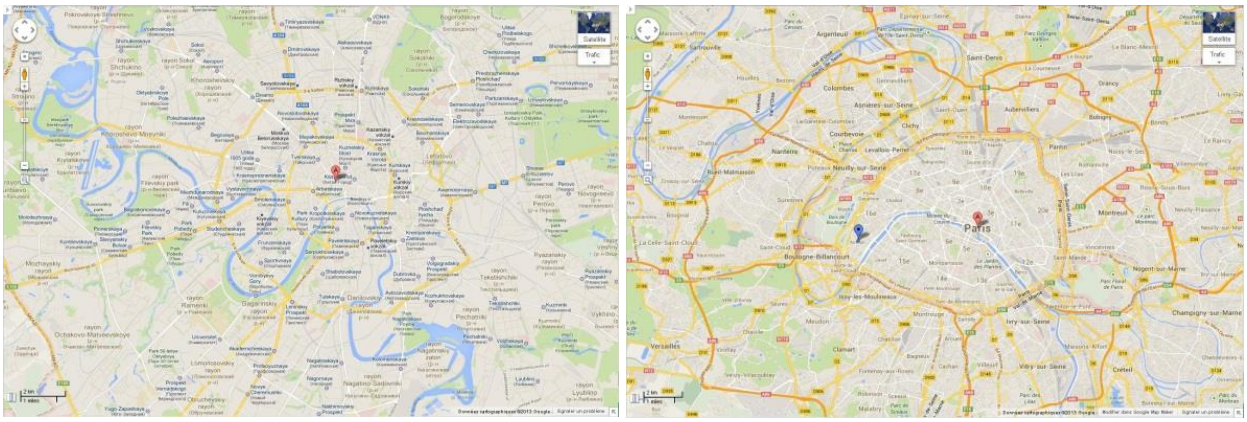

Figure 1: Cities of Moscow (left) and Paris (right)

We have built the simple city depicted in Figure 2 around four key characteristics, with no pretention that they are ubiquitous amongst world cities:

- An ellipse shaped city;
- With a river flowing through it, with a limited number of bridges;
- With multiple inbound/outbound roads across its periphery;
- With demand locations (pickup/delivery points such as retail stores, factories and homes) distributed through its area, yet with local concentrations.

Figure 2 purposefully does not portray specific roads through the city, as we used well known approximations for travel distance and time between locations (Gallez, 2000), taking into consideration that crossing of the river has to be done through one of the bridges.

We have then selected to take a snapshot of the logistics demand at a given time and to concentrate the case on how the set of specific demands was to be treated in a situation with no explicit city logistics solution put in place, and then with specific ones put in place.

In real life, at any given time, there is a stochastic mix of inbound flow of shipments needing to be delivered to city destinations, outbound flow of shipments needing to be picked up in city locations and gotten out to various out-of-city destinations, and an internal flow of intra-city shipments. We could have built a case with these three types of flow, yet it would have been hard to grasp visually. So we have opted to limit the case to deal only with inbound flows at the snapshot time. Readers can readily make up more complex variants for specific purposes.

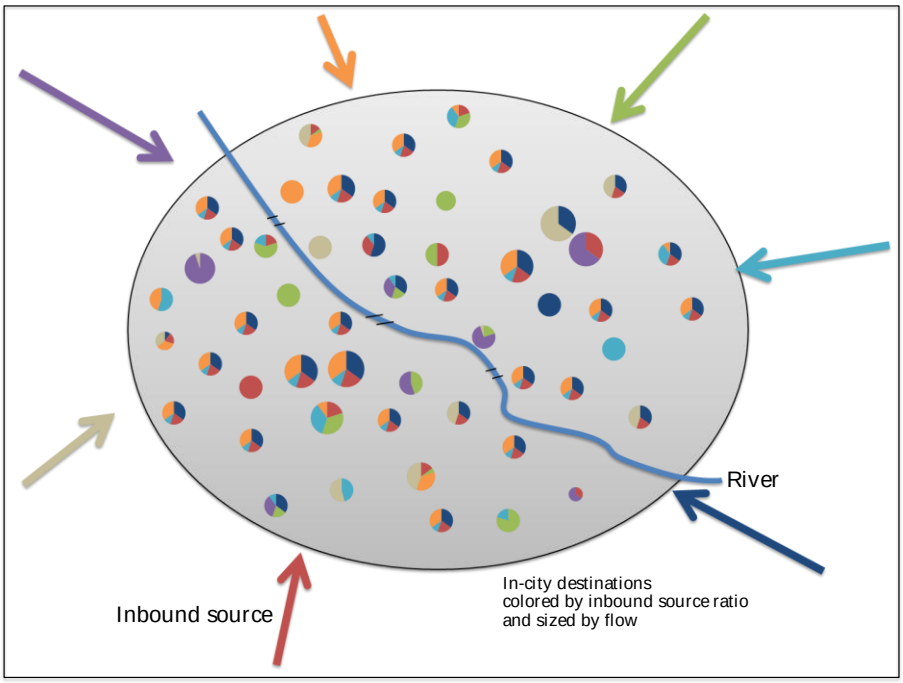

Figure 2: Illustrative simple city with punctual sources and destinations

At snapshot time, the case depicted in Figure 3 has seven out-of-city sources, represented by a specific color, from which shipments are to be delivered to client locations in the city. A total of 52 city destinations are to receive the goods delivered by the shipments. Destinations vary both in terms of the amount of goods they are to receive from which source, and the amount they are globally going to receive. This why, we have represented each destination as a pie chart of a specific size with a specific number of slices, each having a specific relative size. The inbound flows are represented as arrows, each pointing toward a specific entry point along the city circumference.

As a further simplification, we have constructed the specific demands so that the overall demand to be fulfilled from each out-of-city source fits in one carrier sent from the source toward the city, by default to enter the city through the entry point where its representative arrow is pointing. We have assumed that the city-inbound carriers are using city adapted trucks which have $40m^3$ of cargo space. One of these trucks contains ordinary 16 parcels whereas a semi contains 34 parcels in $94m^3$. In the following sections, the terms truck for $40m^3$ and semi for $94m^3$ will be utilized. In the aim of optimizing deliveries, we also mention vans which are utility vehicles with a $20m^3$ normally containing 8 parcels. Routing of vehicles takes into account their loading capacity. We assume that one delivery point receives its freight from one carrier in one time. Each delivery route is constructed by considering two parameters: the logic of delivery order and the quantity of freight that has to be delivered at different points. It is not possible to split a delivery in several routes.

We will subsequently define the alternative city logistics solutions through the way the overall set of shipments is to be dealt with to get each ordered good to its appropriate city destination.

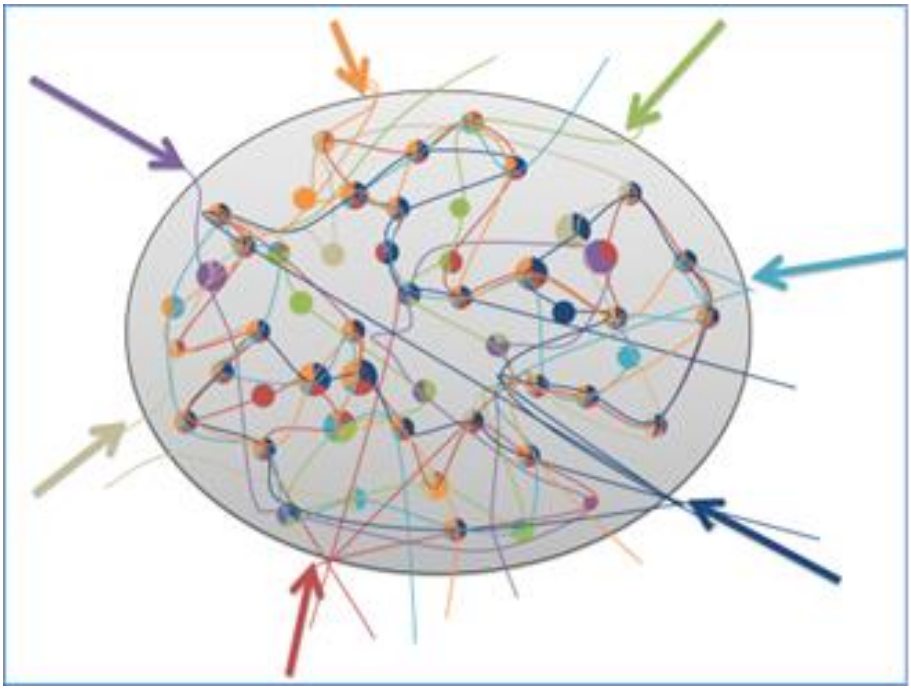

Figure 3: Current fragmented multi-source, multi-destination, multi-party city logistics base case

3 Assessing city logistics configurations

3.1 City logistics Key Performance Indicators

Three key performance indicators (KPIs) were selected to evaluate city logistics actions. The aim is to evaluate the impacts of one or more city logistics actions on a traditional city network. A lot of publications suggest indicators for transport and city logistics. We decide to choose among these indicators to quantify the performance based on obtaining a sustainable assessment of solutions. Evidently, the comparison between different solutions is just an initial step in the general evaluation process. The endgame of our approach is to encourage public decisions-makers to choose the best scenario for their city by knowing the differing impacts of their choices. Nowadays, sustainability is crucial because it reflects the long terms needs of society. The following indicators are basic and often used by others.

The first is the total travelled distance. This indicator is frequent in city logistics studies (Patier and Browne, 2010; Henriot et al., 2008; Ballot et al., 2012; Van Rooijen and Quak, 2010; De Assis Correia et al., 2012). Actually, distance can be perceived as a surrogate of cost for carriers. Distance is taken into account when calculating total transport cost. In addition, it can also be interpreted as a social indicator of working conditions for drivers. This KPI is measured by simply adding travelled distances by each vehicle.

The second KPI is the total travelled time. Certainly, time can be turned into costs, but it is also a sign of customer service quality either for the receiver or sender (Patier and Browne, 2010; Henriot et al., 2008; Ballot et al., 2012; De Assis Correia et al., 2012; Roca-Riu and Estrada, 2012). The total travelled time is an essential factor for timely delivery. This indicator is obtained by adding delivery times (driven and loading/unloading times) of each vehicle. For

senders, the delivery period is a criterion of choice. Users often purchase a service like "24h delivery". Thus it is important for transport companies to optimize delivery time. From the perspective of the last mile, the most beneficial organization is to deliver a maximum of stops per delivery rounds in a minimum time. Most often, senders (companies or private individuals) are looking for the best compromise between cost and time.

Finally, as in (Patier and Browne, 2010; Henriot et al., 2008; Ballot et al., 2012), the last chosen KPI is environmental, specifically the quantity of CO_2 emissions, which is the primary source of greenhouse gases (Albergel et al., 2006).

These three KPIs enable us to evaluate city logistics solutions under the scope of sustainability: social, economic and environmental.

3.2 Assessing the current situation

In order to provide a baseline for comparison, the KPIs must be assessed for the initial situation. To do so, routes have to be determined for each city-inbound carrier to deliver to their specific destinations in the city all the goods it carries.

Due to the relatively small size of the case and to the desire to reflect practical contexts, our approach to routing has been to assign the routing tasks to a knowledgeable engineer that had to interactively develop the routes, checking the satisfaction of capacity constraints while aiming to get routes with good KPIs. In further studies using larger data sets and more dynamic context, this simple approach would have to be replaced by the usage of vehicle routing exact or heuristic optimization techniques (e.g. Cordeau et al., 2007; Crainic et al., 2012; Taniguchi et al., 2012; Toth and Vigo, 2002).

The routing for the current baseline depicted in Figure 3 has achieved the KPI values reported in Table 1. Delivery the sampled inbound shipments has required a total travelled distance of 347 km, a total travel time of 29,9 h and 334 kg of CO_2 emissions. These values will be the basis of comparison to evaluate the opportunities offered by logistics pooling presented in the next section.

Table 1: Current situation assessment results

	Current situation
Total travelled distance	347 km
Total travelled time	29,9 h
Total CO_2 emissions	334 kg

3.3 Centralized pooling

In city logistics, the most popular type of pooling solution is the Urban Consolidation Center (UCC) (Browne et al., 2005; Chwesiuk et al., 2010). The overall logic is to have inbound and outbound city flows to be concentrated in UCCs, allowing efficient pooling when creating routes for pickup and delivery within the city. Most applications rely on a single UCC, what we here characterize as centralized pooling.

The use of UCC is claimed to have significant advantages, such as reduced noise, pollution, CO_2 emissions and congestion (Browne et al., 2011; Chwesiuk et al., 2010; Malhéné et al., 2012), especially due to the driving force of consolidation (Verlinde et al., 2012).

Nevertheless, these kinds of actions have also been demonstrated to have failed in many experiments (Courivault, 2004; Van Rooijen and Quak, 2010). Apparently, researchers have postulated to say that it is caused by the economical involvement: UCC implies flow disruption and increased synchronization costs; and as implemented there is little way to anticipate (Browne et al., 2011), which can produce secondary and harmful effects. More accurate forecasting may help resolve some major issues of UCC.

With its mix of pros and cons, single-UCC implementation has been selected for study in our conceptual city as it represents the most common example of UCC-based pooling. This provides an opportunity to quantify gains through the chosen KPIs, and then to compare with the current baseline. In our study case, an Urban Consolidation Center was implemented in the south of our simplified city, as shown in Figure 4.

The same method as in section 3.2 has been used to generate possible delivery routes. From a visual examination of Figure 4, some relevant observations can be made before calculating KPIs values. First, some carriers have to make a detour to deliver their freight to the UCC. On one hand it implies a higher distance to travel. On the other hand, the average speed in the periphery of the city is higher than inside the city. Second, visually it is obvious that flows are less jumbled than in the initial situation. Third, a total of 10 trucks enter the city vs. 12 in the initial system.

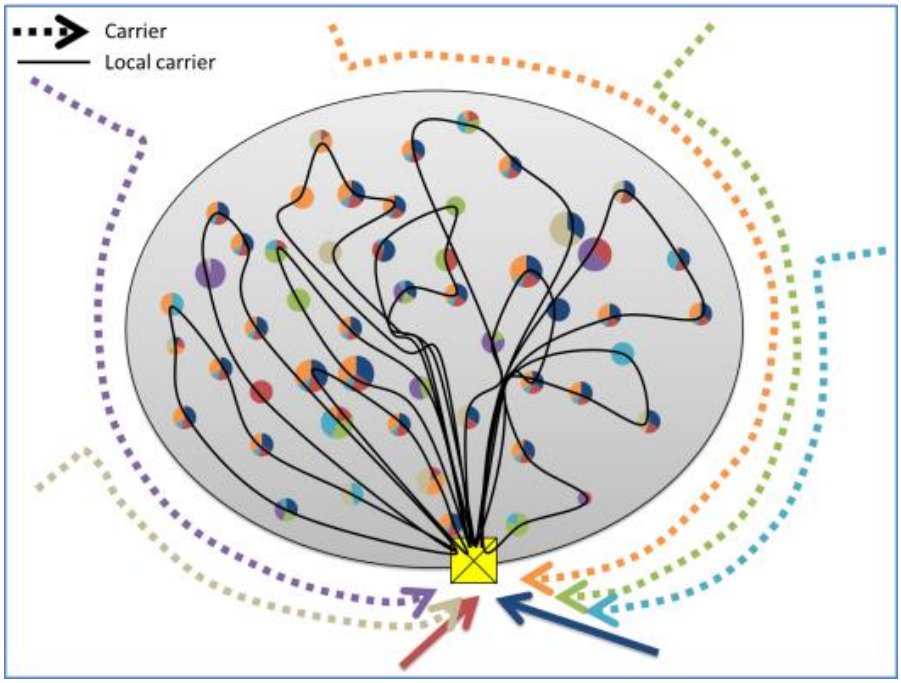

Figure 4: Centralized single-UCC pooling exploited in a simple city

Table 2: Centralized pooling assessment results

	Current baseline	Centralized pooling: KPI values	Centralized pooling: Difference with baseline
Total travelled distance	347 km	231 km	-33%
Total travelled time	29,9 h	14,5 h	-52%
Total CO_2 emissions	334 kg	226 kg	-32%

Table 2 provides the resulting value for each KPI. The first KPI studied is total distance. Even when carriers detour along the city periphery, a reduction of 33% of total travelled kilometers is observed. This is due to the fact that exploiting a UCC allows to construct pools of delivery points very close to each other, leading to efficient delivery routes. The detour make by each carrier is lower than the gain obtained by the pooling. So, the total distance is shorter. The total time is logically lower (-52%) because of the total distance but also because a part of this travel is made faster around the city periphery. Finally, the CO_2 emissions are lower (-32%) because we use less trucks with less travelled distance than in the initial solution. Note that here what is important is not the specific set of resulting KPI values, but the fact that for a known situation, the potential effect of one UCC has been quantified. It is necessary to remember the trend rather the values.

3.4 Interlinked pooling

With centralized pooling, using the single-UCC solution, most carriers have to make a detour to access the UCC. Nevertheless, there seems to be an improvement in efficiency than a situation without this kind of layout. This leads to two queries: How is it possible to avoid these detours? Will the result be even better if this is solved?

An intuitive idea is to shift from centralized pooling to interlinked pooling, multiplying the number of UCCs around the city in such a way that each inbound/outbound vehicle can drop off the freight on their round without an excessive detour. This is a well known approach theorized for city logistics, with a single-tier peripheral-UCC network or a two-tier UCC network for larger cities (Crainic and Sgalambro, 2014).

The interlinked pooling solution proposed for the city case study relies on the implementation of a single-tier network of three peripheral UCCs. This choice is based on the fact that they would represent the beginning of a network of interlinked UCCs shaping a regular layout around our elliptical city. As shown in Figure 5, the location of each UCC has been determined in order to reduce the travelled distance for each carrier when they drop off their freight.

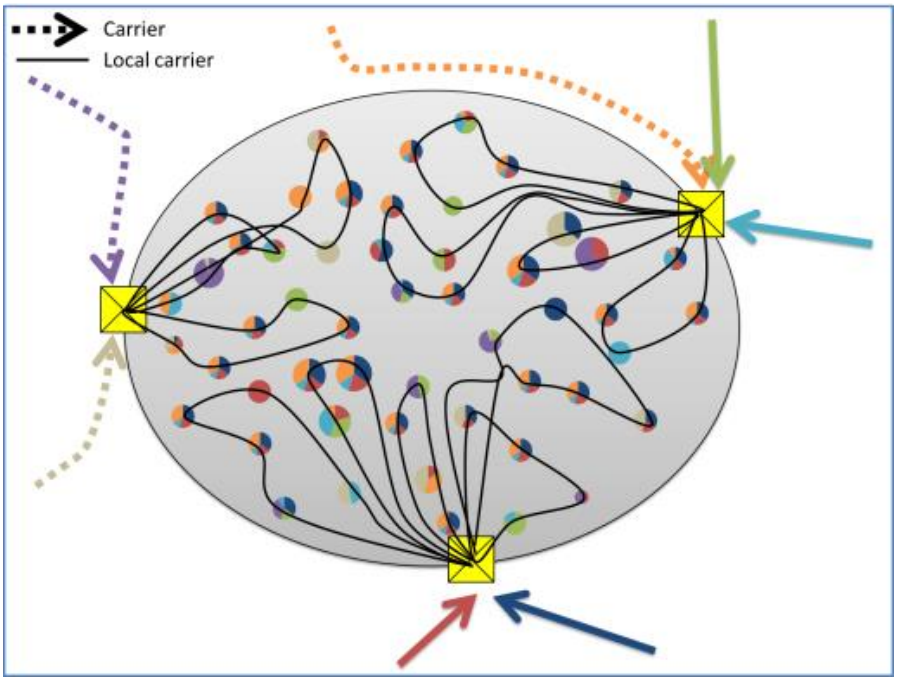

Figure 5: Interlinked three-UCC pooling in a simple city

Even though it graphically looks simple, the operation of such an interlinked solution needs to be explained further. In Figure 5, the red and dark-blue carriers both arrive at the south UCC. The freight from both carriers is split in three packs. The former have a destination that is nearest to the South UCC and will be routed through this UCC. The other two packs correspond to freight whose destination is respectively nearest to West UCC and the Northeast UCC. These packs are consolidated and shipped to their appropriate UCC. Routes are planned from each UCC, launched as soon as their associated freight is available at the UCC.

The KPI results obtained in this case for the proposed second solution are reported in Table 3. First, in general, the situation is better than the current baseline. The improvement is between 32% and 36% for each KPI. This is due to the pooling effect and a reduction of trips by drivers and vehicles. Pooling establishes rounds where each delivery point is close to others along the route. Finally the total distance is shorter, and the total travel time and CO_2 emissions are also reduced.

Second, it is interesting to compare this interlinked three-UCC pooling solution to the centralized pooling solution. The total travelled distance is essentially the same, yet achieved with a different repartition between inbound carriers and local carriers. Inbound carriers gain significantly in efficiency from a reduction of 63% on the total travelled distance. Yet the local carriers suffer an efficiency loss from an increase of 38% of their total travelled distance. Figure 5 shows the local routes to be shorter yet more numerous. The increase in local travelled distance is associated with the inter-UCC transfers explained earlier.

Total travelled time is also worse with 3-UCC than with 1-UCC because it implies additional disruptions with loading and unloading moments. Yet it is still significantly better than the solution without UCCs due to the lower distance and the pooling that delivers only once at each destination.

Finally, the CO_2 emissions are the same in both cases. This is caused by the detour made to dispatch the freight between UCCs as explained above. Trucks using the periphery, driving faster and emitting more, yet the lower distance travelled by carriers neutralizes this negative effect.

Table 3 Interlinked pooling assessment results

	Current baseline: KPI values	**Centralized pooling: KPI values**	**Centralized pooling: Difference with baseline**	**Interlinked pooling: KPI values**	**Interlinked pooling: Difference with baseline**
Total travelled distance	347 km	231 km	-33%	233km	-33%
Total travelled time	29,9h	14,5h	-52%	19,1h	-36%
Total CO_2 emissions	334kg	226kg	-32%	225kg	-32%

In this case, the interlinked pooling solution is more advantageous than the current baseline in the studied city but is less efficient time wise and less environmentally sustainable than a centralized pooling solution. Notably explainable by the introduction of extraneous inter-UCC transfers, these results are quite counterintuitive.

This should not be understood as a generic conclusion, but rather applicable to this single case study. Subsequent studies will be needed to assess whether the phenomenon would appear in numerous real cities. Yet the mere existence of a case where centralized pooling dominates interlinked pooling for city logistics is evidence that a more systemic approach is needed to insure improved efficiency and sustainability.

3.5 Towards Physical Internet enabled interconnected pooling

The Physical Internet initiative proposes an evolution of current logistics towards interconnected logistics (Montreuil, 2011), and more specifically from current city logistics towards interconnected city logistics.

The concept of Physical Internet (PI) uses the Digital Internet metaphor to change the art and the way to move, store, produce, supply and purchase physical objects. The objective is to enable order-of-magnitude improvements in logistics efficiency and sustainability.

PI can be defined as an open global logistics system founded on physical, digital and operational interconnectivity through standardized encapsulation, interfaces and protocols (Montreuil et al. 2013). PI couples multiple characteristics such as an open market for goods transportation, handling only world standard modular designed-for-logistics containers, open and shared transportation and distribution networks and facilities, vast community of users, supplier certification and ratings-by-users to drive logistics performance, as well as continuous tracking

and monitoring. A key aim of PI is to create a global interconnected network of logistics networks, a Logistics Web, where freight can be transported and stored in appropriately size modular containers through open facilities (e.g. hubs and warehouses). Indeed the Physical Internet can be seen as version 2.0 of worldwide logistics.

Recent studies have notably revealed a potential for over 30% reduction of induced costs and up to 60% reduction in greenhouse gas emission, with similar or better customer satisfaction (Ballot et al. 2012, Meller et al. 2012, Sarraj et al. 2014).

Open pooling is a component of the Physical Internet. Therefore the urban consolidation centers (UCCs) on which focuses this paper are in line with the interconnected logistics vision. Indeed, the Physical Internet would exploit all existing logistics facilities and transportation means adapted to interconnected logistics so as to enable open pooling of transportation, transshipment and storage means, and it would include new generations of PI-enabled logistics facilities.

Yet in a Physical Internet vision of city logistics, there would be much more than the simple act of pooling. Everything would be aligned towards efficient seamless interconnectivity: moving goods in smart modular PI-containers; crossdocking them through efficient, often multimodal, PI-hubs equipped with smart PI-container handling and storage technologies; transporting the PI-containers in green city-adapted transportation means across a city logistics backbone network entirely designed for easing interconnected logistics.

In an ultimate PI-context for our simple city, there would have been open pooling of inbound carrier loads well before their arrival to the city; the transfer time and cost of PI-container encapsulated goods at UCCs would have been much smaller; UCCs would have been embedded in a vast network of intra-city PI-hubs, from larger sizes in main peripheral intersections down to tinier drop-and-collect points across the city intra-city; vehicles would exploit green energy; and ubiquitous PI-container and PI-resource monitoring. Extra travelled distances, lost time for transshipment and greenhouse gas emissions would all be minimized.

Whereas the PI offers a target long-term vision, most city logistics initiatives tend to be strongly anchored in the present situation and to offer specific focused solutions, such as logistic pooling in UCCs. The small example used in this paper is revealing that such specific solutions may have unintended counterintuitive characteristics and effects. For example, preferring interlinked pooling to centralized pooling appears to be a great move, one could even say in line with PI. Yet as in current settings, all kinds of goods are transported and moved, the UCCs are usually not world models in terms of transshipment efficiency, information systems do not fully support open pooling with protocols, anticipation and optimization capabilities, etc., the end result may be that the perceived good move is not so good when implemented by itself.

Clearly, one cannot switch in a Big-Bang way from the current undersigned city logistics to a fully PI-enabled interconnected logistics. Modular containerization may not be achievable in the short term; budgets may limit the implementation of UCC-type hubs; etc. Phased transient implementations according to a multi-year roadmap, starting with easy-win steps, are needed. A key learning from this exploratory contribution is that such steps have to be designed using a systemic approach, definitely not piecemeal, and that assessment tools are needed to set expectations right and to allow tackling head-on counterintuitive effects of proposed solutions.

4 Conclusion and future works

A schematic and illustrative city has been used to better understand the impact of city logistics actions on the three sustainable development indicators: social, environmental and economic. This work assesses quantitatively for a small fictitious city the difference current non-designed city logistics and two alternative solutions based on a basic centralized and a more elaborate interlinked pooling. The results obtained are revealing as they show the former to be counter-intuitively dominating the latter.

The paper has provided insights on the importance of avoiding piecemeal solutions in city logistics and of rather proceeding through a systemic roadmap from the current situation towards ever more interconnected logistics.

The paper has also highlighted the need for an *ex ante* assessment method. Every city is different and a lot of parameters have to be taken into account to characterize a city. Nevertheless, some common ground can be found. In any case multi-source multi-destination logistics should be considered. The first step of such a method would be to establish the cartography of the current urban situation, the second step to evaluate the systemic impact caused by the implantation of one, or more, city logistics actions.

This study is a part of the ANNONA project, which is an ANR project (French Agency for the Research). The limited results from this first phase will be improved on in subsequent phases. The scope of city logistics actions will be enlarged and and dealt with in depth. Using illustrative fictitious cities as done here has its uses, yet in future works, real cities will also be modelled to insure the practicality and generic character of the approach, the tools and the results. Moreover, there is need for a prototype decision support system to be developed so as to enable obtaining *ex ante* assessments of city logistics actions impacts, a prototype to be used by researchers and urban decision makers alike.

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