CIRRELT

Centre interuniversitaire de recherche
sur les réseaux d'entreprise, la logistique et le transport

Interuniversity Research Centre
on Enterprise Networks, Logistics and Transportation

Integrating C2E and C2C Traffic Into City Logistics Planning

Teodor Gabriel Crainic
Fausto Errico
Walter Rei
Nicoletta Ricciardi

February 2011

CIRRELT-2011-08

Bureaux de Montréal :
Université de Montréal
C.P. 6128, succ. Centre-ville
Montréal (Québec)
Canada H3C 3J7
Téléphone : 514 343-7575
Télécopie : 514 343-7121

Bureaux de Québec :
Université Laval
2325, de la Terrasse, bureau 2642
Québec (Québec)
Canada G1V 0A6
Téléphone : 418 656-2073
Télécopie : 418 656-2624

www.cirrelt.ca

Université Laval · UQÀM Université du Québec à Montréal · HEC Montréal · École Polytechnique Montréal · Université de Montréal

Integrating C2E and C2C Traffic Into City Logistics Planning

Teodor Gabriel Crainic[1,2,*], Fausto Errico[1,2], Walter Rei[1,2], Nicoletta Ricciardi[1,3]

[1] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT)
[2] Department of Management and Technology, Université du Québec à Montréal, P.O. Box 8888, Station Centre-Ville, Montréal, Canada H3C 3P8
[3] Dipartimento di Statistica, Probabilità e Statistiche Applicate, Università di Roma La Sapienza, Piazzale Aldo More, 5 – 00185 Roma, Italy

Abstract. City Logistics generally addresses inbound movements. Integrating outbound and intra-city traffic may both contribute to make freight transportation more efficient and less intrusive on the quality of life and the environment of the city and raise significant managerial and methodological challenges. We describe and analyze a number of representative service-integration scenarios, discuss operational and managerial issues, examine corresponding methodological challenges, and identify associated research avenues.

Keywords. City Logistics, two-tiered systems, intra-city traffic, outbound traffic, integrated operations and management.

Acknowledgements. Partial funding for this project has been provided by the Natural Sciences and Engineering Council of Canada (NSERC), through its Industrial Research Chair and Discovery Grants programs, by the partners of the Chair, CN, Rona, Alimentation Couche-Tard and the Ministry of Transportation of Québec, and by the Fonds de recherche sur la nature et les technologies (FQRNT) of the Province of Québec through its Team Research Project program.

---

* Corresponding author: TeodorGabriel.Crainic@cirrelt.ca

Dépôt légal – Bibliothèque et Archives nationales du Québec
Bibliothèque et Archives Canada, 2011

INTRODUCTION

Most City Logistics (*CL*) literature and projects address *inbound* movements only, reflecting the dominant position the traffic proceeding from the exterior of the city towards its centre occupies within the travel patterns observed in most cities. Yet, the volumes of freight produced within the city and shipped to locations within or outside the city may be significant. (Due to their particular nature and handling requirements, refuse and recyclable products are not considered here.) Given the mobility, environmental, and quality-of-life objectives of City Logistics, it is relevant to investigate the possible integration of these traffic types into "normal" CL operations. The goal of this paper is to contribute to this investigation.

We consider two types of traffic, *customer-to-customer* (*c2c*), and *customer-to-external zone* (*c2e*), the former representing traffic originated and destined to customers located within the CL-controlled part of the city (that we name *city centre*), the latter representing shipments from the city centre to destinations outside the city limits. Integrating these flows together with the "classical" *external zone-to-customer* (*e2c*) into a single CL system, facilities and vehicles serving simultaneously several traffic types, would presumably contribute to make freight transportation more efficient and less intrusive on the quality of life and the environment of the city. The planning, management, and control activities required by such integration might prove difficult to implement in practice, however. There are, in fact, several levels of service integration that may be contemplated. A thorough evaluation of the expected behaviour and operational efficiency of the resulting CL system, including a cost-benefit analysis, is thus required to compare them and contrast potential gains in system efficiency and city benefits to the corresponding managerial and operational burden. This would provide the basic elements to evaluate tradeoffs and select the policy most appropriate for specific application contexts.

There is, however, a significant gap in knowledge and instruments required to accomplish these objectives. Basic concepts and issues need to be explicitly identified. Most models, methods, and algorithms need to be developed, and the methodological challenges are significant. This paper establishes the basis to fill this gap. We describe and analyze a number of representative service-integration scenarios, and discuss operational and managerial issues. We also propose and examine an operational policy called *Pseudo-Backhaul* to simplify particularly complex service-integration scenarios, while still providing a high level of service flexibility and system efficiency. We finally examine the methodological challenges associated to these scenarios and identify associated research avenues. Two-tiered CL systems (Crainic *et al.*, 2004) present many management and methodological challenges and thus offer a rich analysis framework for our work. The next section recalls this setting.

CITY LOGISTICS

The basic purpose of City Logistics is to reduce the impact of freight-vehicle movements on the city-living conditions, particularly by enhancing the congestion/mobility conditions, improving vehicle utilization, and reducing emissions and pollution, without penalizing the city social and economic activities. Most CL projects are based on consolidating inbound freight before moving it into the city centre using the coordinated routes of a number of vehicles (Benjelloun *et al.*, 2009). Consolidation takes place at one or several major terminals sited at the city limits and known under various names including City Distribution Centres (CDC). Single-tier CL systems, found mostly in small and medium-sized cities, implement *direct-distribution* strategies, serving customers in the city centre by vehicles operating tours starting and finishing at some CDC facility. Two-tiered CL systems (Crainic *et al.*, 2004, 2009), deployed or planned for large cities, are based on a so-called *consolidation-distribution* strategy, which uses a second level of facilities and different vehicle fleets in order to avoid the presence of large vehicles in the city centre, and to reduce the number and length of empty trips.

Sorting and consolidation activities in two-tiered CL systems are performed at facilities organized into an hierarchical structure, as illustrated in Figure 1: major terminals sited at the city limits, the so-called *external zones* (squares in Figure 1) and *satellite* (triangles) facilities strategically located close to or within the city centre. Particular vehicles are dedicated to each system tier, medium-sized *urban vehicles* operating at the first tier (dashed lines) and smaller and "green" *city freighters* performing tours (full lines) at the second tier. Satellites are generally intended to be simple transhipment facilities and operate according to a vehicle-synchronization and cross-dock transhipment model, i.e., urban vehicles and city freighters meet at satellites at appointed times, the *rendez-vous points*, only short waiting times being permitted, loads being transferred without intermediate storage.

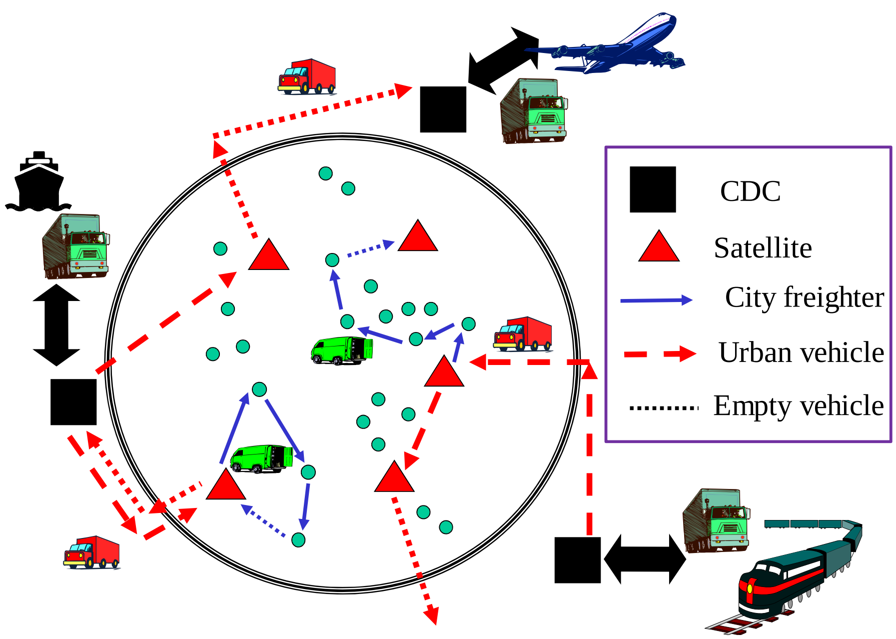

Figure 1. Two-tiered City Logistics

The *external-to-customer* (e2c), demand is assumed to originate at an external zone to be delivered to a customer (or customer zone) within the city centre. Each demand is characterized by product type, quantity, and delivery time window, and is moved on an itinerary made up of an urban-vehicle service from its external zone to a satellite, where it is transferred to a city freighter for actual delivery. The typical city freighter movements are summarized in Figure 2 where octagons, circles, and dotted lines represent depots, customers serviced from the same rendez-vous point, and empty movements. Thus a city freighter meets two urban vehicles at a satellite at a given time, loads freight for four customers, delivers it, then moves empty to another satellite to meet at a pre-defined time with an urban vehicle to load freight and then deliver it. Crainic et al. (2009) discussed associated planning issues and introduced a methodological framework to address them, which we also use in this work.

MANAGING MULTIPLE TRAFFIC TYPES WITHIN TWO-TIER CITY LOGISTICS

Except for their origin and destination locations, the c2c and c2e demands are characterized by the same set of attributes as e2c demands. We adopt the general view that the corresponding volumes are much less than those of e2c demand. Several policies may be contemplated on how to service and integrate them according to the degree of integration of the vehicle fleets and satellite facilities. Dedicated fleets and satellites might be the simplest policy to implement and manage, but it is presumably the most expensive in terms of operating costs and environmental impact. A complete integration policy, where a single fleet services all demands and satellites are shared, makes up the other end of the spectrum, offering economic and environmental efficiency but requiring quite complex operations, particularly at satellites. A large variety of integration and resource-sharing scenarios may be contemplated in between. In this paper, we focus on a limited but representative set of scenarios. We start with the *All-Dedicated* extreme case, then we analyze the e2c+c2e and the e2c+c2c settings, where the + sign indicates a shared fleet for the two respective types of traffic, the third being served by a dedicated fleet. We conclude the analysis with the *All-Shared* policy and a summary of management issues.

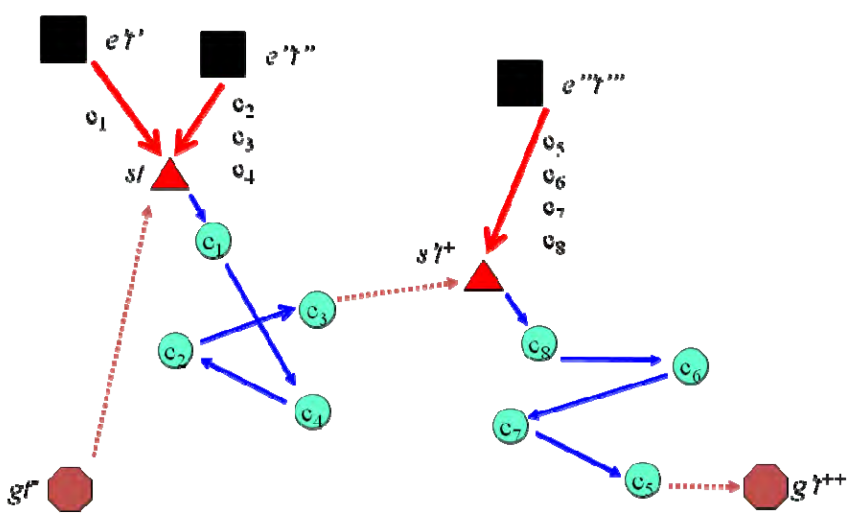

Figure 2. e2c city freighter movements

The various policies define operations of urban vehicles, satellites, and city freighters, external zones being only the origin and destination of traffic coming into or going out of the city. Following the two-tiered city logistics idea, we assume that urban vehicles cannot reach the city centre, where customers are. Consequently, c2c and c2e traffic is to be moved by city freighters, exclusively for the former, possibly in conjunction with urban vehicles for the latter. Moreover, in keeping in line with the idea of decreasing the freight traffic in the city, as well as with the constraints of customer time windows, we also assume that c2c demand is not to be serviced by, for example, picking it all up, moving it to one or several external zones to be sorted and re-distributed via the same processes as the e2c demand.

A second set of hypotheses concerns loading, unloading, and storage operations within the city. As indicated earlier, satellites do not provide storage facilities, loads being transferred without intermediate operations. Moreover, because city freighters operate in the city centre, we assume that, except for satellites, there is no space to allow rearrangement of the loads on a vehicle while operating its route. Consequently, the only item available for unloading is the last item loaded, at the rear of the vehicle, which corresponds to the well-known *LIFO*, *Last-In-First-Out* policy. Even if the LIFO policy seems restrictive, it actually allows for a very wide range of movements and operations. In general, the broader this range is, the more efficient the system is supposed to be. On the other hand, many such alternatives involve complex vehicle movements, which might be difficult to operate and plan. The concept of the *Pseudo-Backhaul* policy will be introduced to address these cases. Notice that the same situation may appear more than once in the following cases, but, for space reasons, they are addressed only once.

Dedicated fleet policies

The *All-Dedicated* fleet case appears as the most simple to design, plan, and operate. The e2c traffic is handled, as usually, by the two-tier consolidated distribution, resulting in a number of empty urban-vehicle movements, which may be undesirable. The c2c demand may be served by a city-freighter fleet operating LIFO pickup and delivery routes. The direction and possibilities of movement of c2c traffic being the exact symmetric of those of e2c, an all-distinct strategy would operate exactly as for the e2c demand, but in reverse, using separate fleets of city freighters and urban vehicles, as well as separate satellites. The strategy is not as attractive as it may appear at first glance, however. Figure 3, which illustrates this setting, emphasizes the resulting empty urban-vehicle flows, the ones returning empty after delivering e2c loads to satellites and the ones coming to satellites empty to pick up c2e loads. Moreover, the strategy assumes there are sufficient appropriate locations available for the increased number of satellites, which may be problematic.

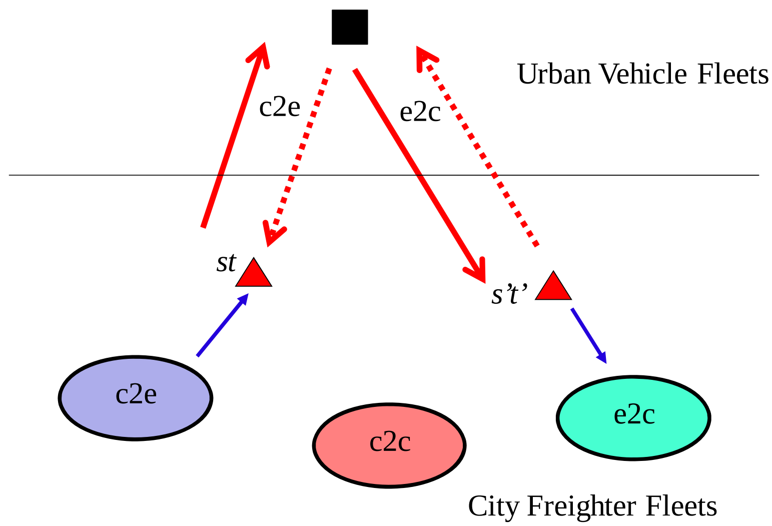

Figure 3. Distinct fleets and satellites

All or some of the satellites could be shared, of course, by the fleets dedicated to e2c and c2e traffic. This strategy could be attractive when the e2c and c2e operations may be performed at different time periods, thus, in effect, obtaining time-induced distinct sets of satellites. The total length of time available for daily satellite operations and the customer time windows may constrain this alternative. When e2c and c2e satellite operations must proceed more or less simultaneously, the satellite capacities might raise a first series of issues. It might simply not be sufficient to service the increased flows. Or it might generate unacceptable levels of congestion at or around satellites. In all cases, however, satellite sharing results in significantly more complex operations, particularly with respect to the management of the traffic of vehicles into and out of satellites, as well as of the transfer operations among vehicles. Notice, moreover, that none of these policies addresses the issue of the empty urban vehicle flows (overlaying the two triangles in Figure 3 still leaves the four traffic arrows linking the upper and lower components of the system), and that the *All-Dedicated* fleet scenarios generate the highest numbers of city freighters circulating within the city centre. The integration strategies of the next subsections aim to alleviate some of these issues.

Combining e2c and c2e traffic

The previous discussion naturally brings up the question of an integrated system servicing e2c and c2e demands (the c2c demand is served by a dedicated city-freighter fleet as previously). The "natural" qualification is warranted by the fact that e2c and c2e flows move along opposite directions and portions of vehicle trips which are empty for one traffic type usually correspond to portions of trips which are loaded for the other. Several partial or complete integration scenarios are possible, each with its own set of advantages and challenges.

A first, partial, strategy is based on the direct-distribution concept. As illustrated in Figure 4, a city freighter picks up c2e loads in the city centre, travels directly to an external zone bypassing the satellites, eventually moves to a different external zone, loads e2c freight and travels directly to the city centre for direct deliveries. The city freighter then resumes usual operations as defined by the rules of the system. It is noteworthy that direct-distribution strategies are not interesting for two-tiered CL systems because they generate too many city-freighter loaded and empty trips. The hybrid c2e+e2c direct-distribution strategy we describe appears interesting, however, as city freighters would move full most of the time and would also reduce the satellite workloads and associated synchronization challenges. Furthermore, it may be combined to most of the other strategies described in this paper. Notice that, other than the hypothesis that c2e demands are relatively low, otherwise the consolidation approach offers less impact on the city, city freighters must enjoy sufficient autonomy of movement to perform the associated tasks.

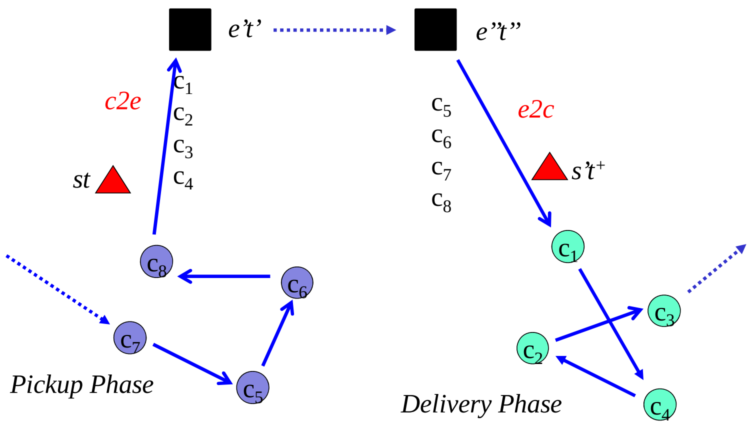

Figure 4. Direct-distribution strategy for e2c+c2e demands

A first integration scenario for the general consolidation-distribution context addresses the operations of the urban-vehicle fleets. According to this so-called *Mix-Shared* fleet strategy, illustrated in Figure 5, city-freighter fleets are dedicated to e2c and c2e traffic, but the same fleet of urban vehicles moves both types of traffic (the satellites are obviously shared). The policy has great merit in taking care of the empty movements at the first tier of the system. On the other hand, it implies more complex operations at satellites than in the All-Dedicated case. Increased coordination is indeed required to adequately sequence the bi-directional transfer operations and synchronize vehicles from three distinct fleets, one of urban vehicles and two of city freighters, at rendez-vous points.

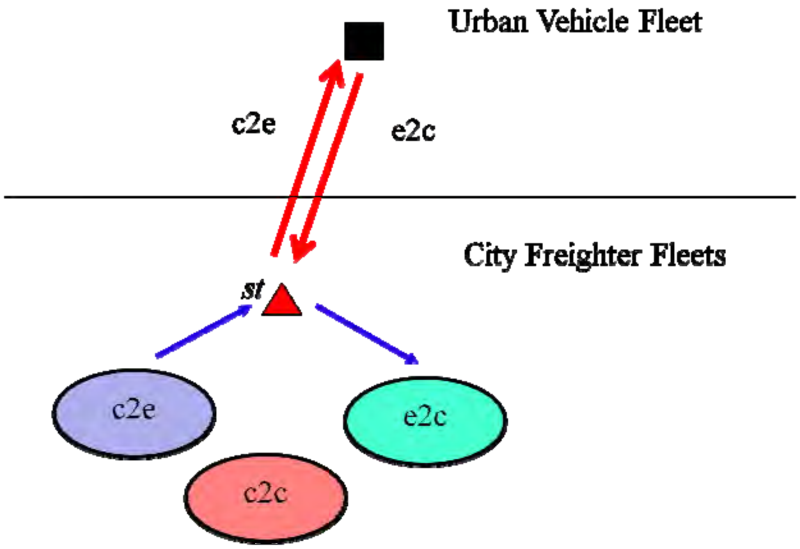

Figure 5. Mix-Shared fleet strategy for e2c+c2e traffic

A complete integration of e2c and c2e operations would reduce some of this complexity, as well as the number of city freighters moving through the city centre. According to this strategy, urban vehicles would, as previously, bring e2c traffic to satellites, unload it, load c2e traffic, and move it to an external zone. A single city-freighter fleet would deliver the e2c demand to customers from satellites and pick up the c2e demand at (the same or different) customers to deliver it at satellites.

The city-freighter routing problem becomes more complex, however. Let's define a *delivery phase* as the operations of picking up e2c loads at satellites to deliver at customers and, symmetrically, a *pickup phase* as the operations of picking up c2e demand at customers to deliver at satellites. Notice that a city freighter could very well interlace these two operations by, e.g., loading at a satellite, making a partial delivery, pick up at a number of customers, go to a satellite, unload the last loads, eventually take on additional loads, and continue the delivery operations. Figure 6 illustrates such an interlaced city-freighter route.

Such sequences obey the LIFO rule and are therefore feasible, but would most probably make managing operations, routes, and drivers too complex to be practically implementable. We therefore introduce a simple strategy, called *Pseudo-Backhaul*, which forbids interlacing different type of operations (delivery and pickup phases in this setting). As illustrated in the lower part of Figure 7 (the upper part corresponding to the interlacing of Figure 6), any delivery or pickup phase must be completed before another one may be started. This strategy simplifies the routing problem and the management issues, yet still provides a high degree of resource sharing and operational flexibility. Notice that, the Pseudo-Backhaul policy corresponds in this particular case, to what is commonly called “Backhaul”. We generalize the idea to more complex situations in the next subsection.

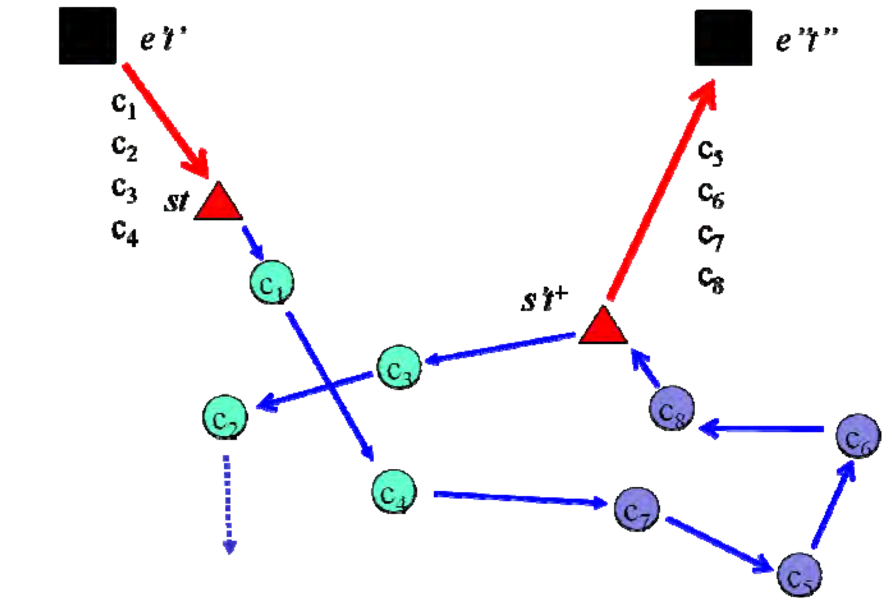

Figure 6. Interlaced delivery and pickup phases for e2c+c2e

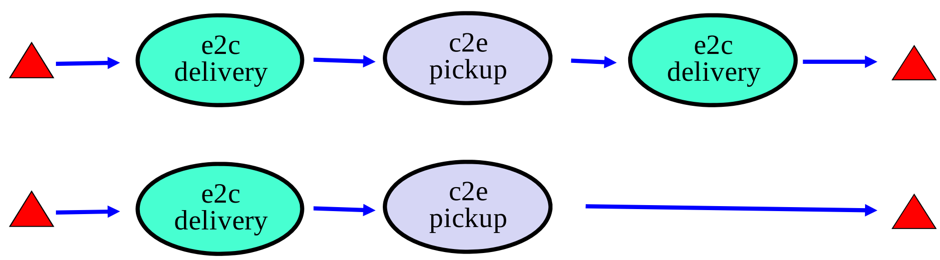

Figure 7. Interlaced and Pseudo-Backhaul routing for for e2c+c2e

Combining e2c and c2c traffic

The *e2c+c2c* integration case focuses on the sharing of the city-freighter fleet between the e2c and c2c flows, which cannot be serviced by urban vehicles. As for the c2e traffic, it is serviced by dedicated fleets as in the All-Dedicated fleet scenario, or by a dedicated city-freighter fleet that also takes care of part of the e2c demand according to a direct-distribution strategy.

Servicing c2c together with e2c adds a pickup & delivery dimension to the domain of possible city-freighter routing activities, which may increase the complexity of planning and operations. Possible policies are defined according to operations that may be performed at satellites, the status of a city-freighter load when passing at a satellite, and the sequence of vehicle activities at customers. Other than the e2c *delivery* phase introduced above, let's define the c2c *pickup*, *delivery*, and *pickup & delivery* phases as the respective operations of picking up and delivering c2c demand. As in the previous e2c+c2c setting, these phases can be interlaced, e.g., by loading at a satellite, making a partial delivery, picking up one or more c2c loads, delivering them according to the LIFO rule, continuing the delivery of the remaining e2c loads, and so on and so forth. Such an interlacing can be further compounded by allowing a number of operations at satellites, such as, passing at the satellite already partially loaded, transferring loads between city freighters, and rearranging the load of a city freighter.

Figure 8 illustrates such a setting, where two vehicles represented by full and dashed-dotted lines, respectively, arrive at a satellite already loaded with c2c freight. At the satellite, freight from the full-line vehicle is transferred to the other one, which also loads e2c traffic, but only after temporarily unloading its existing freight to permit loading everything into the appropriate LIFO order for the delivery phase. Many such possibilities can be defined, vehicle capacity, satellite synchronization, and customer time window imperatives further constraining planning and operations. Figure 9 illustrates the possible different routing resulting from such constraints and the interdiction to rearrange loads, while no satellite operations are permitted in the case of Figure 10 but city freighters may arrive loaded.

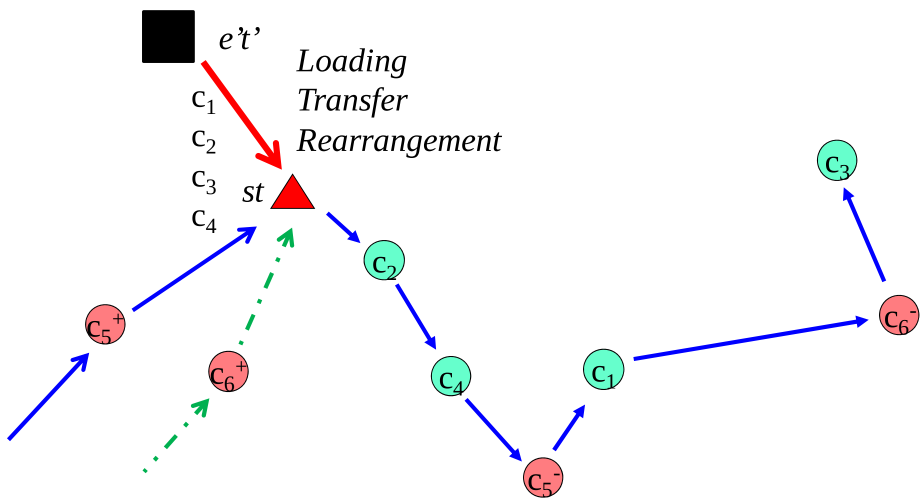

Figure 8. Interlaced routing with satellite rearrangement operations for e2c+c2c

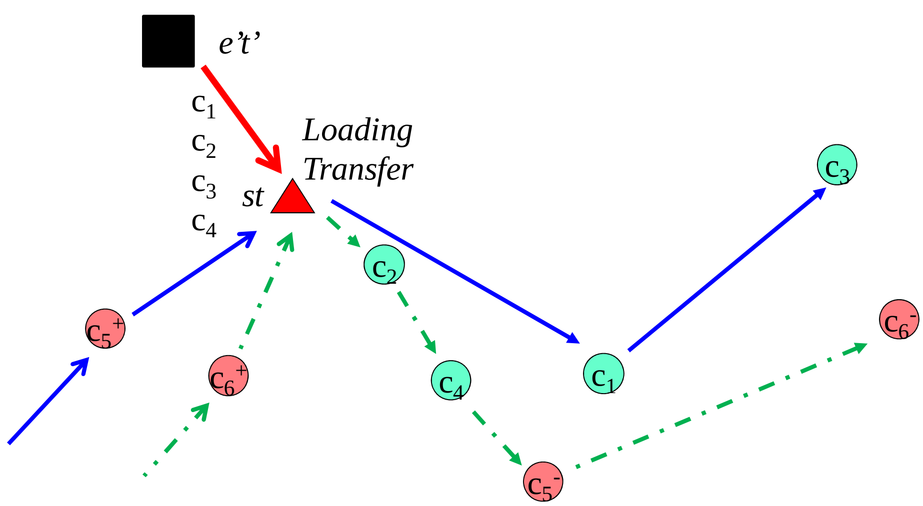

Figure 9. Interlaced routing with satellite transfer operations for e2c+c2c

In all generality, it could therefore be possible to 1) pass already loaded at a satellite; 2) perform transfers and rearrangements (it is difficult to imagine a policy that would allow taking off freight but forbid putting it in the correct order|) of loads at satellites; and 3) execute any sequence of customer service activities as defined above. This allows, of course, a very high degree of flexibility and, arguably, the highest level of city-freighter utilization in this context, the LIFO rule being "softened" to a certain degree and "better" loading arrangements becoming available for city freighters. On the other hand, it also brings a high level of complexity in the planning and management of operations. Thus, on the one hand, satellite operations might become quite complex, which is incompatible with the type of facility one usually thinks of as "satellite" (in many settings, no actual physical facility is involved). Adding loading, sorting, and re-loading operations would complicate the allocation of resources, manpower and space, and the sequence of operation, while also increasing congestion. On the other hand, highly interlaced routes that also synchronize easily with urban vehicles could prove more difficult to build.

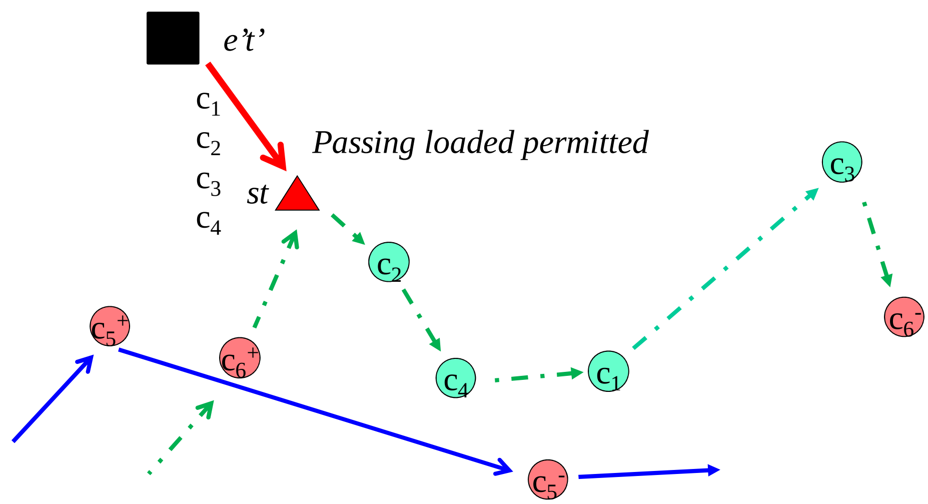

Figure 10. Interlaced routing of loaded vehicles at satellites for e2c+c2c

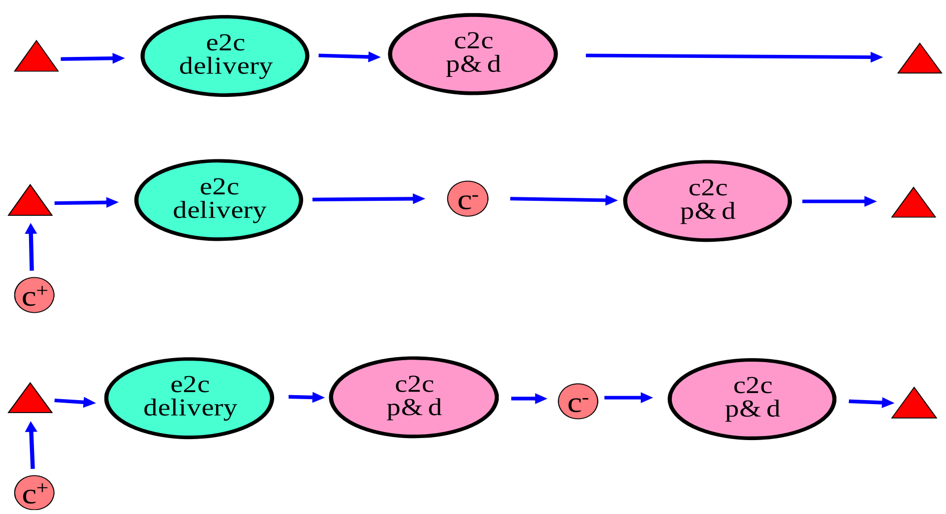

Figure 11. Various Pseudo-Backhaul policies for e2c+c2c

The Pseudo-Backhaul concept may be applied to e2c+c2c routing to address some of these issues by imposing a specific order among the different phases. In particular, requiring that any delivery phase be completed before a pickup & delivery one may start would significantly simplify the setting. Several possible options may still be defined, however. Figure 11 illustrates three of these, where transfers and rearrangements are not permitted, but arriving at a satellite partially loaded is. The top imagine corresponds to completing an e2c delivery phase before a c2c pickup & delivery one, while the two others illustrate the case of a vehicle arriving loaded with some c2c freight, which is delivered, once the e2c delivery phase is completed, either before or in between two c2c pickup & delivery phases.

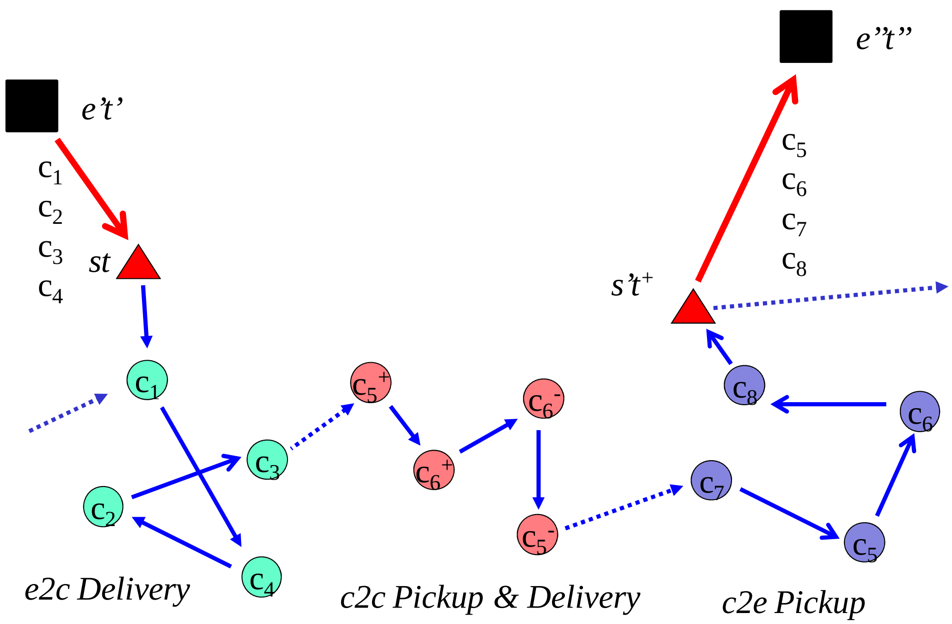

Figure 12. Example of Pseudo-Backhaul routing for the All-Shared policy

Servicing all traffic types with the same vehicle fleets and facilities

All demands are serviced by the same vehicle fleets and facilities in the *All-Shared* setting. Urban vehicles and satellites are shared between c2e and e2c flows, while the city-freighter fleet services the three types of demand. All the previous discussions and issues apply, but the number of possible sequences of urban-vehicle and city-freighter operations is even larger. Generally speaking, a city-freighter route could be any sequence of delivery, pickup, and delivery & pickup phases, "short" delivery & pickup phases being potentially be performed between two consecutive operations of a delivery or pickup phase.

Pseudo-Backhaul-based policies could assume an important role in this setting, as they could represent the right balance between managerial burden and the potential gain in efficiency. An example of Pseudo-Backhaul policy applied to the present settings is depicted in Figure 12, where the city-freighter operations follow a predefined sequence of phases: delivery of e2c demands first, pickup & delivery of c2c second, pickup of e2c third. This is a general definition where, if necessary from an efficiency point of view, any of the phases could be empty.

A summary of managerial challenges

The previous discussion emphasizes that increased integration and flexibility comes with increased complexity in operations and planning, Policies, such as the Pseudo-Backhaul routing concept we introduced, may be devised to address some of these complexities, without eliminating them completely. A number of common threads may be found in most settings, and the objective of this subsection is to sum them up.

A first set of issues are related to satellite utilization, shared or not, and the operations city freighters may perform therein. A second important issue concerns the introduction of the direct-distribution concept for some e2c+c2e movements. The interlacing of customer service activities performed by city freighters makes up the third major set of challenges (these are conditioned by the decisions on operations allowed at satellites).

The main challenge, of course, is to decide whether the CL system addresses some of the other types of traffic and demand for service and, in the affirmative, what degree of integration of operation to implement. As mentioned in the Introduction, evaluation instruments and decision-support methods are required to make these decisions and, then, to plan and manage the resulting system. This raises new challenges, which are examined in the next section.

METHODOLOGICAL CHALLENGES

The scenarios described in the previous section require the solution of complex optimization problems. Focusing on tactical planning issues (Crainic *et al.*, 2009), the models corresponding to the various integration possibilities are not simpler than the ones proposed by Crainic *et al.* (2009) for the e2c case, and include scheduled service design and two-level, synchronized, multi-commodity, multi-tour, multi-period, heterogeneous fleet vehicle routing problems with hard and soft time windows and time-dependent travel times. It is noteworthy that there is not, as yet, a solution method able to address this class of problems as a whole. Devising exact and meta-heuristic algorithms to do so constitutes a major methodological challenge.

The only proposal currently available is the heuristic decomposition framework proposed by Crainic *et al.* (2009), illustrated in Figure 13. The framework decomposes the tactical planning problem in two parts corresponding, respectively, to the first and second tiers of the CL system. The decomposition is based on the assumption that the first-tier problem is provided with a good approximation of the behaviour of the second tier. Then, the solution of the scheduled network design problem on first tier becomes the input of the second tier city-freighter routing problem. The output of the latter problem may then be used either to obtain a feasible solution to the tactical problem, or to update the approximation of the first tier and iterate to obtain more accurate solutions. Integrating c2c and c2e traffic changes the nature of the first and second tier problems in most cases, and may even challenge the principles of the decomposition framework for some settings. Methodological developments are required both to address the whole problem and these two major components, as the latter are also required for other planning methods and instruments, e.g., the simulators required to evaluate policies, strategies, decision-support methods, hard and sot technology, etc.

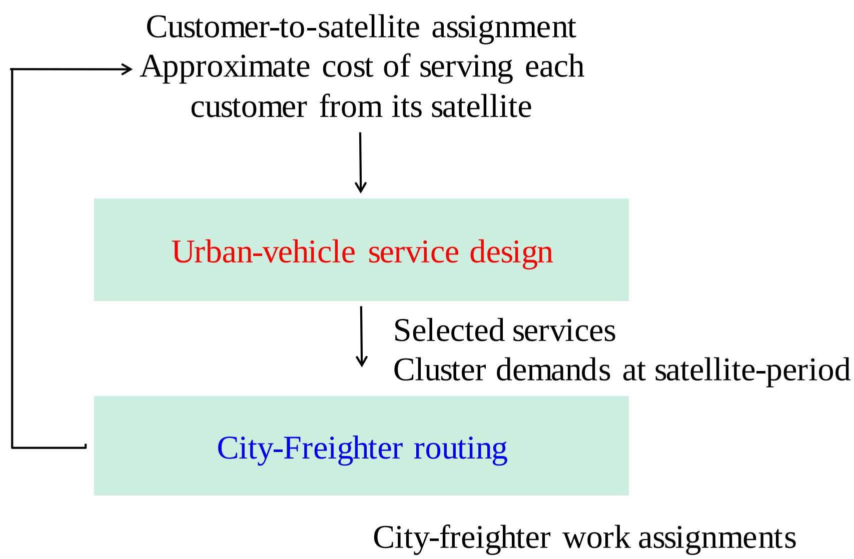

Figure 13. The decomposition approach of Crainic *et al.* (2010)

Introducing the direct-distribution approach in the e2c+c2e case belongs to the class of settings that deeply impact the decomposition framework. The formulation can be generalized, but the new type of work assignment for some city freighters, which move between tiers and take over part of the work performed by urban vehicles, makes the decomposition by tier and fleet ineffective. A heuristic around this problem would first determine a partial city-freighter circulation corresponding to the part of demand to be served by direct-distribution, would fix this circulation (in effect, dropping the corresponding demand and vehicles), and solve the resulting problem by a decomposition approach.

Other settings also challenge the decomposition but to a lesser extent. Thus, all strategies that allow city freighters to arrive loaded at satellite impact the estimation of the capacity to distribute out of each rendez-vous point. The increased complexity in satellite activities also affects the estimation of the satellite capacity at any given point in time. Turning now to the two subproblems described above, one notices that some settings do not impact much, while others change significantly the nature of the problem or even introduce new problem settings.

The first tier scheduled service network design problem selects urban-vehicle services and departure times, determines the rendez-vous point to service every demand and, thus, impacts the utilization of the satellite capacities and the .number of city freighters required at each rendez-vous point. The problem (see also Crainic and Sgalambro, 2009) does not change much when the first tier distribution of e2c and c2e traffic is served by dedicated satellites and fleets of urban vehicles, as each fleet may be addressed separately. Slightly more complex is the situation when satellites might be shared, because the problems are no longer independent as the satellite capacity might be consumed by either traffic type. The nature of the resulting problems is not different, however, only the dimension of the problem grows and thus the computational challenges. Sharing the same fleet of urban vehicles modifies the operation of the vehicles and, thus, the definition of the services and demand itineraries. Moreover, the approximation of the behaviour of the second tier becomes more complex as one needs to estimate the effect of the interaction of several city-freighter fleets. But, again, these do not change the nature of the problem, only its dimension and combinatorial degree, requiring the development of advanced solution methods combining exact, heuristic and parallel optimization solution methods.

The second-tier addresses the routing and scheduling of city freighters according to customer time windows and synchronisation at satellites. Crainic *et al.* (2009) defined new classes of vehicle routing problems for which most methodological development is still to come. Related, but simpler settings are addressed in Perboli *et al*. (2010), Taniguchi *at al.* (2001), Thompson (2004). The c2e routing problem belongs to the same classes. The c2c traffic requires new developments, however, even when its distribution is provided by a dedicated fleet. The problem can be viewed as a Pickup and Delivery Problem (PDP) with time-dependent, multi-tour, multi-product, multi-depot, heterogeneous-fleet, time window features and LIFO rule. The literature addresses PDP with only subsets of these features (e.g., Cordeau *et al.*, 2008; Dohn *et al.*, 2009; Ropke and Pisinger, 2004). Addressing the complete problem presents a considerable challenge, particularly the time-dependency that, as far as we know, has never been addressed, not even for basic versions of PDP.

Assuming these developments are undertaken, settings with dedicated fleets may be addressed by solving separately each corresponding problem (when satellites are shared, arguments similar to those used for the first-tier problems apply). Significantly more complex are the scenarios where city-freighter fleets are shared among several traffic types, the complexity growing with the permitted interlacing of routing activities and satellite transfer and rearrangement operations. In most cases, the developments are still to come and present significant challenges, particularly when c2c traffic is involved. In this context, the Pseudo-Backhaul policy simplifies the formulations and opens the door to the development of efficient solution methods, as illustrated in Errico *et al.* (2008) for the e2c+c2c case.

CONCLUSION

We considered two types of traffic, intra-city or customer-to-customer and outbound or customer-to-external zone, not usually within the scope of City Logistics literature and projects, more dedicated to inbound, or external zone-to-customer movements.

We investigated several integration scenarios of these types of flow within the same City |Logistics systems, identifying implications and challenges in terms of impact on the quality of life and the environment of the city, system efficiency, operation policies, managerial activities, and methodological developments. The analysis underlined how higher degrees of integration and resource sharing generally imply higher degrees of operational, managerial and methodological complexity. It also emphasized the need to indentify tradeoffs among system efficiency and impact on the city, simplicity of operating and planning, and computational tractability. In this context, we introduced the Pseudo-Backhaul routing policy, which provides for high degree of resource sharing and operational flexibility together with a reasonable level of complexity of operations, management, and solution methodology. We believe the present work provides the first fundamental step in broadening the scope of City Logistics to other types of freight and in developing the required planning models, methods, and instruments.

ACKNOWLEDGMENTS

While working on this project, T.G. Crainic was the NSERC Industrial Research Chair in Logistics Management, ESG UQAM. Partial funding for this project has been provided by the Natural Sciences and Engineering Council of Canada (NSERC), through its Industrial Research Chair and Discovery Grants programs, by the partners of the Chair, CN, Rona, Alimentation Couche-Tard, and the Ministry of Transportation of Québec, and by the Fonds FQRNT of the Province of Quebec through its Team Research Project program.

REFERENCES

Benjelloun, A., T.G., Crainic, and Y. Bigras, (2010). Toward a Taxonomy of City Logistics Projects, *Procedia - Social and Behavioral Sciences*, **2(3),** 6217-6228, Elsevier.

Cordeau, J.-F. , G. Laporte, and S. Ropke (2008). Recent Models and Algorithms for One-to-One Pickup and Delivery Problems. In *The Vehicle Routing Problem: Latest Advances and New Challenges* (Golden, B.L., Raghavan, S., and Wasil, E.A., eds.), pp. 327–357. Springer.

Crainic, T.G., N. Ricciardi, and G. Storchi (2004). Advanced Freight Transportation Systems for Congested Urban Areas. *Transportation Research Part C: Emerging Technologies*, **12(2),** 119–137.

Crainic T.G. and A. Sgalambro (2009), *Service Network Design Models for Two-tier City Logistics*, Publication CIRRELT-2009-60, Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport, Université de Montréal, Canada.

Crainic, T.G., N. Ricciardi, and G. Storchi (2009). Models for Evaluating and Planning City Logistics Transportation Systems. *Transportation Science*, **43(4)**, 432–454.

Dohn, A., E. Kolind, and J. Clausen (2009). The manpower allocation problem with time windows and job-teaming constraints: A branch-and-price approach. *Computers & Operations Research*, **36 (4)**, 1145 – 1157.

Errico, F., T.G. Crainic, W. Rei, and N. Ricciardi (2009), Integrating Intra-city Movements into Two-tier City Logistics Planning, *Proceedings of the Forth International Workshop on Freight Transportation and Logistics, ODYSSEUS*, Çesme, Turkey.

Ropke, S. and D. Pisinger (2004). An adaptive large neighborhood search heuristic for the pickup and delivery problem with time windows. *Transportation Science*, **40**, 455–472.

Perboli, G., R. Tadei, and D. Vigo (2010), The Two-Echelon Capacitated Vehicle Routing Problem: Models and Math-Based Heuristics, to appear *Transportation Science*.

Taniguchi, E, T. Yamada, and M. Tamaishi (2001). Dynamic Vehicle Routing and Scheduling with Real Time Informations. In *City Logistics II, Second International Conference on City Logistics* (Taniguchi, E. and Thompson, R.G., eds.), pp. 111–125. Institute of Systems Science Research, Kyoto.

Thompson, R.G. (2004). Intelligent Vehicle Routing and Scheduling. In *Logistics Systems for Sustainable Cities* (Taniguchi, E. and Thompson, R.G., eds.), pp. 97–109. Elsevier, Amsterdam.