RAIL SERVICE DESIGN FOR MIXED PASSENGER AND FREIGHT TRANSPORT[1]

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1 Introduction

In the context of global trends towards urbanization, population concentration in cities, and e-commerce, the demand for goods deliveries in urban areas has been fast growing. Increasingly, urban goods movement is playing a central role in the urban economy. Goods distribution has been widely dominated by the use of trucks within the borders of cities. However, the ensuing trucktraffic growth is threatening urban transport networks with more congestion, emissions, noise pollution, and pavement damage (Cochrane et al., 2017). As cities attempt to move toward efficient andeco-friendly systems, the use of urban rail for certain types of goods movement may be a reasonable alternative.

Urban rail has potential to be an effective andenvironmentally-friendly way to transport goods. Urban rail lines are generally planned and built to satisfy passenger travel demand between suburban and downtown during peak hours. During off-peak hours, passenger demand is lower and there may be potential to use these rail lines for goods transport. Makingbetter use of existing rail facilities at all times of day can increase revenues for the rail operator.The transition of goods movements from trucks to trains also facilitates a greener and more energy-saving city logistic system.

To integrate urban freight transport into passenger rail lines, some challenges need to be addressed. First, freight service must be designedin the context of the existing urban rail infrastructure. For example, it is impossible to change the train formation within the relatively short dwell times which are typical of passenger rail service. Second, passenger transportation must remain the priority in the urban rail system when a new freight service is introduced. The new service could only be acceptable ifit does not noticeably increase passenger wait time or travel time, or cause other conflicts. Careful coordination between passenger and freight train service is essential. Third, space on or near the platforms is required for storage of goods between the time of drop-off and loadingonto the rail vehicle. The size of storage space at stations and the inventory cost should be taken into consideration.

In this paper, the train service design problem for mixed passenger and freight transport is addressed. Passenger trains have a prescribed timetable that is assumed to be fixed. Freight can be transported by adding dedicated freight trains or using the residual space on passenger trains. Station platforms can be used to load and unload goods and passengers at the same time.An optimization model for the train service design is proposed to maximize the overall profit,which is affected by the freight revenue and cost incurred by the freight service. Efficient timetables of freight trains are determined. A numerical example based on the Union-Pearson Express in Toronto is introduced to demonstrate the proposed methods.

The remainder of this paper is organized as follows. Section 2 describescase studies of freight on transit across the world, demonstrating the technical feasibility of this strategy. Section 3describes the problem and proposes the general framework of the optimization model. Section 4demonstratesthe proposed model with a numerical example. Section 5 presents the summary and conclusions.

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2 Case studies

The use of urban rail for freight transport is a rising trend in cities with comprehensive rail infrastructure. Efforts have been made toevaluate the environmental benefits and technical feasibility (Motraghi et al., 2012, Dampier et al., 2015), or to optimize systems at the strategic or operational level (Behiri et al., 2018; Ozturk et al., 2018, Cleophas et al., 2018). Five successful implementations that use rail in urban logistics are described as follows.

Case 1:Hokuhoku Line in Japan(Hokuetsu Express Hokuhoku Line, 2017)

The Hokuhokuexpress line is a railway line of 59.5 km between Rokkaicho and Ogata in Japan, operated by Hokuetsu Express. To increase the revenues and make use of residual capacity of trains with few passengers, Hokuetsu Expresscollaborates with Sagawa Express, a leading home delivery company, to operate trains with mixed shipments of passengers and goods. Goods are transported in a box with the fixed characteristicsof 1650 mm in height, 652 mm in width, 936 mm in length, and maximum loading capacity of 200 kg, as shown in Fig. 1 and Fig. 2.Each passengercarriagecontains two boxes, which are fixed to the wall surface of rail vehiclesusing a lashing belt. The delivery service is only carried on weekdays.

Hokuetsu Express expects to gain revenues from this freight service with little increase in operational cost. Sagawa Express addresses theirshortage of truck drivers and reduces carbon dioxide emissions. Based on the publication data of the Ministry of Land, Infrastructure and Transport(Open Data: statistics, 2018), the travel distance of conventional truck transport is reduced from133 km to 20 km in total. The emission of carbon dioxide is reduced by 88%.

Fig. 1. Boxes fixed via the lashing belt*

Fig. 2. Loading work*

(*Source: Hokuetsu Express Hokuhoku Line, 2017)

Case 2: Sapporo subway-integrated city logistics system in Japan(Kikuta et al., 2012)

Sapporo is a large and highly populated city in Japan where traffic congestion and delivery delays resulting from heavy snowfall pose great challenges to city logistics. A new delivery system is designed to integrate Sapporo's subway system with the truck delivery service toconnect Sapporo's suburbs and its city center.
To assess the new subway-integrated city logistics system, a pilot experiment was carried outon a 10 km line between the Yamato Transport Sapporo Base (suburb) and the Odori Home Delivery Center (citycenter).The pilot was conducted during off-peak hours from 10h30 to 14h00 from September 2 to 15,

2010. The goods were transported by a hand cart, which is shown inFig. 3. The size of the hand cart is 900 mm in height, 500 mm in width, 700 mm in length, and 60 kg in maximum weight. As shown in Fig.4, the cart was loaded on the floor of the residual space in passenger carriages.

Fig. 3 Delivery cart used in the project*

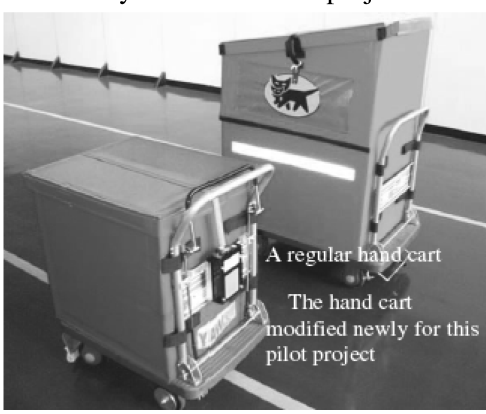
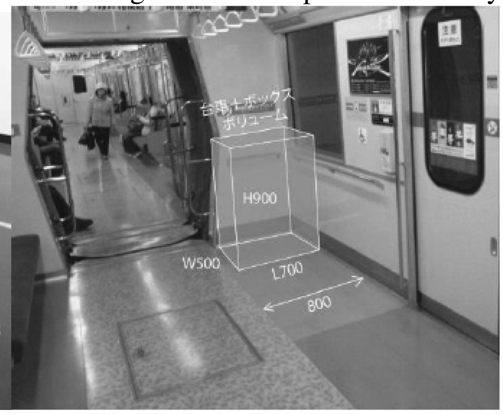


Fig. 4 Residual space for delivery cart*



(*Source: Kikuta et al., 2012)

Case 3: Tokyo Subway Experiments in Japan (Tokyo Metro trial, 2016)

To facilitate logistics during the 2020 Tokyo Olympic, Tokyo Metro Company, which is the largest subway in Tokyo with a daily ridership of nearly 7 million passengers, is collaborating with five other rail and transportation firms to test the feasibility of using its subway trains to deliver parcels into the city center. Some experiments were conducted 10 times between September 9 and October 15 in 2016. Two loading schemes, at stations or at depots, were carried out to test the time and workforce needed. The objectives were to verify the safety and work efficiency of freight transport using subways, check the facility conditions, and analyze how it would affect passenger transport.

Fig. 5 Loading work in Tokyo Subway Experiments*

(*Source :Express delivery at Tokyo Metro, 2016)

Case 4: Monoprix in Paris (Dablanc, L (2009))

Monoprix is a chain ofsupermarkets with 60 stores located in Paris. Monoprixutilizes the RER D line in Paris to transport goods such as soft drinks, textiles, cosmetics, household goods, and leisure products, from their warehouses outside Paris to Bercy station in Paris. Trainstransport goods to Paris Bercy station everyevening and then transfer to CNG operated trucks which deliver the goods to the stores early in themorning. This project is supported by the City of Paris with an investment of 11 million euros. This line carries 210,000 pallets with an annualreduction of10,000 diesel trucks, 280 tonnes of carbon dioxide and 19 tonnes of nitrogen oxides(1 tonne = 1,000 kg).

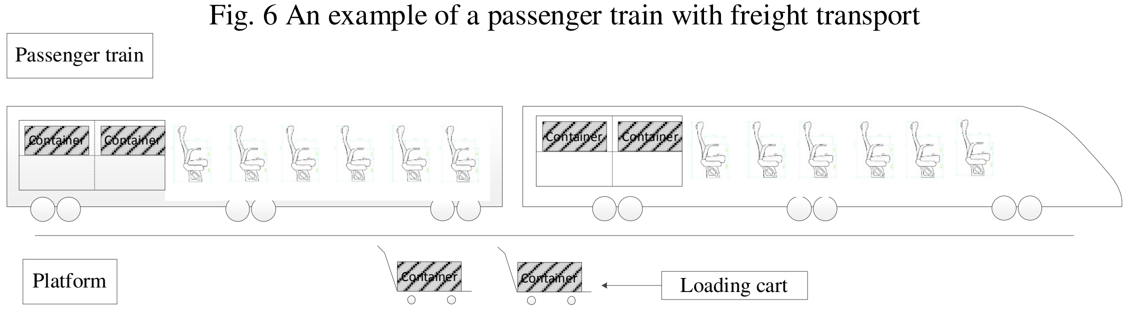
Case 5:Subway station refuse collection in New York (Metropolitan Transportation Authority, 2014)

This case concerns the subway station refuse collection in New York. As the New York subway runs 24/7, refuse trains and passenger trains share tracks in the subway network. Refuse trains primarily operate between 10pm and 6am and they enable the collection of 40 tons/day. These refuse trains cover 359 stations with 567 stops. The schedule of refuse trains needs to be designed to avoid conflicts with passenger trains and track maintenance time.

3 Model formulation

The scheduling problem on a single urban rail with freight transport isdiscussed in this section.Passenger trains are assumed to have a predetermined timetable that takes priority over freight service. Freight service is permitted to share the existing infrastructure with passenger trains. Considering the case studies described in the previous section, two kinds of freight service are considered. The first uses residual space in passenger trains to transport goods, which is shown in Fig. 6. These goods are fixed in a specialized storage space in a carriage, where they can be prevented from moving. The secondinserts dedicated freight trains between passenger trains, with goods loading/unloading at station platforms.

Fig. 6 An example of a passenger train with freight transport



Freight demand along the urban rail line is assumed to be known in advance, including goods departure and arrival stations, ready time and due time. Ready time is the earliest time when goods can be transported by trains and due time the latest time when they should arriveat their destination station. However, it is hard to satisfy all freight demand because time requirements for freight demand are heterogeneous and the transportation capacity is limited. Understanding of how to best use existing passenger trains service and adjustheadway to serve the most profitable demand is crucial for rail operators to make decisions on the freight service design.

The train service design problem in urban rail lines with freight is to find an efficient operation planto maximize profit, which is equal to revenueminus the marginal train operation cost, loading cost, and inventory cost.As passenger demand and passenger train service are assumed to be fixed, the additional revenue comes only from the freight service and train operation cost increases only when dedicated freight train service is introduced. Inventory cost occurs when goods have to be stored if trains arrive later than the ready time. Loading cost is consideredbecause extra work is required to deliver goods from the inventory onto the rail vehicles. Based on the freight demand, the timetables of these dedicated trains and the numbers of train carriages aredecided.Simultaneously, aspecific plan to allocate freight on passenger trains and dedicated freight trains is produced. Train capacity and safe distances between any two successive trains (i.e. a minimum headway) must be guaranteed.Loading/unloading work at each station needs to becompleted within dwell time of each train.

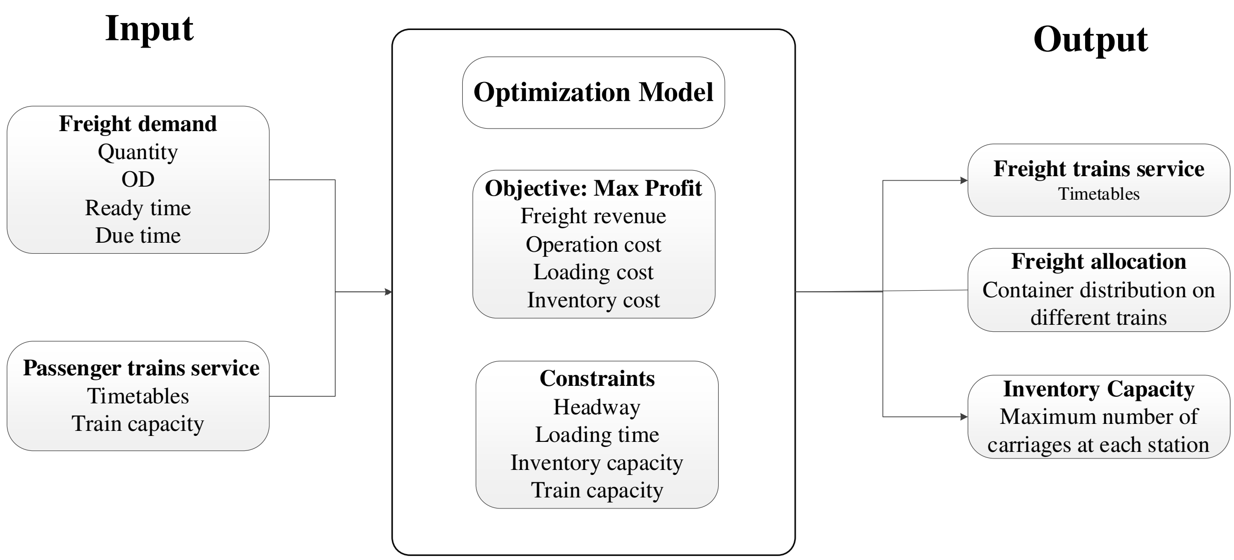
To facilitate the formulation, assumptions are made as follows.

Assumption 1:
The freight demand considered in this paper is quantified as containers of the same volume and weight. Standard containers would enhance the loading/unloading efficiency. Each carriage of a passenger train is assumed to hold several equally sized containers. Each carriage of a freight train can hold more containers since the whole carriage is dedicated to freight.

Assumption 2:
The freight demand from one order is not allowed to be split among different trains. The freight demand can only be loaded/unloaded at their departure and arrival station.

The model framework for the train service design problemis presented in Fig 7. Based on the freight demand information and existing passenger trains timetables, an optimized operation plan of freight trains and freight demand distribution plans can be produced. The inventory capacity needed at each station can also be calculated according to the optimized train timetables and the pre-scribed freight ready time.

Fig.7 Model framework



4 A numerical example

This section applies the proposed model to the design of a freight service for Union-Pearson Express. Union-Pearson Express connects the Pearson International Airport, in the Region of Peel, to Union Station in the Toronto City Centre. Air cargo and other delivery demand from businesses in the vicinity of the airportcan be transported to the Toronto City Center using this service.

The stations are numbered from S1 to S4from Pearson Airport to Union Station. Table 1 shows link running time of the UP express. The research period is one hour and the first passenger trainsdeparts from station 1 at 9:00 am. All passenger trains have parallel timetables and are operated with a headway of 15 minutes. Passenger trains dwell at each station for 1 minute. The minimum headway between two successive trains is 4 minutes. Table 2 shows the freight demand. Each passenger carriage can hold 1 container and each freight carriage can hold 6 containers. Passenger trains consist of 3 carriages and the number of carriages on freight trains is to be determined. The loading/unloading time for each container is 15 seconds. Table 3 shows other parameters.

Table 1 Link running time

Station	S1-S2	S2-S3	S3-S4
Link Running Time(mins)	11	5	7

Table 2 Freight demand

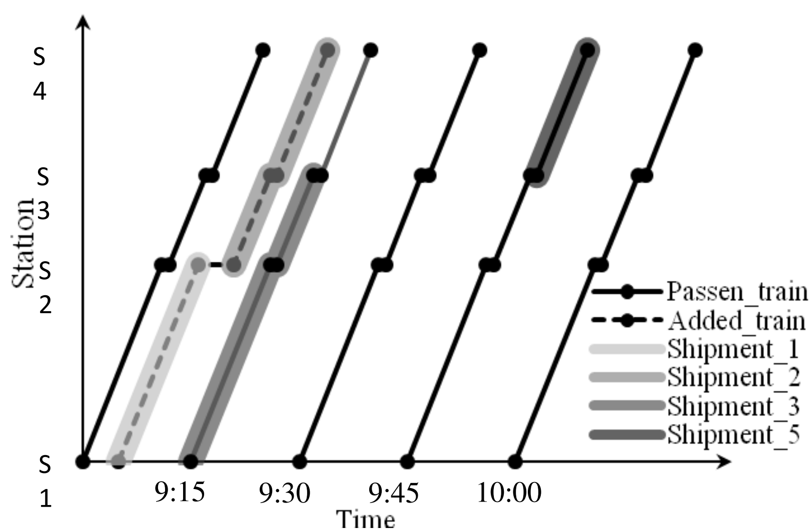
Shipment	Quantity (Containers)	Originating station	Destination station	Ready time	Due time
1	12	1	2	0	9:40
2	8	2	4	9:20	10:00
3	3	1	3	9:10	9:40
4	5	2	4	9:15	9:50
5	1	3	4	9:50	10:20

Table 3 Other parameters.

Parameters	Quantity	Unit
Revenue per container	20	dollar/km
Operation cost per carriage	60	dollar/km
Load cost per container	15	dollar
Inventory cost per container	20	dollar

This section discusses the performance of the proposed model for the specified problem instance. Fig. 8 presents the optimized timetable with passenger trains and an added freight train. A freight train departs at 9:05 at station 1 and consists of 2 freight carriages. The freight train dwells at station 2 for 5 minutes and at station 3 for 1 minute. The freight distribution on trains is also presented in Fig. 8.Demand 1 and demand 2 are transported by the added freight train. Demand 3 and demand 4 are transported by residual space in passenger trains.

Fig. 8 Time-distance diagram for the optimized operation plans



With the optimized train service plans, revenue and cost introduced by freight service are calculated in Table 4. The revenue comes from those freight demand transported by trains in the optimized plan. Inventory cost at each station is related to the maximum number of containers stored at the same time.

Operation cost is calculated by the number of added trains since passenger trains service is fixed.

Table 4 Revenue and cost

Revenue		
Shipment	Quantity (containers)	Revenue (dollars)
1	12	2640
2	10	1920
3	3	960
4	5	-
5	1	140
		5660
Inventory cost	Capacity (Maximum number of containers)	Cost (dollars)
station 1	12	240
station 2	8	160
station 3	1	20
		420
Loading cost	Quantity (containers)	Cost (dollars)
	24	**360**
Operation cost	Number of carriages	Cost (dollars)
Added train 1	2	**2760**
Profit (dollars)		**2120**

In the numerical case, the final operation profit is 2280 dollars with the consideration of freight revenue, inventory cost, loading cost and operation cost. Demand 4 is not satisfied since the capacity of passenger train 2 is limited and it would not be economical to add another freight train. Station 1 and station 2 are required to have storage spaces with the capacity of 12 containers and8 containers, respectively. The inventory cost at each station, which is fundamentally linked to the operation plan, plays an important role in the total cost. Operation cost is a large proportion of the total cost since a dedicated freight train is added.

5 Conclusions

This paper develops an optimization method to enable introducingfreight service on urban rail transit. Using urban rails to transport goods represents an environmental-friendlyalternative for urban freight transport to decrease impacts of trucks on urban roadways. The technical feasibilityis demonstrated via five case studiesof freight transport on urban rails. In these experiments, goods are transported in a standardized container to enhance transport efficiency. Adding a dedicated train or using residual space in a passenger train carriageare both feasible ways to introduce freight service on urban rail lines.

The service design of trains on urban rail transit with freight is addressed in this paper. An optimization model is proposed to maximize profit which considers freight revenue, operation cost, load cost and inventory cost brought by the freight service. Adding a dedicated train and using residual space in a passenger train carriage are both permitted in the model. Based on prescribed passenger train service plans, freight train timetables and distribution plans of freight are determined. A numerical case based on Union-Pearson Express in Toronto shows the performance of the model, in which operation profit increases with the introduction of freight train service. It is found that it is not necessarily profitable to satisfy all freight demand, due to the high cost of additional freight trains.

Reference

Authority, M. T. (2014). NYCT Trash Can Free Stations Pilot Update. *Report Presentation, January, Metropolitan Transportation Authority*.

Behiri, W., Belmokhtar-Berraf, S., & Chu, C. (2018). Urban freight transport using passenger rail network: Scientific issues and quantitative analysis. *Transportation Research Part E: Logistics and Transportation Review*, *115*, 227-245.

Cleophas, C., Cottrill, C., Ehmke, J. F., & Tierney, K. (2018). Collaborative urban transportation: Recent advances in theory and practice. *European Journal of Operational Research*.

Cochrane, K., Saxe, S., Roorda, M. J., &Shalaby, A. (2017). Moving freight on public transit: Best practices, challenges, and opportunities. *International Journal of Sustainable Transportation*, *11*(2), 120-132.

Express delivery at Tokyo Metro --- Field trial. (September 10, 2016). Retrieved from https://response.jp/article/2016/09/10/281579.html

Dablanc, L. (2009). Freight transport for development toolkit: Urban freight. *The World Bank, Waszyngton*.

Dampier, A., &Marinov, M. (2015). A study of the feasibility and potential implementation of metro-based freight transportation in Newcastle upon Tyne. *Urban Rail Transit*, *1*(3), 164-182.

Hokuetsu Express Hokuhoku Line "Delivery Luggage Train" Departure Ceremony at Rikkocho Station. (April 18, 2017). Retrieved fromhttps://response.jp/article/2017/04/18/293658.html

Kikuta, J., Ito, T., Tomiyama, I., Yamamoto, S., & Yamada, T. (2012). New Subway-Integrated City Logistics Szystem. *Procedia-Social and Behavioral Sciences*, *39*, 476-489.

Motraghi, A., & Marinov, M. V. (2012). Analysis of urban freight by rail using event based simulation. *Simulation Modelling Practice and Theory*, *25*, 73-89.

Open Data: Statistics, freight transportation/ logistics (2018), Retrieved from http://www.mlit.go.jp/statistics/details/kamotsu_list.html

Ozturk, O., & Patrick, J. (2018). An optimization model for freight transport using urban rail transit. *European Journal of Operational Research*, *267*(3), 1110-1121.

Tokyo Metro trial using its trains to move packages and parcels. (August 31, 2016). Retrieved from https://www.smartrailworld.com/tokyo-metro-to-trial-using-its-trains-to-move-packages-and-parcels.