LEVERAGING DATA OF A MULTI-MODAL AND MULTI-OPERATOR SMART CARD AUTOMATIC FARE COLLECTION SYSTEM FROM THE PERSPECTIVE OF A REGIONAL TRANSIT AUTHORITY

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ABSTRACT

Public transit actors have specific data needs as they target various aspects of public transit planning and management. A regional transit authority, due to the nature of duties it assumes, is highly involved in the collection, assembling, storage, processing, analysing, exchange and distribution of transport and mobility data. Meanwhile, the smart card automatic fare collection (AFC) system, often multi-modal and interoperable among transit operators in a region, provides a continuous source of detailed activity data within a transit network. This paper demonstrates the use of three types of transactional data generated by a smart card AFC system, namely sales, fare validation and verification data, from the perspective of a regional transit authority. The results, based on currently available data, would help to refine the financial mechanism, better manage fare products, extend the understanding the travel and purchase behaviour of users and improve transit service planning. The types of analysis can be generalized to other transit agencies with access to similar data.

Keywords: public transit, smart card, data analysis, planning, finance

CONTEXT

Agence métropolitaine de transport (AMT), the governmental transit authority of the Greater Montréal region in Québec, Canada, plans, coordinates and integrates regional public transit services. It has a major stake in public transit finance with its roles in establishing integrated fare products and their fares, managing the sale of those products, distributing the revenue among transit operators and allocating government subsidies. In addition, it operates the commuter rail network, one express bus service and manages regional termini, reserved lanes and park-and-ride facilities. With its roles in the financial mechanisms and regional transit services, the nature of duties requires AMT to be an active leader and a repository of various transport and mobility data of the region. The latter mainly includes periodic large-scale household travel surveys, fare product usage surveys, transit network and operations of the whole region, sales data of integrated and local fare products, on-board surveys and passenger counts. These involve the collection, assembling, storage, processing, analysing, exchange and distribution of data.

The financial mechanism for revenue and cost sharing is based on the concept of transit network usage. Currently, data on network usage are mainly gathered through traditional telephone survey which is labour-intensive and costly to perform and process. Since it is a cross-sectional survey, it is not well adapted to changes in network and fare. Recently, a multi-modal (subway, commuter rail and bus) and multi-operator (17 operators) smart card fare collection system in the greater Montréal area, OPUS, has been deployed. This passive data collection method provides an opportunity to acquire comprehensive and continuous data on activities in the transit network. Although deployment of the system is still underway, this paper explores how smart card data can address the specific data needs of a regional transit authority and of an operator by illustrating some potential applications. Several lessons are learned during the preliminary stage of data analysis.

Background on the Region, Transit Network and Fare Structure

Region

The territory of AMT covers a total area of about 4,000 km^2 and a population of 3.6 million. It comprises 83 municipalities and one Indian reserve. The City of Montréal, located on an island with more than 1.6 million inhabitants, is the main employment and education centre. About half of the population in the territory resides outside the Island of Montréal.

Multi-modal

There are multiple transit modes in the region:
- the métro, a completely underground heavy rail network with 68 stations on four lines;
- the commuter rail network with 5 lines and 51 stations;
- the express and local bus networks and
- the paratransit service.

Those networks are interconnected to form a regional network and transfers among modes are possible at regional termini, train and métro stations.

Multi-operator

In general, each municipality is responsible to organize and operate transit service within its territory. Three transit corporations provide service on the Island of Montréal and the inner suburb. Since municipalities within the region vary greatly in size and population, some municipalities group together to form intermunicipal or regional transit councils (conseil intermunicipal / régional de transport) to jointly organize transit service. The regional character of the commuter rail network and the express bus service commands an operation by a regional transit agency. Each transit operator establishes the local fare structure, fare products and fare control strategy.

Integrated Fare System

Apart from transit trips made within a local network, many trips require the use of more than one networks. An integrated fare system was established to facilitate regional travel. The system is divided into eight concentric fare zones, based roughly on the distance from the central business district (CBD) of Montréal (Figure 1). The zonal fares are inclusive, meaning they allow travel in an inferior zone.

The integrated fare system offers significant monetary discount to inter-network travel, 20 to 40% for monthly pass products. Instead of paying for each of the local networks, users only need to purchase one product that covers the maximum fare zone. In addition, different levels of fare discount are given to children up to the age 18, students between the age of 19 and 25, and senior aged 65 and over. A monthly pass allows unlimited travel in a calendar month. A single-journey ticket allows unlimited transfer within a time threshold. There are some exceptions, as the system is constantly evolving.

As the administrator of the integrated fare system, the AMT has the mandate of distributing fare revenues and government subsidies among transit agencies. The latter intends to compensate for the loss of revenue due to the fare integration initiatives. The method is based on the concept of transit network usage, which is measured by passengers and passenger-kilometres. The computation of those indicators is essentially based on large-scale fare product usage survey and a regional transit network model. Expertise in survey tools and methodology are gained through extensive experience with large-scale regional household travel surveys.

On the other hand, AMT also distributes subsidies on the basis of ridership. The latter involves turnstile counts, passenger counts and point checks. All of these data collection undertakings are conducted infrequently, rely on a sample and expansion, costly to perform and process and prone to error and delay. Nonetheless, the methods remain the most truthful and reliable within the available means.

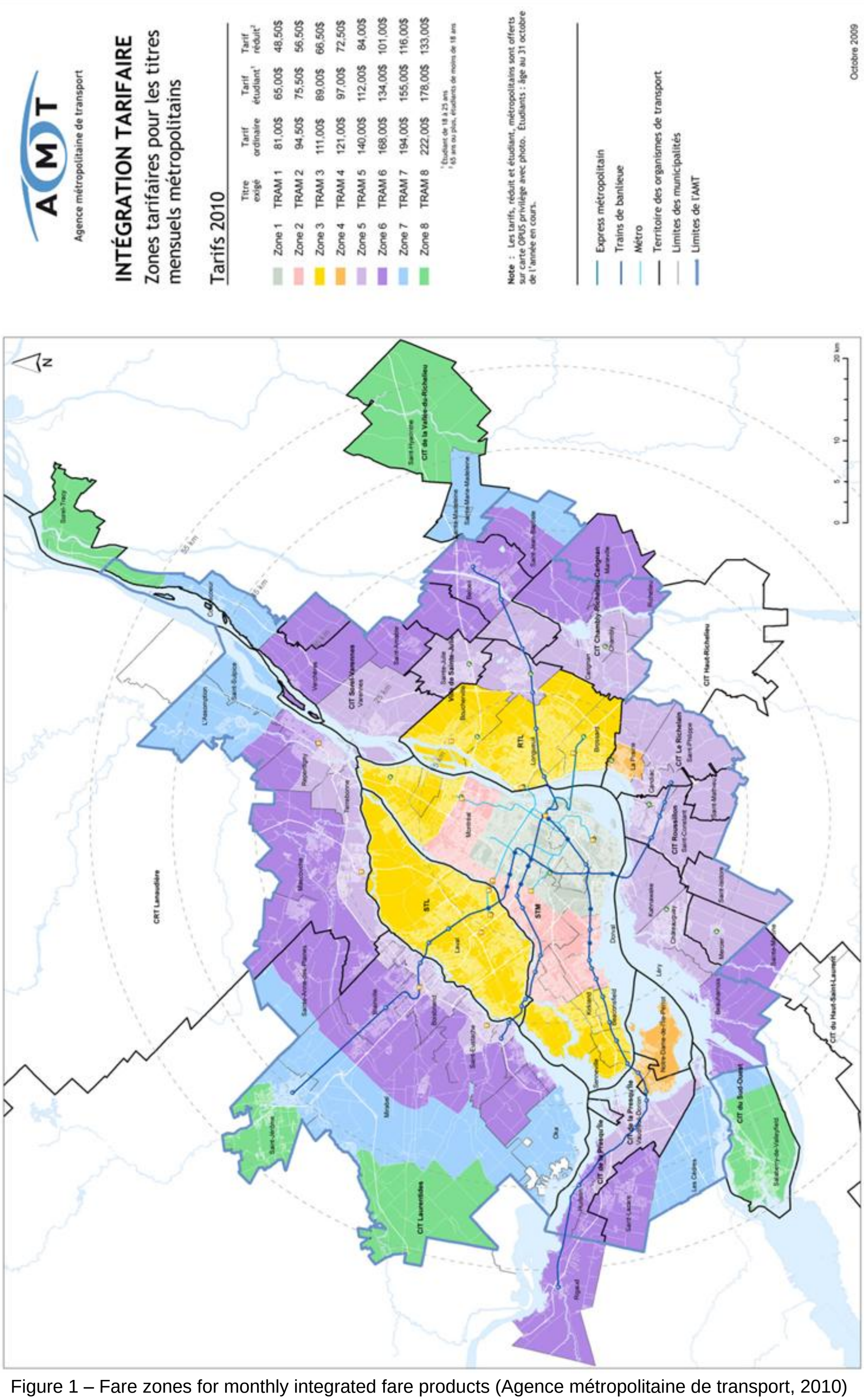

Figure 1 – Fare zones for monthly integrated fare products (Agence métropolitaine de transport, 2010)

OPUS: the Newly Implemented Smart Card Automatic Fare Collection System

OPUS is a proprietary smart card automatic fare collection (AFC) system and is configured to maintain the existing fare structure. It replaces the magnetic fare cards and paper tickets with electronic tickets (fare products). Progressive deployment has started since April 2008 and is still continuing to date. Each piece of equipment requires a unique location code to communicate with the system. Fare products can be purchased and loaded onto media including rechargeable smart card, disposable smart card and disposable magnetic card. Cash fare on buses is registered in the AFC system if the fare box accepting cash is integrated to the system. To take advantage of reduced fare, one must hold a personalized rechargeable smart card as proof of admissibility. Fare is validated almost exclusively at entry for all modes except the commuter rail, which uses a self-service and barrier-free system.

LITERATURE REVIEW AND MOTIVATION

There are many actors in the public transit operation, planning and management. Their different mandates affect what data they require and how data are used. Sammer (2009) provides an up-to-date overview of data needs and collection methods in the public transit domain. A transport authority collects data for activities including transport modelling, compilation of ridership for regular transit and para-transit, revenue distribution to operators and travel behaviour study. An operator, in addition to ridership counts, needs data to measure service performance and quality, customer perception, satisfaction and behaviour.

Discussion on the potential uses and applications of smart card data have been well documented in recent literature (e.g.: Trépanier et al., 2004; Bagchi and White, 2005; Utsunomiya et al., 2006). Most of the papers tend to explore the use of validation data (commonly referred as transaction records) from a transit service planning perspective: studying transit network and demand by deriving load profile, trip itinerary and origin-destination matrix (Chu and Chapleau, 2008; Farzin, 2008; Seaborn et al., 2009); system performance by calculating indicators on usage, supply, travel time and reliability (Park et al., 2008; Trépanier et al., 2009; Jang, 2010; Uniman et al., 2010); and travel behaviour by measuring transit use variability and characterising transit trip with multi-day attributes (Morency et al., 2007; Chu and Chapleau, 2010).

Since a transit authority or an operator has various roles in addition to planning and that a smart card AFC system provides other types of data, it is necessary to explore potential applications of smart card data within the context of regional transit authority and of an operator.

DATA

The transit system interacts with the transit clientele in three different situations:

- During the advanced purchase of a fare product from a ticket booth, an automatic ticket vending machine, an authorized ticket vendor or by subscription. This involves a fare product being loaded onto a fare medium.
- During fare validation, when a fare product is consumed for a transit service. This can take place at a validation machine (validator) located at a turnstile inside a métro station, in a bus vehicle, on a train station platform or using a handheld validator. The system distinguishes first boarding, transfer boarding or refused validation.
- During fare verification, when fare product and fare medium are checked for their validity inside the controlled area of the transit network by an inspector with a handheld card reader (verifier).

The smart card AFC system captures all these events. In each of the situations, including unsuccessful attempt, a transactional record is generated, stored and subsequently uploaded to the central server. These can be classified as sales, validation and verification events respectively. Each record represents the communication between a fare medium (thus its holder) and an equipment at a specific time and place. The concept of a transactional record is therefore based on the serial number (unique ID) of the fare medium, the unique location code (ID) of the equipment, a time and a fare product. Depending on the type of host, the location of the equipment can be fixed (e.g. in a station) or variable (e.g. in a vehicle). A simplified diagram of the data flow is illustrated in Figure 2.

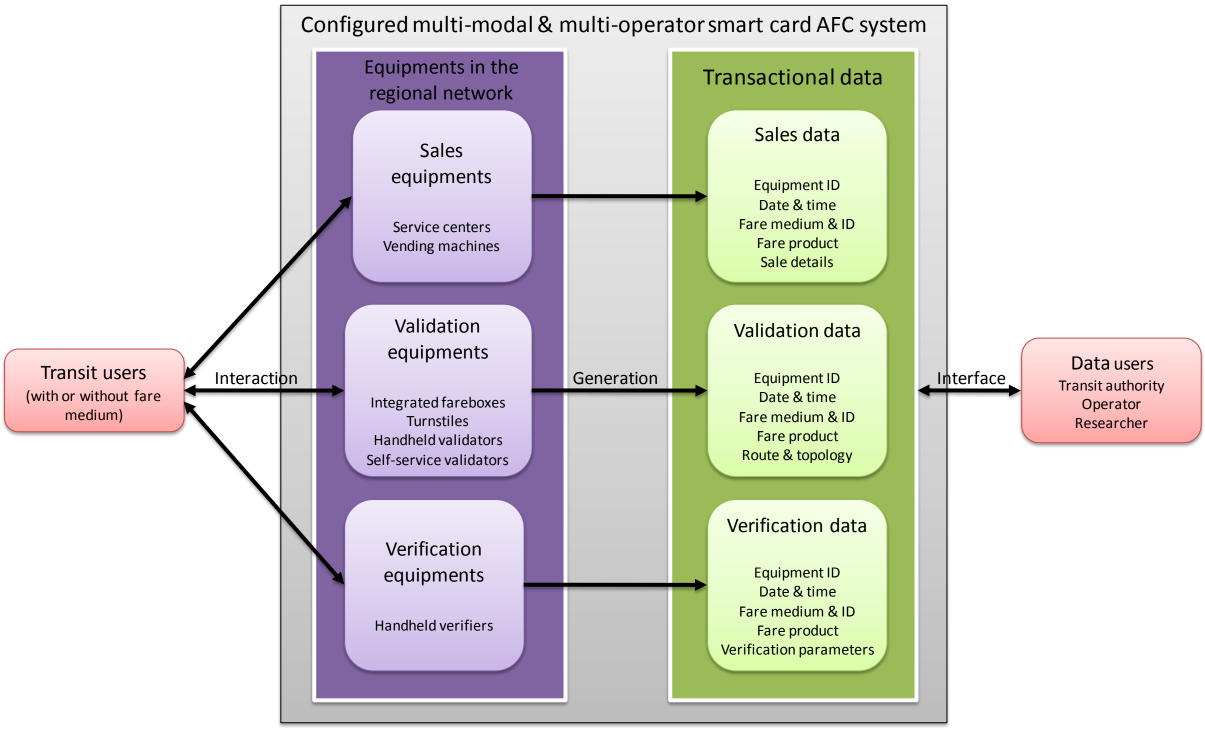

Figure 2 – Simplified diagram of the data flow in a smart card AFC system

A web interface is available to all agencies to generate data reports from the central server. Reports are predefined with the combination of various levels of aggregation on transaction time (e.g. daily or monthly) and on equipment (e.g. a single machine or a group of machines). Disaggregate data, which contains all the details of a transaction, can also be queried. Meanwhile, raw data are available in XML format. An accounting interface, developed outside the OPUS system framework, imports and organizes sales data. It provides a faster and more flexible means to perform queries and process the data for accounting and analysis purposes.

ANALYSES AND RESULTS

Although the implementation is still partial, data can be effectively used for some analyses. They involve measuring:

- boarding and transfer activities of a mode or a network with validation data
- sales of local and integrated fare products with sales data
- usage and purchasing pattern of fare products with validation and sales data
- fare evasion rate with verification data

Illustrations are organized according to the type of data.

Application of Sales Data

A regional transit agency constantly handles a large amount of sales data on local and integrated fare products from transit agencies for accounting purposes. They include the revenue distribution, government subsidies and commissions. The manual data exchange and assembling process is labour intensive, prone to delay and handling error.

Other than for traditional accounting purposes, sales data provide information in a more diverse context and can be used for applications such as:

- the management and marketing of fare products by studying sales volume and spatial distribution
- users' purchase behaviour from a spatial-temporal perspective
- the usage of various types of sales equipment

Figure 3 maps the spatial distribution of the sales of integrated fare monthly pass products by zone. The black dots represent points of sale that sell integrated fare products with OPUS. They include regional termini, commuter rail stations and retail stores. The relative sales intensity for each product group is spatially shown by kernel density and distinctive sales patterns are revealed:

- The CBD, where the termini of five commuter rail lines and regional buses are located, is a major point of sales for all products.
- Sales are important at major intermodal junctions: commuter rail-métro, métro-regional bus, commuter rail-métro-regional bus.
- Otherwise, the sales location of products is highly spatial according to the fare zones.

This information can be used to study of spatial sales pattern and purchase behaviour as well as to target specific clientele in communication campaign.

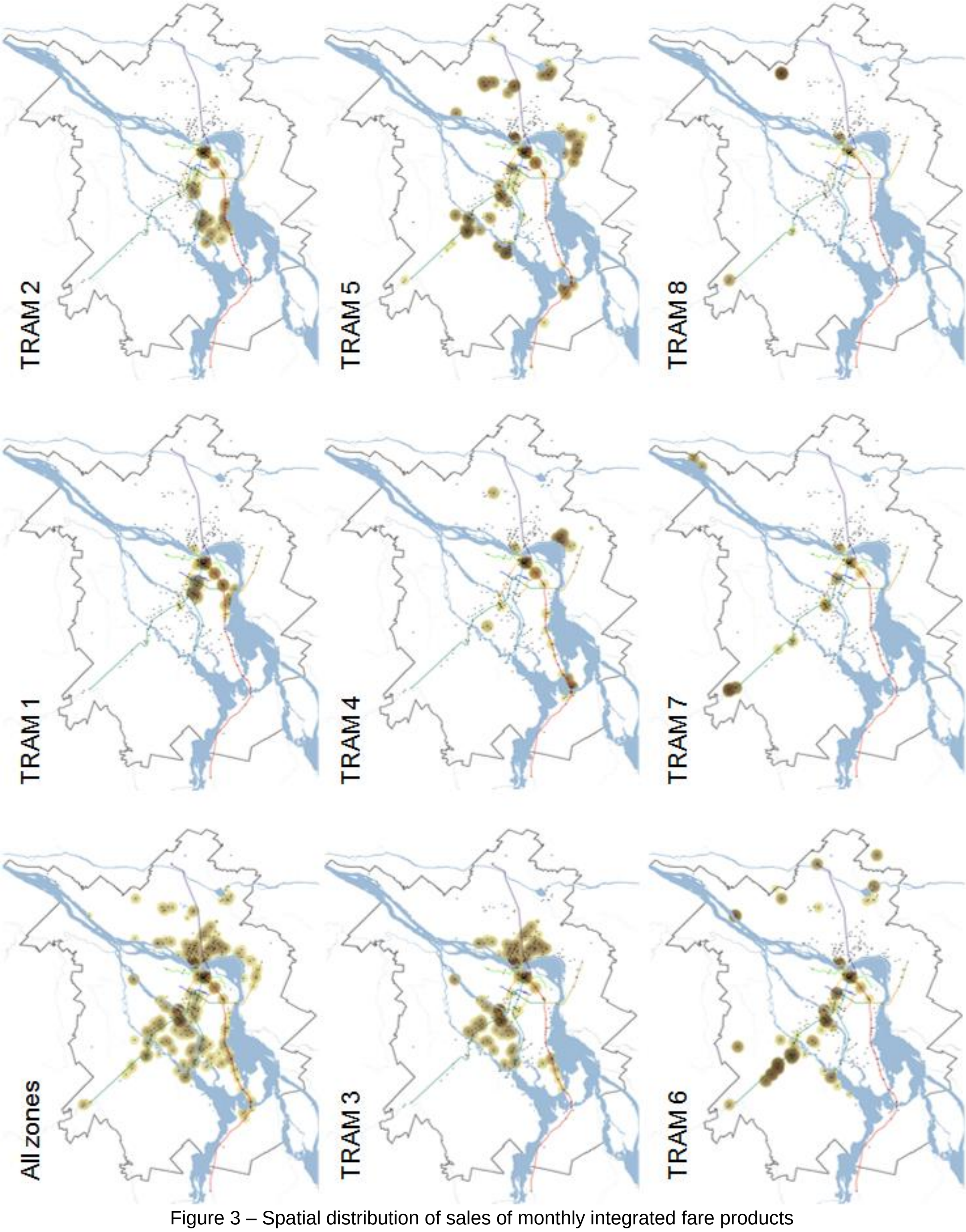

Figure 3 – Spatial distribution of sales of monthly integrated fare products

Figure 4 presents the sales of integrated fare monthly passes of October, November and December 2009 by OPUS as cumulative percentages. The pass is valid for unlimited travel within a calendar month and is available for sale at least one month in advance. With “1” representing the first day of a month and the first day of use for a monthly pass, the figure shows the temporal distribution of sales by day, shedding light on traveller’s aggregate purchase behaviour. Each of the monthly passes has more than 70,000 units sold. About 6% of the sales are completed more than a week before the first day of the month and 98% are completed within the first week of the month. Sales pattern varies slightly from month to month. Only 48% of all November passes are sold one day before the start of the month, compared to 66% and 69% for the October and December passes. It is probably due to the fact that November 1st was a Sunday. As a consequent, about 20% of the purchases are made on the first weekday of the month, which was November 2nd. The data analysis suggests that very few people purchase the monthly pass in advance even though it is put on sale well in advance. In addition, the day of week plays an important role on the purchase pattern of monthly pass. The information can be used by the marketing and public relations departments to encourage advance purchase and to prevent long queue.

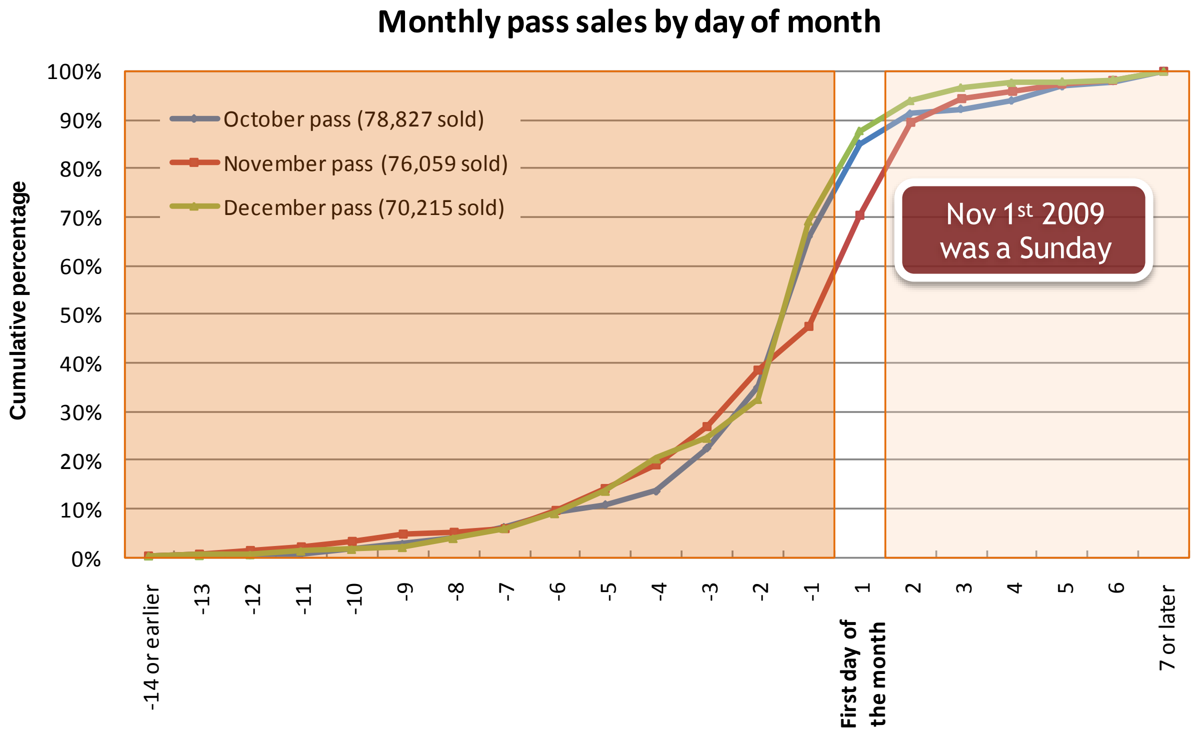

Figure 4 – Sales data for purchase behaviour study

Using disaggregate sales data with transaction time precise to the second, Figure 5 illustrates the combined temporal sales pattern on November 30, 2009 from four automatic vending machines at the Longueuil Terminus. The high level of sales, as illustrated by clients purchasing the December monthly pass, provides an interesting setting to study the capacity and level-of-service of the sale equipments. First, the duration of a sale is calculated from the gap between two successive transaction times, using both successful and unsuccessful sale attempts. Second, the average duration for successful sales for each 15-minute interval is derived. The observed minimum average duration during the day can then be identified. On the one hand, the duration is bounded by the user delay in the lower limit. On the other hand, the duration is determined by a successive transaction. Therefore, by assuming that the capacity is reached at some point during that day (no gap between two users), the observed operational capacity can be estimated.

The observed minimum duration per 15-minute interval is 62 seconds, which gives a maximum capacity of 58 sales per 15 minute for 4 machines combined. This would represent the best scenario in the observation. Considering variance in user delay and time lost due to unsuccessful sale attempts, during intervals with an average duration close to the minimum, namely from 7:00 to 9:29 and 15:15 to 19:14, the automatic vending machines are operated at or close to capacity. A more elaborate statistical model incorporating variance in user delay is envisioned.

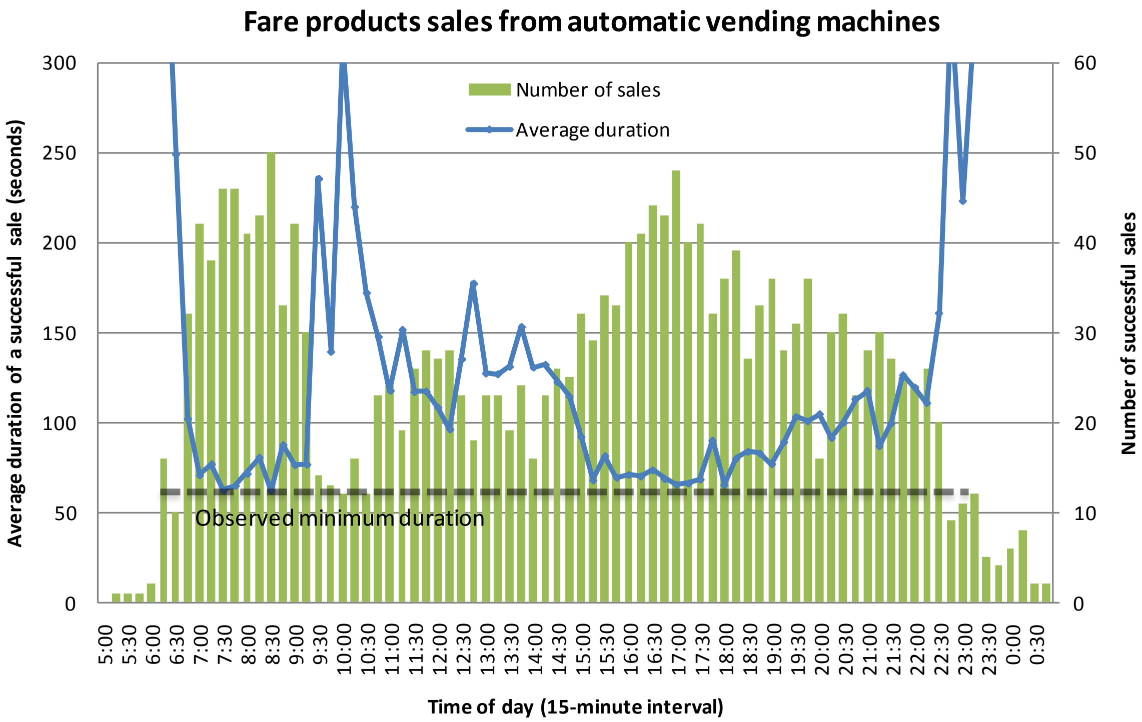

Figure 5 – Sales pattern of automatic vending machines for level of service study

Lesson Learned

Analysis should be performed continuously in order to verify trends and hypotheses. As shown in the purchase behaviour study, special pattern can only be detected with the analysis of several months of data.

Application of Validation Data

Validation transaction records are generated when a client enters the transit network or transfers between modes. As such, the data provide an accurate measure of network usage, including variations due to seasons, incidents and special events. Figure 6 shows the total number of validations in the métro network for the month of November, 2009. They include both first validations (entry into the local transit network) and transfer validations (within the same or into other transit networks) with local and integrated fare products. The size of the pie indicates the cumulative entries in the month and the ridership of each station. This information is up-to-date and can be used for the distribution of government subsidies.

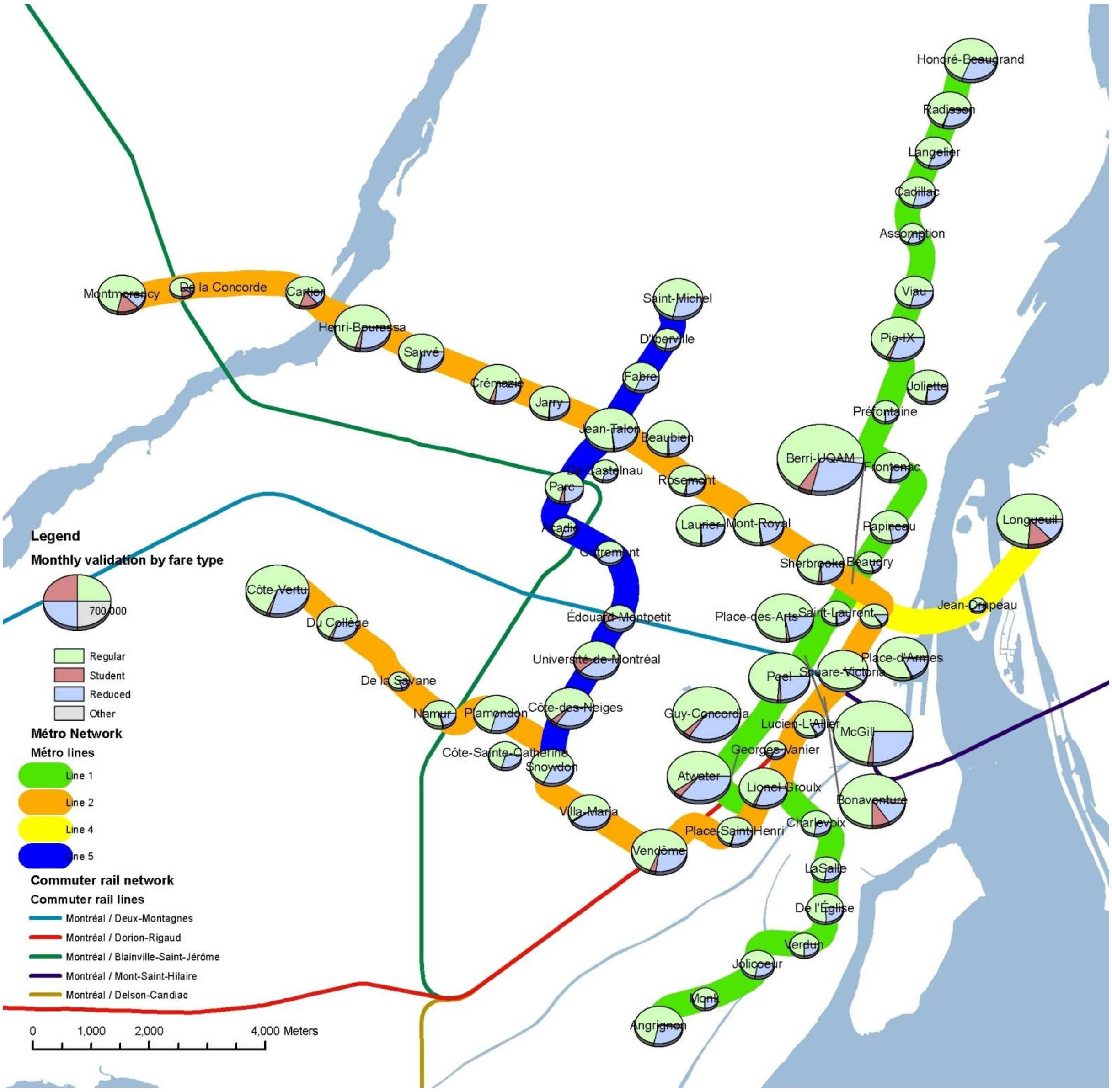

Figure 6 – Monthly validation in the metro network by fare type

Moreover, each entry point of the transit network can be characterized by the type of clientele that it serves by using the fare product as an attribute. Figure 6 displays the share of each fare type at the entry station of the metro network. Fare products are grouped into four types:

- regular – local and integrated fare products used by adults
- student – integrated fare products for students between the age of 18 and 25
- reduced – local fare products for students up to the age of 25, integrated products for people up to the age of 18 and senior aged 65 and over
- other – employee, free and promotional fare products

Université-de-Montréal and Édouard-Montpetit stations on Line 5 have over half of their clientele using student or reduced fare. They are mainly college and university students as there are several educational institutions located nearby. The same dominance cannot be observed at other stations close to universities, namely Guy-Concordia, McGill and Berri-UQÀM, due to a more diverse range of destinations in the CBD. The use of integrated fare products is more prominent at stations outside the Island of Montréal and at Bonaventure where the regional bus terminus is located.

In a more microscopic scale, the within-day validation pattern can be examined. The total number of entries by 15-minute interval in a weekday (Thursday) of three métro stations, namely Longueuil, McGill and Montmorency, is illustrated in Figure 7. Although the number of entries at Longueuil station doubles that of Montmorency, both stations exhibit very similar usage pattern. They have a strong AM peak (6:00 to 8:59), accounting for almost half of the daily ridership; a noticeable PM peak (15:30 to 18:29) with about 16% of the daily ridership; a stable mid-day ridership and a weak off-peak. Their similarities may be explained by the fact that they both are regional transit terminus located in the suburb with many transfer activities. In contrast, McGill station, serving important destinations in the CBD, displays another usage pattern. It is characterized by an intense PM peak, accounting for half of the daily ridership. There are also important off-peak activities. The small peak from 21:00 to 21:14 coincides with the store closing hour on Thursdays. In addition, the temporal dynamic allows operators and planners to evaluate the level-of-service of transit services and of validation equipments.

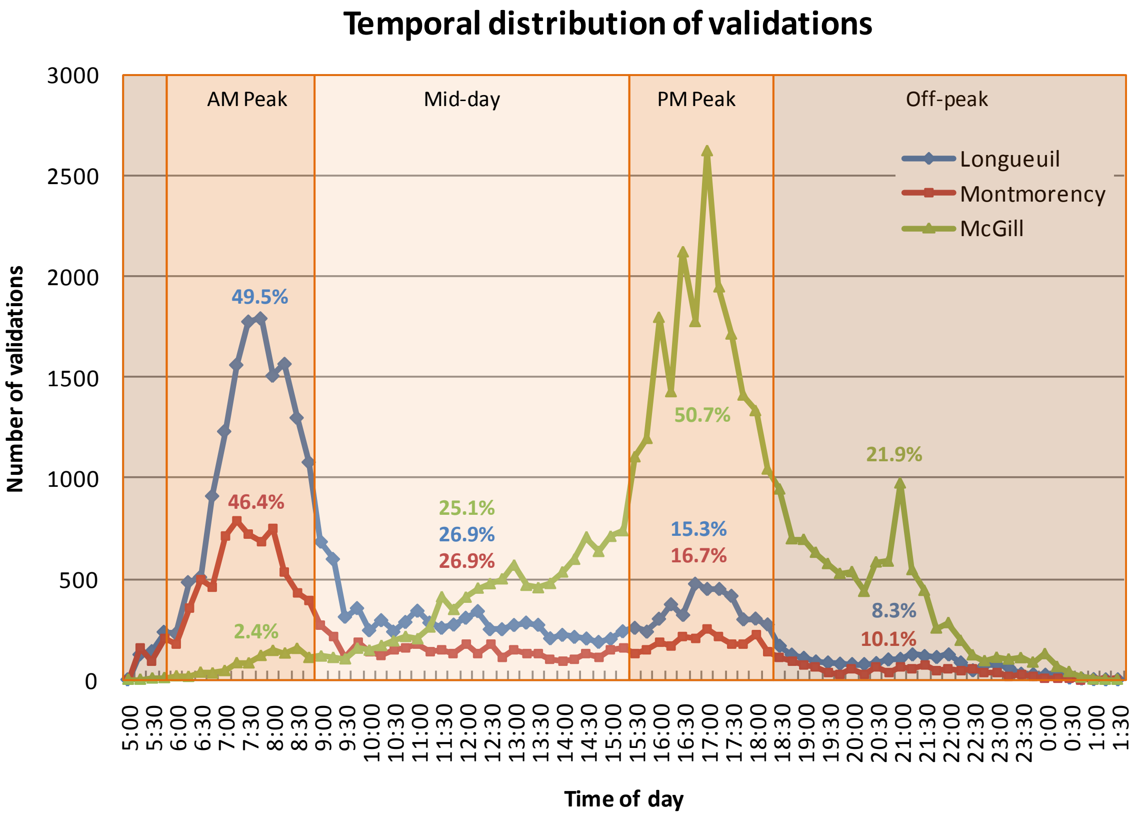

Figure 7 – Temporal distribution of validations in three metro stations

For finance and marketing purposes, detailed information on how often and when a fare product is used is captured. This is especially important for unlimited travel passes, since this information is required for distributing revenue from integrated fare products and government subsidy on fare integration.

The Advantage of Disaggregate Fare Validation Data

Data such as station turnstile counts, vehicle on-off counts and farebox data provide aggregate network usage indicators. The disaggregate fare validation data from the smart card AFC system, with post-processing algorithms, allow:

- the synthesis of spatial-temporal load profiles of each individual run in a bus network and details on individual itinerary (Chu and Chapleau, 2008)
- the continuous data collection on the transit network and its users (Chapleau et al., 2009)
- the study of travel behaviour related to public transit of both an individual and people affiliated to the same group (Chu and Chapleau, 2010)

An important advantage of disaggregate fare validation data is that transaction data can be studied by individual card. It can be highlighted with the following illustration: instead of computing an average number of transactions for a fare product as a ratio of total number of transactions and the total number of product sold, disaggregate data provide the number of transactions for the product on each card. As a result, a distribution of usage rate across all holders of the same product can be known. At the same time, it is possible to merge information on the usage rate of other fare products loaded on the same card.

The concept used in financial mechanism, network usage measured in passenger-kilometres, can be addressed with disaggregate validation data. The current practice of fare usage survey can be enhanced with continuous and up-to-date validation data from the whole population of transit users. Alighting location for each fare validation can be estimated by studying multi-day transaction history of individual card. Using a regional transit network model that handles disaggregate trip data, such as the MADITUC model in Montréal (Chapleau, 1992), trip segments and itinerary can be derived. This allows the calculation of passenger-kilometres consumed on each local network.

Validation data can be used to calibrate transit network assignment model and complement other surveys such as the large-scale origin-destination survey where public transit trips may not be sufficiently sampled in areas with low transit share.

Lessons Learned

It is important to recognize the limitation of an entry-only AFC system. Some heavy-rail networks and bus networks use a distance-based fare system and require tap-in at entry and tap-out at exit. This effectively provides the origin and destination pair of each trip segment. However, for systems not requiring tap-out, destination needs to be estimated with algorithm. In cases where several fare products are valid on the same card, the smart card AFC always choose the one with the highest priority, which does not necessary match the one which is required for the journey. This confusion must be taken into account when calculating fare product usage rate and network usage indicators.

On-board distance is calculated based origin and destination. As mentioned before, some validation equipments are quasi-permanently placed at a fixed location, while others are placed inside a moving object or handheld. The latter requires a system, usually the GPS, to georeference the transaction location in order to acquire the origin and destination pair. Otherwise, spatial aggregation or new algorithm that makes use of route information and multi-day boarding pattern of a route is needed. However, even when the validation data are location-stamped, the locations need to be validated and corrected as the literature shows that the amount of errors is significant (Furth et al., 2002; Utsunomiya et al., 2006; Chu and Chapleau, 2007).

Application of Verification Data

AMT operates a commuter rail network which uses a self-service and barrier-free system. There is no turnstile at the entrance and users are responsible to validate their ticket when entering the controlled area and to keep a proof of payment during the journey. AMT employs a team of inspectors who regularly perform three types of inspection to deter fare evasion:

- on-board
- at the entry station
- at the exit station

There are numerous issues regarding a self-service and barrier-free system (Multisystems et al., 2002) and data generated by OPUS have the potential to address some of them, particularly in:

- measuring more accurately the fare evasion rate
- monitoring the productivity of the inspectors
- improving the inspection strategy

Verification data are generated by a handheld verification unit which reads a rechargeable or a disposable smart card. According to the parameters entered by the inspector, which include the inspector identification number, the type and the location of inspection, the unit determines whether the fare product is valid. In addition, the unit records the exact time and the reason of refusal. The inspector also verify the whether the client is the legitimate owner of the card with reduced fare privilege. In contrast, methods that rely on inspectors' field report only provide approximate data, which affects the reliability of fare evasion measure.

Fare evasion can be analysed by date. Figure 8 shows the daily number of verifications for November 2009 in the commuter rail network. It also shows the evasion rate which is the ratio between the number of infractions and the number of verifications. Fare evasion rate can also be analysed by day of week (Table 1). The preliminary result suggests that the level of evasion may vary across days. It is also possible that the fluctuation can be explained by the fact that evasion can be more easily captured on some days. Data on the type and location of inspection allows analyses by train line and fare zones, as illustrated in Table 2.

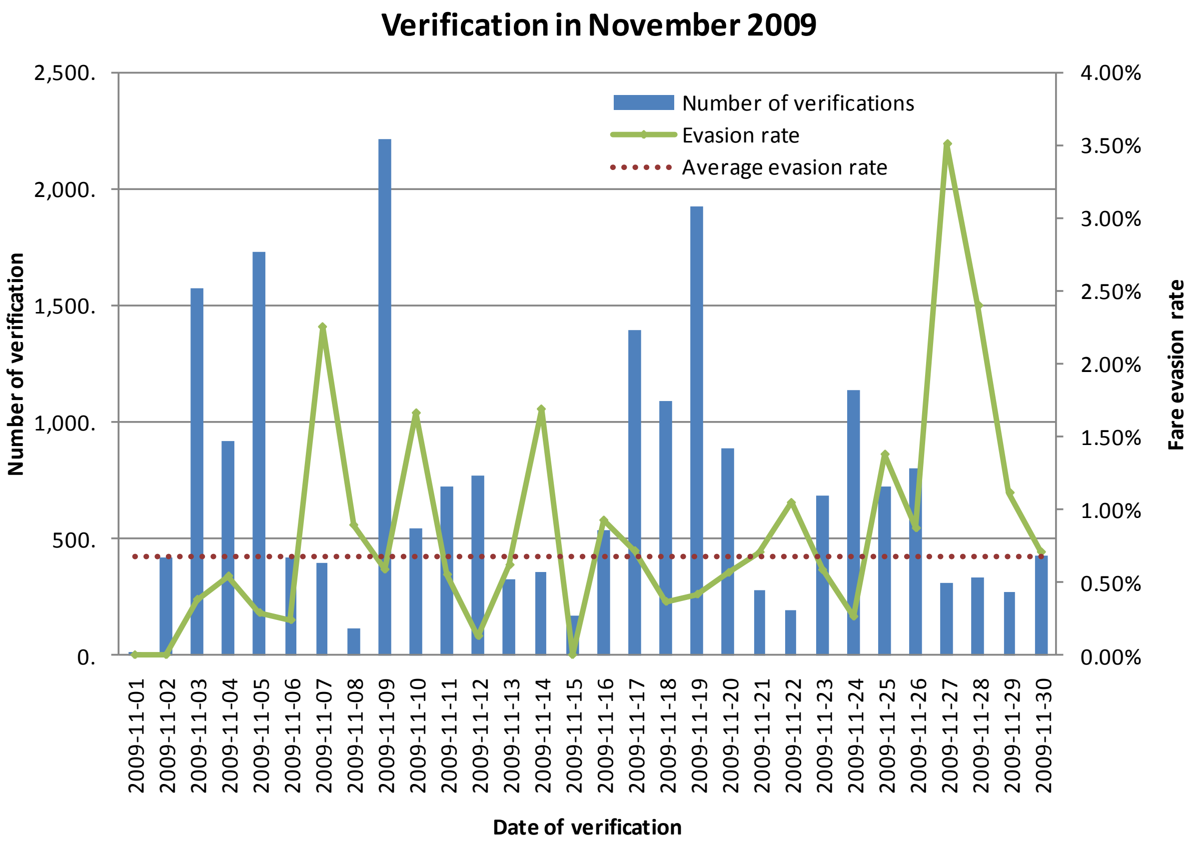

Figure 8 – Verification in November 2009

Table 1 – Evasion rate by day of week

Day of weeks	Number of infractions	Number of verifications	Evasion Rate
Monday	25	4,278	0.58%
Tuesday	28	4,648	0.60%
Wednesday	23	3,464	0.66%
Thursday	21	5,221	0.40%
Friday	19	1,937	0.98%
Saturday	25	1,370	1.82%
Sunday	6	751	0.80%
Total	147	21,669	0.68%

Table 2 – Evasion rate by fare zone and station on the Deux-Montagnes line.

Line	Fare zone	Station	Number of verifications	Number of infractions	Evasion rate
Deux-Montagnes	1	Centrale	1407	8	0.57%
		Canora	592	15	2.53%
		Mont-Royal	158	1	0.63%
		Montpellier	1545	8	0.52%
	2	Du Ruisseau	871	7	0.80%
		Bois-Franc	248	8	3.23%
		Sunnybrooke	264	1	0.38%
		Roxboro	1062	4	0.38%
	3	Île-Bigras	69	0	0.00%
		Ste-Dorothée	263	3	1.14%
		Grand-Moulin	42	0	0.00%
	5	Deux-Montagnes	186	0	0.00%
		St-Eustache	2	0	0.00%
	Unknown		72	0	0.00%
	Total		6781	55	0.81%

Lessons Learned

The burden of recording the number of verifications, date and time is lifted from the inspectors. At the same time, the productivity of inspectors can be measured as they are required to log onto the handheld verifier. However, analysis results are largely dependent on the accuracy of the parameters entered into the unit by the inspector. The unit merely acts as a device which facilitates the inspection and the recording of data. For example, analysis of productivity implies that inspectors log on with the correct ID number and fare evasion analyses assume the type and location of inspection are correctly entered.

Since inspections are performed on a sample of transit users, the evasion rate can be biased if there is no sound inspection strategy. Analysing verification data helps to identify weakness in strategy and to improve it.

For on-board inspection, there is a possibility of associating inspection records with train departure using disaggregate data. By integrating with the time stamp of verification data with timetable or, preferably GPS data, evasion rate by train departure can be studied.

CONCLUSION AND PERSPECTIVE

This paper explores the confluence between data from a multi-modal and multi-operator smart card AFC system and the data needs of a regional transit authority. Three types of data are generated by interactions between the users and the system, namely sales, validation and verification data. Unlike traditional surveys or data collection methods, smart card AFC system continuously provides detailed data from the whole transit user population. Even though system deployment is not complete in the region and tools are still under development, basic analyses with available data demonstrate that smart card data can make significant contributions in the following areas:

- measuring ridership
- revenue and subsidies distribution according network usage
- fare product management and marketing
- understanding travel and purchase behaviour of users
- management of regional transit equipments
- measuring fare evasion

The types of analysis can easily be generalized and transferred to transit agencies with similar smart card AFC system.

To further the use of smart card data, issues need to be addressed:

- The current fare control strategy is entry-only and in the case of commuter rail, an honour system in a barrier-free environment. These two constraints represent the biggest obstacle to obtain unbiased and accurate origin and destination data for applications such as revenue distribution and demand modelling. Recent research shows that alighting location estimation is achievable and the use of multi-day data has the potential to improve accuracy.
- The data query interface and reports provided by the proprietary system have limited flexibility and do not necessarily answer to the day-to-day needs of a transit authority to compile information and perform analyses. Similar to the accounting interface for sales data, fare validation data repository and interface are needed in order to facilitate queries and large-scale post-processing.
- Frequent changes in fare products, equipments, operations and other parameters in a multi-operator system require the assembling and regular updates of a reference dictionary that can relate to the codes used in the system.
- Data storage and processing procedures need to be capable of handling the large amount of data generated in a regional transit network. This is especially true when complex algorithms are required to validate, correct and enrich the data.
- Data processing and analysis should not compromise the privacy of transit users.

The role of smart card data will eventually become more important as smart card AFC systems are now increasing common and tools to exploit the data mature. The next steps aim to derive network usage data and trip details, such as destination, passenger-kilometre and trip purpose, from multi-day validation data as well as to extend the understanding of travel and purchase behaviour of the clientele. These would help a regional transit authority to refine the financial mechanisms and to devise more suitable products and services.

The results and views expressed in this paper are the sole responsibility of the authors and do not necessarily reflect those of the Agence métropolitaine de transport (AMT) or other transit operators in the region.

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