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Overview Paper

Smart card data use in public transit: A literature review

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ABSTRACT

Smart card automated fare collection systems are being used more and more by public transit agencies. While their main purpose is to collect revenue, they also produce large quantities of very detailed data on onboard transactions. These data can be very useful to transit planners, from the day-to-day operation of the transit system to the strategic long-term planning of the network. This review covers several aspects of smart card data use in the public transit context. First, the technologies are presented: the hardware and information systems required to operate these tools; and privacy concerns and legal issues related to the dissemination of smart card data, data storage, and encryption are addressed. Then, the various uses of the data at three levels of management are described: strategic (long-term planning), tactical (service adjustments and network development), and operational (ridership statistics and performance indicators). Also reported are smart card commercialization experiments conducted all over the world. Finally, the most promising research avenues for smart card data in this field are presented; for example, comparison of planned and implemented schedules, systematic schedule adjustments, and the survival models applied to ridership.

1. Introduction

Although the smart card is being used more and more by public transit agencies, this technology is not new. The first patent was published in 1968 by two German inventors, Dethloff and Grotrupp, who developed the concept of a plastic card containing a microchip (Shelfer and Procaccino, 2002). In 1970, the Japanese followed the lead of the Germans and registered a patent for their own version of the smart card (Attoh-Okine and Shen, 1995). At the end of 1970, Motorola developed the first secure single chip microcontroller, which is used by the French banking system to improve security in transactions. However, it is since 1990 that the use of the smart card has become significant, with the exponential growth of the Internet and the increased sophistication of mobile communication technologies (Blythe, 2004).

Smart card technology has begun to enter the market, and attempts are being made to use it in many areas of business activity. Attoh-Okine and Shen (1995) remind us that Germany has been using the smart card for health care since 1992, and it was adopted in France for postal, telephone, and telegraph services in 1982. In fact, the smart card (contactless or otherwise) is used in many sectors: health care, banking, government, human resources and, of course, transportation. The card is

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used to store identification, biometrics, photos, fingerprints, medical data, DNA results, religious affiliation, banking data, transportation fares, and other individual data.

Transit agencies are interested in this kind of technology, and many of them are now using the smart card to replace the traditional magnetic card, or tickets, as a viable payment option (Blythe, 2004). It is perceived as a secure method of user validation and fare payment (Trépanier et al., 2004). It also makes the driver's job easier, as he or she no longer has to collect the fare. Furthermore, the smart card improves the quality of the data, gives transit a more modern look, and provides new opportunities for innovative and flexible fare structuring (Dempsey, 2008). While smart cards are mostly in use in Europe and Asia, they have now been implemented in Canada, especially in Québec, where all major transit operators are equipped with smart card technology. The government of the United States has the stated intention of establishing world-class transit systems throughout the country, and the smart card is expected to play a role in achieving this goal (United States Department of Transportation, 2010).

This review focuses on the use of smart card data in the transit field, showing that data can be used for many purposes other than the one for which smart card systems were designed, which is revenue collection. This paper is intended to fill the gap between the technical elements of smart card systems, which are documented in technical journals, and the potential applications of the huge amount of data collected by these systems. Here, transit planners and researchers, smart card systems vendors, and transportation decision makers – that is, everyone interested in smart card payment systems – will find examples of what can be done with the data collected. This could help them to justify the implementation of a smart card system or to recognize the value of the ones already in place. In addition, the paper could help enhance the use of other data collection systems by transit authorities, because these systems sometimes collect the same types of information (automated vehicle location, on-board count systems, surveys, etc.).

Section 2 presents the technologies related to the use of the smart card in public transit networks, as well as the associated standards. An example of the information system that is necessary to support smart card implementation and the various objects that could be involved in data analysis are described in Section 3. Section 4 reviews the work that has been conducted over the years with smart card data. The topics in this section are divided according to management level and in terms of the type of analysis: strategic, tactical, and operational. Section 5 summarizes some efforts that have been made to commercialize the public transit smart card by adding financial services and commercial advantages to its use to increase its popularity among travelers. Finally, a discussion synthesizes the advantages and disadvantages of the smart card, compares this revenue collection method with other existing methods, and presents some research perspectives on the smart card field, based on work already carried out or currently under way.

2. The smart card

This section describes smart card hardware and standards, and then focuses on smart card automated fare collection systems for transit use. An example of an accompanying information system is given, in order to identify the various objects associated with the smart card collection process.

2.1. Features

Smart cards are devices designed to store and, in most cases, process data. They are very portable (the size of a credit card) and durable (Lu, 2007), which makes them suitable for many applications involving identification, authorization, and payment. Since the invention of the card in the 1970s, the technology has evolved, and many features have been added to the original concept (Shelfer and Procaccino, 2002).

- The card can be equipped with memory only (a memory card), or with memory and a small microprocessor to execute preprogrammed tasks.
- A *contact* card (usually a memory card) is placed in direct contact with the reader, while a *contactless* card communicates with the reader by high-frequency waves similar to radio frequency identification (RFID). The energy needed is provided by the electromagnetic field generated by the reader.
- The data on the card can be either encrypted or unencrypted. The triple data encryption standard (3DES) is often used to encrypt data.
- The amount of memory on the cards varies, depending on the application. Blythe (2004) suggests between 2 and 4 kb to store financial data, personal data, and transaction history. Nowadays, up to 64 kb is available. Usually, less memory is needed in public transit applications, since most of the information is not stored on the card itself (see Section 3).

In the contact smart card, a chip is embedded within slices of plastic, but the surface of the chip must not be covered, because it has to be able to be brought into contact with the chip reader for data recognition. In the contactless smart card, the chip can be completely embedded within plastic, but is usually visible. A small antenna is also installed in the contactless card, which makes smart card technology similar to radiofrequency identification (RFID) technology.

2.2. Standards

Like many telecommunications technologies, smart card hardware must be compatible with international standards. Contact-based smart cards are usually covered by ISO/IEC7816, which defines the contact plate layout and usage (parts 1 and 2 of ISO7816), the electrical interfaces (part 3), and the selection of applications (part 4) (Hendry, 2007). For contactless cards, there are several standards that cover the lower levels of interface between cards and terminals (Table 1). The standards define the signal frequency and the data transmission speed. The activation distance is bounded by these parameters and the reader technology used. In transit applications, an activation distance of 10 cm is sufficient, because the cards are usually tapped over the reader when the user enters the vehicle. In public transit, the systems are usually closed, which means that the operators issue their own card, and it is used only for their system. An open system would allow the smart card to be used for other purposes, such as retail transactions and parking payment.

2.3. Privacy concerns

The nature of the data available on a smart card is raising major privacy concerns on the part of users, and is an issue that has been debated in some research studies. This debate is evolving, along with the larger issue of security in transit systems. In some cases, the increase in the amount of information stored can be viewed as an improvement in security, because the operator has considerable knowledge of the location of users, and this can be used as evidence in police investigations (Dempsey, 2008). The following elements of smart card use have been identified as having a critical impact on privacy (Table 2).

As reported by Clarke (2001), the concerns related to smart card usage are about the same as those for credit cards, cell phone communication, and other tracking technologies. In theory, the nature of the smart card system makes it vulnerable to identity theft, or to the misuse of behavioral information. Data could be intercepted with a hidden terminal placed at short range, and hackers could target the onboard terminal itself. Of course, exchanges between the cards and the terminal are normally encrypted, but the most vulnerable part of the system is the centralized database storage of transactions and card holder information (Reid, 2007).

The linking of smart card use to an individual's demographic or socioeconomic information is not likely to be accepted by users (Cottrill, 2009). Separation procedures can be applied to isolate transactions from card holder information, and one way encryption protocols can be used to re-encode card numbers, making it impossible to trace data back to individual users (Dinant and Keuleers, 2004). In most of the studies presented in Section 4, personal user information was not made available to the researchers.

3. Public transit implementation

International standardization of the higher layers of smart card applications is not widely accepted, and consequently each sector has developed its own standards (Hendry, 2007). In public transit, the most popular standards bodies are the ITSO (Integrated Transport Smartcard Organization, 2009) and the Calypso network of associations (Smart Card Alliance, 2009). ITSO is a nonprofit organization (NPO) supported by bus operators, train companies, industry suppliers, and regional and local authorities, mainly in the UK. Their specifications cover the cards, the terminals, the information systems, and the data format protocols. Calypso is also linked to an NPO, one that provides support for ticketing, payment, and services.

Smart card automated fare collection systems are now widely implemented all over the world. The concept is well advanced in Europe, especially in France, the UK, and Italy. It is also extensively used in Asia. In the United States, there are implementations in New York, Washington, Chicago, and San Francisco, and in more than 10 other metropolitan areas. In Canada, the card is implemented in transit systems in the Gatineau region of the province of Québec, and in Montreal, Kingston, and Brantford, with planning ongoing in others. The smart card is also increasingly being used in South America, for example in Santiago, Chile (Munizaga et al., 2010).

Table 1
Characteristics of some contactless smart card standards (based on McDonald (2000)).

Technology	Frequency (MHz)	Data transmission speed (kbps)	Activation distance	System	Applications
ISO/IEC14443 (Type A or B)	13.56	106	10 cm	Open or closed	Transport, off-line purchasing, vending, and physical access control
ISO/IEC15693 Vicinity card	13.56	26	Up to 1 m	Closed	Physical access control, ticketing, parking, and drive-thrus
Felica ISO/IEC15408 EAL4	13.56	212	n/a	n/a	Transport, identification, and others
NFC (Near Field Communication) ISO/IEC18092	13.56	212	Up to 20 cm	Open	Payment
EZ-PASS Proprietary Ultra-High-Frequency Technology	902, 928 and 5900	n/a	3–10 m	Closed	Highway toll booths and fast-food drive-thrus

Table 2
Principal sources of concern about the smart card (based on Dempsey (2008)).

Concerns	Impact
Type of information gathered	The information can be linked to prepayment functionality, financial and trip data, personal information (passenger name, home and work address, age, and gender), biometric identification, and information on the possible criminal activity of passengers
Potential uses of the information gathered	The smart card can be used solely for fare payment, planning, and advertising purposes, and to monitor the personal behavior of individuals in the network
Who has access to the information?	Should the information be available only to authorized transit agency personnel, shared with other institutions, or be broadcast to the general public? There is a need to implement a strict system for accessing data (Schwartz, 2004)
Implications for personal privacy	Advances in technology have outpaced personal privacy law (Archer and Salazar, 2005)
Uses for the smart card	If the smart card is used for multiple purposes, there is a risk of creating a central database that stores all kinds of personal information

3.1. An example of implementation: Gatineau, Quebec

In public transit, the use of smart cards for payment requires the existence of a corporate information system, which makes it possible to validate the use of the card through the network, while storing transaction data for its financial accounting process. The *Société de transport de l'Outaouais* in Gatineau, Quebec, is a mid-sized transit agency that implemented a smart card fare collection system in 2001 (Morency et al., 2007). Its 200 buses are equipped with contactless smart card readers that are linked to a GPS device. The fare structure is divided into student, adult, and senior categories. There are different fares for regular, express, and interzonal routes.

The information system data flow is shown in Fig. 1. The central server (called the "SIVT" in the figure) stores data on card holders and all transactions, and comprises the core of the system. Note that user and validation data are not stored in the same database, in order to preserve the confidentiality of the information. In the central server, data on routes, schedules, and bus allocation are provided by the service operation information system. These data are transferred to the onboard card readers on a regular basis. When the smart card is read in the bus, the status of the card is validated: fare expiration date, compatibility of the fare with the type of service, and verification that the card has not been blacklisted (for fraud or falsification). The information on the transaction is stored in the onboard device, and then transferred to the central server asynchronously, each time the bus returns to the garage. For accounting purposes, information is also exchanged between the smart card issuing and reloading locations, the corporate accounting system, and the central server.

Typically, this is what is stored at each onboard validation point: date and time of the validation, status of the transaction (boarding acceptance, boarding refusal, and transfer), card ID, fare type, route ID, route direction, stop ID, bus ID, driver ID, run ID, and internal database ID.

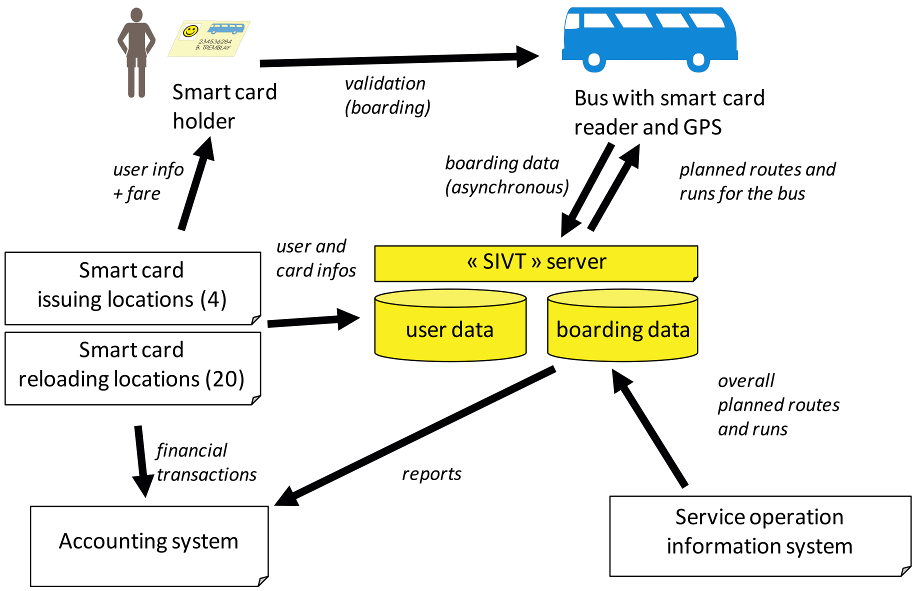

Fig. 1. An example of a smart card information system ("SIVT"; "user and card info" above).

3.2. Transit smart card object-oriented model

Looking at the database alone is not sufficient to gain an understanding of the full potential of the use of smart card data for planning purposes. Fig. 2 presents the transportation object-oriented model of the smart card in a transit context (Agard et al., 2006). This modeling was developed by Trépanier and Chapleau (2001) to better assess the multiple dimensions involved in that context: the elements that move on the transportation network (dynamic objects), the elements that channel transportation modes and describe the movements (kinetic objects), the elements that characterize land use and fixed infrastructure (static objects), and, finally, combinations of elements (system objects).

In the transit smart card area specifically, four sets of objects have been identified:

- The network objects are associated with the part of the transit network that is visible to smart card holders. In the case study (Fig. 2), there are 57 routes and 1858 stops, making up 7262 route-stops (possible passage points for the 30,430 bus runs).
- The operations objects are associated with the internal functioning of the transit authority. In the case study, 289 drivers and 201 buses are involved in 377 "work pieces", which can be repeated every weekday or during weekends.
- The administrative objects are linked to the smart card system itself. The 11,573 cards were issued at one of the 106 points of sale, and generated 387,588 transactions during that month.
- The demand objects represent user behavior. In this case, the number of users is equal to the number of cards, because the cards have a photo ID, and so can be used by that individual only. Among the transactions, 378,260 were identified as trips, because they were declared valid by the system and included route-stops. For each trip, a vanishing route is created on the network to estimate the alighting point (Trépanier et al., 2007).

3.3. Comparison with other fare collection systems

This section compares smart card use to other forms of payment for public transit: cash, prepayment (tickets, monthly passes), and magnetic cards. The comparison is based on the criteria presented by Vuchic (2005) for the evaluation of fare collection systems:

- *User convenience:* The smart card is a permanent fare payment method which can be used over a number of years. This makes it much more convenient than magnetic cards, which are not as durable, or regular tickets. In addition, the smart card does not require the user to insert the card in a reader, as is the case for magnetic cards (Blythe, 1998).

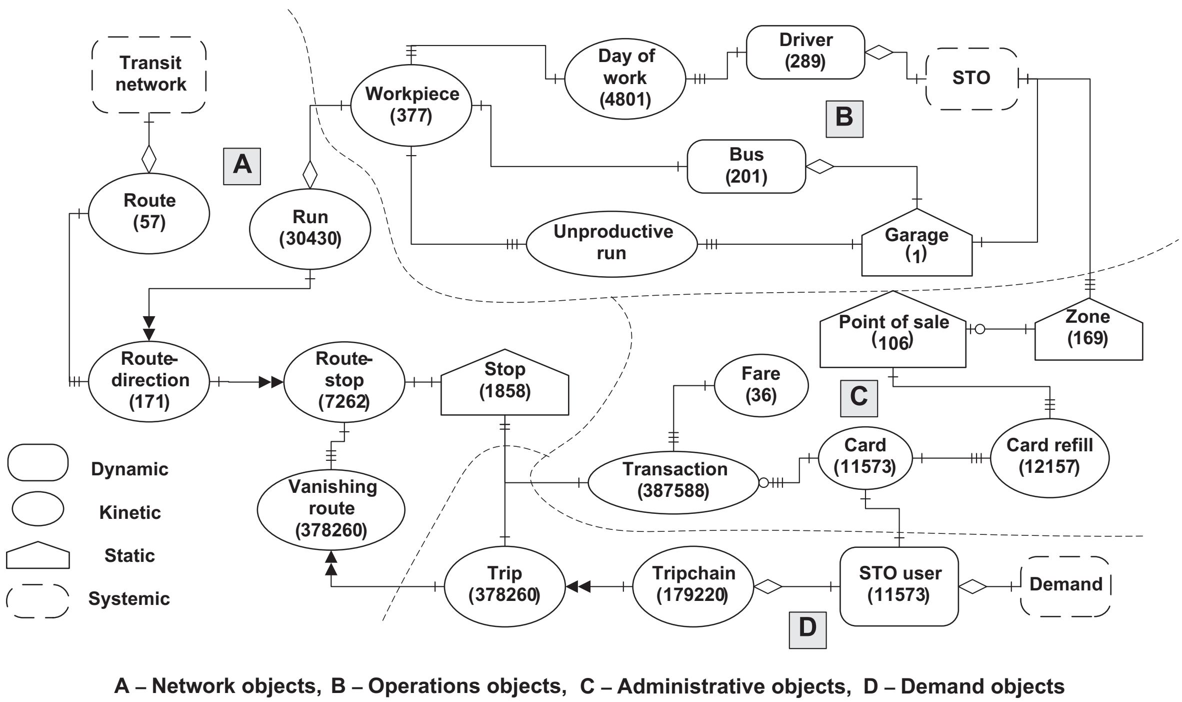

Fig. 2. Transportation object-model of the smart card in transit (Société de transport de l'Outaouais, July 2003 data) ("trip chain" above).

- *Vehicle delay:* Interactions between a smart card and a reader are quite quick on boarding a vehicle (about 1.5 s), and so boarding is much faster than with cash-based payment (White, 2010). This situation can be improved by implementing self-service fare collection, where users can board the vehicle by any entry. Smart card readers placed at each door then ensure that the fare is collected.
- *Ease of monitoring payment:* Relative to magnetic cards and other forms of automated payment, smart card transactions are easy to compile to produce accurate financial reports for the transit authority.
- *Cost of equipment:* The smart card requires a capital investment for the equipment aboard the vehicle or at stations, plus the information system infrastructure and the dedicated staff. This is seen as a major disadvantage of the system, but the equipment can be made more profitable by adding other functions, such as cash-counting devices, automated route display, and driver-related management roles. In general, transit authorities spend about 5–15% of their revenues on collecting and processing fares for tickets, on collection boxes, and on equipment maintenance and staff (Smart Card Alliance, 2010). The implementation of a smart card fare collection system can help to reduce this part of the cost, and would justify the relatively high investment required.
- *Fare deposit security:* Like magnetic cards, the smart card reduces fraud, because it validates the right to travel each time a user boards a vehicle or enters a station. The correct reporting of tickets and cash payments is time-consuming and demands a large number of staff.
- *Interoperability*: This is the ability to use different fare structures and types. Smart cards can support different fare types at the same time, and the system can validate boarding and prioritize fares. Moreover, the fare structure can be modified by reprogramming the reading devices. Complex fare structures with multiple zones are difficult to implement with traditional ticketing and monthly passes, because sometimes the system must validate at both the entry and exit points, which is incompatible with the driver's role.

3.4. Advantages and disadvantages

In recent years, justification of the use of smart card fare collection systems has been debated in several countries. The major investment required for implementation (about $100 million CDN for the Montreal area (AMT, 2007)), along with the technical difficulties that arose in the early installations, have caused hesitation among promoters. However, these days, the technology has improved and the benefits have become evident. Table 3 presents the advantages and disadvantages revealed in the literature review. On the positive side, authors report long-term cost reduction, flexibility in pricing options, potential information sharing, and better revenue management. On the negative side, the question of the high implementation costs, technological complexity, and slow social acceptance are seen as possible obstacles. In most cases, external

Table 3
The pros and cons of smart card use in public transit.

Advantages	Disadvantages
• The user role in data collection previously achieved by the survey process is minimized (Bagchi and White, 2004)	• No information on trip purpose or on user assessment of service can be provided (Bagchi and White, 2005)
• Trip data combined with personal data improves data quality and increases the amount of statistics available (Bagchi and White, 2005)	• The user's ultimate destination is not provided, despite a method to deduce it (Bagchi and White, 2005)
• Examining travel behaviors by "reconstructing" user trips is easier than doing so by studying existing data (Bagchi and White, 2005)	• The research and development cost is high (Deakin and Kim, 2001)
• The feasibility and convenience of a variety of pricing options for road use, parking, and transit fares are improved (Deakin and Kim, 2001)	• The introduction of new components and processes into systems is complex (Deakin and Kim, 2001)
• A universal payment method for a number of systems (Deakin and Kim, 2001) and integration with other transportation fare collection activities (Cunningham, 1993) are provided	• The cost of implementation is high (Deakin and Kim, 2001)
• Cost is reduced (McDonald, 2000)	• There is a high risk associated with investing in smart card technology (Deakin and Kim, 2001)
• Service is improved (McDonald, 2000)	• Institutional change is slow (Deakin and Kim, 2001)
• Flexible and creative fare policies are implemented (McDonald, 2000)	• Social acceptance is slow (Deakin and Kim, 2001)
• Revenue management is improved (McDonald, 2000)	• There is a need for service providers to undertake surveys to confirm analysis of use and assumptions made (Bagchi and White, 2005)
• Convenience and system utilization time are improved for users (Bagchi and White, 2005)	• There is no guarantee of profitability improvement (McDonald, 2000)
• The user's perception of public transport is improved by using new technology (Ibrahim, 2003)	• The success of the implementation often depends on the users (McDonald, 2000)
• The payment mechanism and information flow are improved (Blythe, 2004)	• Market penetration needs to be sufficient to provide a representative sample of the entire population (Utsunomiya et al., 2006)
• The potential for information-sharing offers innovative revenue-earning possibilities (Blythe, 2004)	• The more complex the card, the less its reliability is guaranteed (Blythe, 2004)
• The life span of the smart card is longer than that of traditional cards (Utsunomiya et al., 2006)	
• The user's boarding time is reduced (Chira-Chavala and Coifman, 1996)	
• The driver's workload is reduced (Chira-Chavala and Coifman, 1996)	

funding seems to be necessary to initiate large implementation projects (Iseki et al., 2007). However, there are many organizational patterns that can be used to acquire, operate, and maintain smart card payment systems (Transit Cooperative Research Program, 2006): the private corporation (as in Hong Kong), public single operator ownership (as in London, UK), a joint power authority (as in Singapore), or a public–private partnership (as in Scandinavia).

4. Data use in transit

Several studies have been conducted in recent years on the use of smart card data in public transit. To better assess these studies, they have been grouped here into three categories. Strategic-level studies are related to long-term network planning, customer behavior analysis, and demand forecasting. At the tactical level, the focus is on schedule adjustment, and longitudinal and individual trip patterns. Finally, operational-level studies are related to supply-and-demand indicators, as well as to smart card system operations.

4.1. Strategic-level studies

In this section, we present various works related to long-term planning (see Table 4). It seems that many researchers agree on the use of smart card data for this task. For example, Agard et al. (2006) and Bagchi and White (2005) state that smart card data analysis can help to achieve a better understanding of user behavior, because each user can be followed during his journey. However, not all transit users in a network use smart cards, and some adjustments must be made to create a general network usage view. As seen in the table, most research is focused on user characterization and classification, but without having personal information on users a priori. Only Utsunomiya et al. (2006) had access to such data to conduct their interesting marketing analysis. They have conducted a study of the demographic profile of users by route and by station.

Conducting strategic planning with the help of smart card data is an improvement over the data collection methods currently used in the industry (Bagchi and White, 2005). The large amount of data collected gives more observations in space and time than with any other means of data collection (Agard et al., 2006; Bagchi and White, 2005). For every smart card fare collection transaction, the date, time, and card numbers are available, which facilitates the calculation of ridership statistics on a precise time scale. In some cases, boarding location is also available, which means that these statistics can be spatially detailed over a network. However, since there is usually no information available on the card holders themselves, these data lack socio-demographic attributes, and so there is a need to enrich them by traditional means of collection, like the household survey (Trépanier et al., 2009a,b). Smart cards can also be used to measure the loyalty of users in the network: the

Table 4
Review of studies on smart card systems for strategic transit planning.

Author(s)	Data	Analysis/use	Benefits
Agard et al. (2006)	Boarding date, time, and location. Card type	Define typical user type and measure their trip habits. Analyze use variability according to the day, the week, or the season	Better understand user behavior
Bagchi and White (2005)	Time, space, and structure. Personal and travel data	Turnover analysis. Marketing	Analyze the consistency of users' travel behavior over time. Produce targeted marketing campaigns to retain users in specific groups
Blythe (2004)	Route load profiles	Manage the demand through the network	Make public transit more attractive
Chu and Chapleau (2008) and Chu et al. (2009)	Boarding date, time, and location. Estimated alighting point. Card type	Runtime estimation. Itinerary reconstruction. Spatio-temporal portrait of the network. Concept of Driver Assisted Bus Interview (DABI)	Make adjustments to network geometry and schedules. Obtain richer information than that from a travel survey. Adapt the network to user needs
Utsunomiya et al. (2006)	Personal information. User address, boarding point, frequency of use. Trip information, demand elasticity	Development of a mailing list for service change announcements. Fare policy analysis. Marketing analysis: identification of market segments with low penetration, conduct targeted surveys. Analysis of a demographic profile of riders by route or station	Allow users to follow an alternative itinerary. Improve user trust in the service. Fare adjustment according to user needs. Demand forecasting
Park and Kim (2008)	Historical data	Future trend estimation. Creation of a future demand matrix	Service adjustment (long-term). Network extension and adaptation
Trépanier et al. (2004)	Boarding date, time, and location	Transportation Object-Oriented Modeling. Planning of the public transit network	Anticipate network extensions
Trépanier et al. (2009a,b)	Boarding date, time and location. Estimated alighting point. Card type	Comparison of smart card data with household survey data (bus use, temporal and spatial distribution of trip)	Improve the accuracy of data from both sides. Complete the survey with smart card data
Trépanier and Morency (2010)	Boarding transactions by card. Starting and ending dates	Calculate the lifespan if the card and the ratio of use of smart card users	Model the loyalty of users from smart card data. Would help to focus on loyalty and retention improvements

lifespan of each card can be deduced by looking at the starting and ending date of use of the transit system (Trépanier and Morency, 2010).

4.2. Tactical-level studies

On the tactical side, service adjustment is the most frequent topic (see Table 5). While most transit authorities provide a similar schedule for all weekdays, there can be large variations in ridership on those days, and so a different schedule could be posted for each day (Utsunomiya et al., 2006). The problem can be tackled route by route, with the longitudinal data provided by a smart card system. The maximum loading point can be identified more easily, because the load profiles can be derived for each run (Trépanier et al., 2007).

Since most systems do not have the alighting point for individual trips, an algorithm like the one proposed by Trépanier et al. (2007) is needed to estimate the most probable one. This is achieved by looking at the next boarding point in the day, or by looking at similarities to other trips made with the same card in the historical database. Then, the load profile of the route can be calculated, because the boarding and alighting points are available for each transaction. Munizaga et al. (2010) have proposed an improvement to this method in the case of subway stations, where the direction of travel is unknown. When the boarding location is not available, it is theoretically possible to estimate it by matching the time of boarding to the bus schedule, but we did not find this method applied in the literature.

Another topic of interest here is the study of transfer journeys, as proposed by Hoffman et al. (2009), based on magnetic card systems, which collect similar figures to smart cards. A better knowledge of transfer habits (in space and time) will help planners rearrange their network geometry and schedules to best accommodate the needs of travelers. The daily availability of smart card data can also help to measure the effects of the application of new policies on ridership (White, 2010).

4.3. Operational-level studies

At this level (Table 6), smart card systems can be used to calculate precise performance indicators on a transit network, like schedule adherence, vehicle-kilometers, and person-kilometers for every individual run, route, or day (Trépanier et al., 2009a,b). Schedule adherence can be estimated by comparing the boarding times at given stops along the route with the route schedule. In this case, data must be carefully filtered to retain the first transaction at each stop to represent the bus arrival time, because boarding can take several seconds. In fact, smart card time stamps can also help estimate the average boarding time at different stops, and for different types of routes and vehicles. So, these cards can collect data indirectly,

Table 5
Review of studies on smart card systems for tactical transit planning.

Author(s)	Data used	Analysis/use	Benefits
Bagchi and White (2004)	Trip data and personal data	Reconstruction of user trips, by identifying the bus used and the transfer point	Transport offering adjustment. Improved data quality. Statistics available. Schedule adjustment
Blythe (2004)	Pattern behavior, profile, and preference	Customer-loyalty scheme	Better understanding of customer needs
Bagchi and White (2005)	Origin and destination	Construct trips made and examine travel pattern	Service adjustment
Chapleau and Chu (2007)	Boarding date, time, and location. Estimated alighting point. Card type	Analyze the boarding passenger variability on a specific route. Detect transfer coincidences. Analyze transfer activities. Identify linked and no-link itinerary	Detection of maximum number of boarding point and return runs. Schedule coordination between bus and metro
Hoffman et al. (2009)	Magnetic card data on entry points	Iterative classification algorithm to obtain more information on transfer journeys	Better view of transfer journeys. Could be applied on smart card data
Munizaga et al. (2010)	Boarding date, time, and location	Algorithm to estimate potential destination. Special algorithm for subway stations	Generation of a detailed origin–destination matrix
Utsunomiya et al. (2006)	History of use	Determine frequency and consistency in user patterns	Service adjustment
Morency et al. (2006, 2007)	Boarding date, time, and location. Estimated alighting point. Card type	Longitudinal analysis. Spatio-temporal variability. Frequency of use of bus stops. Temporal variability	Classification of cards according to boarding patterns. Better knowledge of user behaviors
Seaborn et al. (2009)	Oyster smart card data	Method for identifying complete journeys	Identification of direct links or reroutes to minimize transfers
Trépanier et al. (2007)	Boarding date, time, and location. Card type	Algorithm to estimate the most probable alighting point by looking at card journeys and historical data	Route load profile for each run available

Table 6
Review of studies on smart card systems for operational transit planning.

Author	Data used	Analysis/use	Benefits/potential
Attoh-Okine and Shen (1995)	Personal data, fares	Payment	Reduces perception cost
Chapleau and Chu (2007)	Boarding date, time, and location	Detect, quantify, and analyze errors and inconsistencies in the transaction data	Improvements can be proposed to the system, and corrected data can be obtained
Deakin and Kim (2001)	History of use and personal data	Implementation of fare structure permitting time-of-day pricing	Better flexibility in fare perception
Deakin and Kim (2001)	Information from 'Travel Information Services'	Provide information in real time on actual and planned conditions of the network	Allow users to follow an alternative itinerary or to make a well-informed choice before a journey
Morency et al. (2007) and Trépanier et al. (2009a,b)	Boarding date, time, and location. Estimated alighting point. Card type	Analyze transit user behavior with data mining techniques. Follow buses	Performance indicators. Schedule adherence
Park and Kim (2008)	Personal data and bus run data	Describe user characteristics (transfer point, boarding time, bus run by mode, type of user)	Better understanding of user habits
Reddy et al. (2009)	Entry-only automated fare collection system data. Magnetic fare cards	Several operational statistics available at individual level	Reduces costs previously needed to calculate performance indicators
Trépanier and Vassivière (2008)	Boarding date, time, and location. Estimated alighting point. Card type	Several operational statistics available at bus run level. Intranet for dissemination	Service can be adjusted at micro level. Defective equipment can be detected if data are incorrect or missing. Improves use of embedded system

similar to the way in which automated vehicle location (AVL) systems do so (Hickman, 2002). In addition, they can provide these statistics by fare type. There is also an interesting use of the data for traveler information systems, by helping to provide individual itineraries, as reported by Deakin and Kim (2001) and Utsunomiya et al. (2006).

Smart cards can also help to detect irregularities and errors in the smart card payment system itself, in addition to fulfilling the core purpose of these systems, which is payment management (Deakin and Kim, 2001). The presence of errors in transaction data can lead to the rapid identification of defective equipment, fraud, or employee errors. The most common error is the desynchronization between the onboard smart card reader and the planned routes, perhaps because of an entry error by the driver, a last minute detour in the route, or an unplanned vehicle re-assignment. This type of error can be corrected afterwards, using data comparison methods and attribution techniques (Chapleau and Chu, 2007).

5. Commercialization

The potential of public transit smart card systems for commercial applications has not yet received intensive focus by researchers, but experiments on such applications are currently under way throughout the world. There are two types of commercialization approach. On the one hand, experiments can be linked to fare policies published by the transit agency or the government. In this case, the use of smart cards is encouraged by specific financial incentives, in the form of fare reductions or volume rebates offered to commuters to promote the use of the smart card payment system (Table 7). Smart

Table 7
Smart card marketing experiments for fare policies in a public transit context.

Place	Experiences	Impacts
New York (Lueck, 1998; Newman, 1998)	Free transfer between subway and bus, and 10% fare bonuses when more than $15 was loaded on the magnetic card	Thirty percent this way increase in bus ridership and 17% in subway ridership in following year
Washington (Layton, 2000)	Ten percent fare bonuses when more than $15 was loaded on the smart card. Lowest fare program, balance protection, and negative balance	Twenty-three percent of riders subscribed
London (Smart Card Alliance, 2009)	E-purse on Oyster card. Balance protection	2.1 million cards issued
Hong Kong (Meadowcroft, 2005)	Ten percent fare reduction. Multiple incentive measures: balance protection, negative balance, and auto loading	N/A
The Netherlands (Cheung, 2006)	"Travel first, pay later" program. "Best price principle"	The effects have not yet been calculated
Seoul (Smart Card Alliance, 2009)	Variable fare system depending on user type (adult, child, or student), by transportation mode and total distance traveled. Free transfer for smart card user	Proportion of smart card use is more than 90% for buses and 75% for subway use

Table 8
Smart card marketing experiments for non-fare policies in a public transit context.

Place	Experiments	Impacts
Brussels (Belgium), Lisbon (Portugal), Konstanz (Germany), Paris (France), Venice (Italy) (CNA, 2009)	Multi-use Calypso smart card	Cost reduction, service improvement, flexible fare policies, and revenue improvement
United Kingdom (Davis, 1999)	Implementation of loyalty programs in drug stores, giving shoppers bonus points equal to 4% of purchases	Smart card holders spend an average of 10% more than other customers
Hong Kong (Meadowcroft, 2005)	Cards allowing some non transit-related transactions, e.g. Coca-Cola vending machines, car parking, and public phones. Discounts with some retail participants and transit operators	Card became more convenient for users. 86% of trips paid using Octopus card in metro and 60–70% in buses
The Netherlands (Cheung, 2006)	Card not personalized, and so can be used by more than one individual	Frequency and intensity of letting other people use the card increased from 19% to 28%
Singapore (Smart Card Alliance, 2009)	Publicity in newspaper, television, and posters in residential estates. Intuitive system. Gradual implementation, and existing and new systems working in parallel. Card is accepted by non transit participants, like restaurants, movie theaters, schools, libraries, and bowling centers	Generated interest. Limited resistance to change. Gave time to users to make the transition between systems, and to the transit agency to improve system reliability and performance

cards can also be used to provide the user with the best fare available. In fact, because the boarding and alighting locations can be known, it is easy to calculate fares by distance and offer individual packages to users, as is done in The Netherlands' "travel first, pay later" program (Cheung, 2006) and in Seoul (Smart Card Alliance, 2009).

On the other hand, where no special fares are offered, smart card users may receive a series of benefits from commercial partners (rebates, reductions, or a loyalty program, for example). Research in the UK has shown that smart card users spent 10% more than other customers in drug stores that had established a loyalty program based on the card (Davis, 1999). Users are able to pay for products and services with their card, which may be more convenient than another mode of payment (Table 8). In Hong Kong, the smart card is used for many financial transactions not related to public transit, in vending machines, for parking, and in public phones, for example (CNA, 2009).

6. Conclusions

This paper reported on research related to the use of smart card payment systems data in public transit. It has shown that, although it is in constant technological evolution, the smart card is now well established in the field. In addition to the fare collection function, smart card systems can be useful for providing data to both planners and researchers. This continuously flowing data on passenger behavior can serve to enhance the strategic, tactical, and operational performance of transit authorities.

In light of this review, the following research issues are identified as potential challenges for smart card transit operators and researchers in the years to come:

- *Technological improvements:* Smart card payment systems use electronic devices that need to evolve in the coming years to make them more robust and reliable. Prices of cards, microchips, and readers will likely decrease, as is the case for most RFID technology. This will contribute to a better acceptance of the system among operators. Interoperability is also key here. Standards will have to be improved and partnerships developed between operators and commercial partners.
- *Data validation:* Smart card systems are complex and generate huge quantities of data. In addition to simple database validation logic, more rules will need to be developed to clean and validate the data generated by transit smart card payment systems. Obtaining the geographical location of boarding activities and achieving precision of the related operational information (route number, direction, and run number) remain day-to-day challenges for transit operators.
- *Economic feasibility:* As with any other information system, smart card system benefits are difficult to estimate. There is a need to better assess the gains related to fraud reduction, staff reorganization, fare management, and other potential benefits. In terms of the equipment, as stated above, reducing the cost of the electronic devices making up these systems will help considerably in improving their viability.
- *Journey validation:* Even though smart cards provide detailed information on each trip, the trips must be linked in order to retrieve individual journeys (trip chains). Better algorithms will have to be developed to estimate the alighting points, when these are not available.
- *New modeling approaches:* For the mass of data available on individual trips, new modeling methods will be needed, such as the Totally Disaggregate Approach, because classical models cannot be used at a such detailed level of resolution. The first task is to link appropriate socio-demographic information to the "anonymous" database (without question, data privacy will continue to be required). It will then be possible to calibrate individual base models from these large datasets.

- *New methods of analysis:* The resulting travel behavior database, available on a continuous basis, will help in the derivation of new analysis methods, especially for longitudinal studies, like the use of survival models applied to ridership or the application of time series modeling.

In the coming years, smart card fare collection systems will become the mostly widely used method of payment in transit networks. Millions of smart cards will provide a daily – and endless – source of data, with promising potential for using this data for strategic, tactical, and operational purposes. If privacy concerns are overcome and adequate security measures are put in place, planners and researchers will finally have a continuous source of data to enable them to gain a better understanding of transit user behavior, helping to improve the public transportation system and increase its role in sustainable transportation.

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