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Smart Card Data in Public Transit Planning: A 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 use in the transit planning context. First, the technologies are presented: the hardware and information systems required to operate these tools. Privacy concerns and legal issues related to the dissemination of smart card data, data storage, and encryption are also 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 survival models applied to ridership.

Keywords. Smart card, fare collection, transit planning, public transportation, transportation demand, intelligent transportation systems.

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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 Dethloff and Grotrupp, two German inventors, 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 & 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).

“Contactless” 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 has many uses, including access control, and to store information like biometrics, photos, fingerprints, medical data, DNA results, religious affiliation, and banking 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).

This review focuses on the use of smart card data in the transit planning field, showing that data can be used for many purposes other than the one for which smart card systems were designed, namely revenue collection. Section 2 presents the technologies related to the use of the smart card in public transit networks, as well as the associated standards, along with an example. The information system that is necessary to support smart card implementation and the various objects that could be involved in planning analysis are described. Section 3 reviews the work that has been conducted over the years with smart card data. The topics are divided according to management level and the terms of the type of analysis: strategic, tactical, and operational. Section 4 summarizes some efforts to commercialize 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 method, and presents some research perspectives on the smart card field based on work already carried out or currently under way.

2 Technologies

This section describes smart card hardware and standards, and then focuses on smart card automated fare collection systems for transit. 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 Hardware

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 & 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, and 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. In fact, the contactless smart card is an RFID technology specialization.
- The data on the card can be either encrypted or not. The triple data encryption standard (3DES) is often used to encrypt data.
- The amount of memory on the cards can vary, 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. In public transit, the amount of memory needed is usually less, since most of the information is not stored on the card itself (see section 2.2, *Information system*).

In the contact smart card, a chip is embedded within slices of plastic, but its surface must not be covered because it has to be in contact with the reader's PINs. 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.

2.1.1 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).

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	until 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	until 20 cm	Open	Payment.
EZ-PASS Proprietary Ultra-High-Frequency Technology	902, 928 & 5900	n/a	3 to 10 m	Closed	Highway toll booths and fast-food drive-thrus

Table 1: Characteristics of some lower-level contactless smart card standards (based on McDonald, 2003)

2.1.2 Public transit implementation

International standardization 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 non profit organization (NPO) supported by bus operators, train companies, industry suppliers, and regional and local authorities, mainly in the United Kingdom. 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. In the United States, there are implementations in New York, Washington, Chicago, and San Francisco, and in more than ten other metropolitan areas. In Canada, the card is implemented in the Gatineau, Montreal, Kingston, and Brantford transit systems, with planning ongoing in others. The smart card is also popular in Asia and is increasingly used in South America, for example in Santiago, Chile.

2.2 Information system

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. This section shows an example of such an information system, and the objects involved in the whole process of smart card use.

2.2.1 An example of implementation: Gatineau, Quebec

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 Figure 1. The SIVT server stores data on card holders and all transactions, and comprises the core of the system. SIVT is the fare validation information system (*système informatisé de validation des titres*). Note that user and validation data are not stored in the same database, in order to preserve the confidentiality of the information. In the SIVT, 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 is not on the "blacklist" (for fraud or falsification). The information on the transaction is stored on the onboard device, then transferred to the SIVT asynchronously, each time the bus returns to the garage. For accounting purposes, information is also exchanged between smart card issuing and reloading locations, the corporate accounting system, and the SIVT.

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

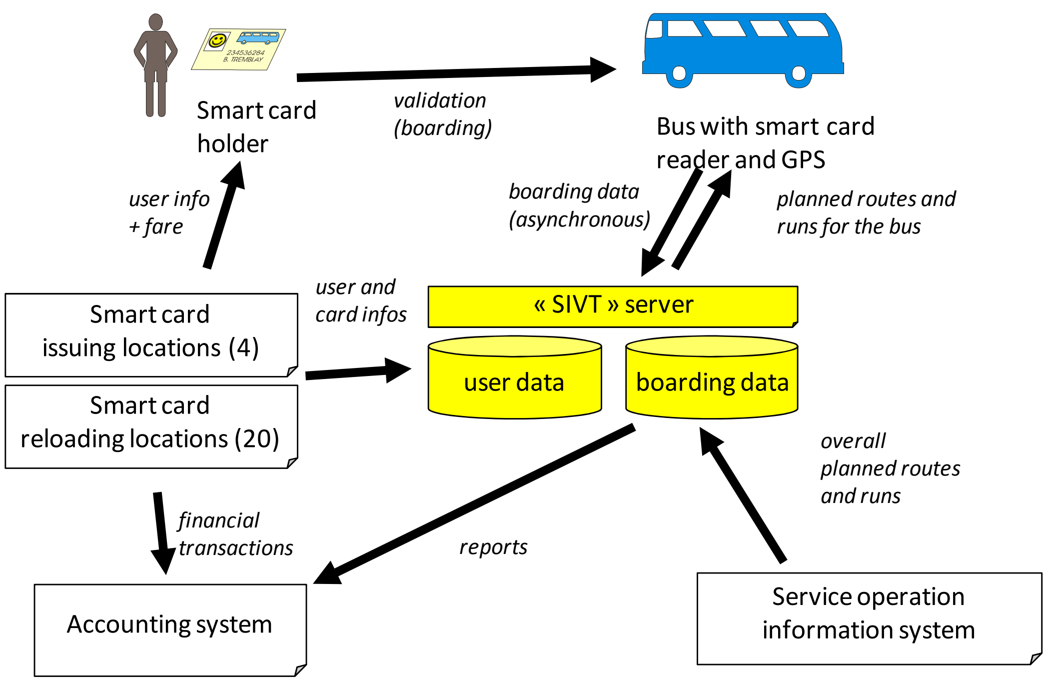

Figure 1: An example of a smart card information system

2.2.2 Smart card object-oriented model

Looking at the database alone is not sufficient to understand the full potential of the use of smart card data for planning purposes. Figure 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, the combinations of elements (system objects).

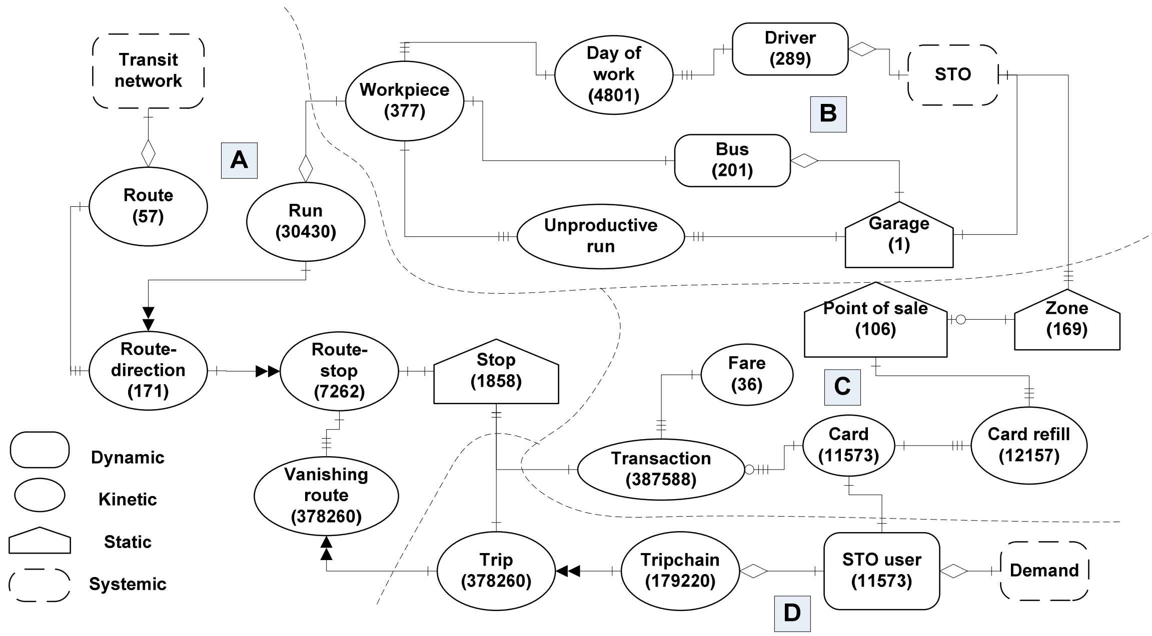

Figure 2: Transportation object-model of the smart card in transit (STO, July 2003 data)

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 (Figure 2), there are 57 routes and 1,858 stops, making up 7,262 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 the route stops. For each trip, a vanishing route is created on the network to estimate the alighting point.

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 which has been debated in several research studies. This debate is evolving along with the huge issue of security in transit systems. In some case, the increase in the amount of information stored can be seen as an improvement in security, because the operator has a better 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.

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 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 personnel of the transit agency, 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 2005).
Uses for the smart card	If the smart card is used for multiple purposes, there is risk of creating a central database that gathers all personal information.

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

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 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 is the centralized database storage of transactions and card holder information (Reid, 2007). The linking of smart card use to an individual's sociodemographic or socioeconomic information is not likely to be accepted by users (Cottrill, 2008). 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 & Keuleers 2004). In most of the studies presented in section 3, personal user information was not made available to the researchers.

2.4 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 very convenient compared to magnetic cards, which are not as durable, and regular tickets. In addition, the smart card is contactless and does not require the user to insert the card in a reader, as is the case for magnetic cards (Blythe 1998).

- Vehicle delay. Interactions between a smart card and a reader are quite quick on boarding a vehicle, but is not as quick as showing a monthly pass to the driver. 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 costly equipment aboard the vehicle or at stations. This is seen as the major disadvantage of the system, but this equipment can be made more profitable by adding other functions, such as cash-counting devices, automated route display, and driver-related management roles.
- Fare deposit security. Like magnetic cards, the smart card reduces the amount of 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.
- 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 entry and exit, which is incompatible with the driver's role.

3 Data use in transit planning

Several studies have been conducted during recent years on the use of smart card data for transit planning purposes. 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, longitudinal , and individual trip patterns. Finally, operational-level studies are related to supply and demand indicators, as well as to smart card system operations.

3.1 Strategic-level studies

In this section, we present various works related to long-term planning (see Table 3). Researchers seem to agree on the use of smart card data for this task. However, not all transit users in a network use smart cards, and some adjustments must be made to create a general network usage view. 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.

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 season.	Better understand user behavior.
Bagchi & White (2005)	Time, space, and structure. Personal and travel data.	Turnover analysis. Marketing.	Analyze 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 transport more attractive.
Chu & Chapleau (2008), Chu et al. (2009)	Boarding date, time, and location. Estimated alighting point. Card type.	Runtime estimation. Itinerary reconstruction. Spatio-temporal portrait on the network. Concept of Driver Assisted Bus Interview (DABI).	Make adjustments to network geometry and schedules. Richer information than that from travel survey. Adapt network to user needs.
Deakin & 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 journey.
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 demographic profile of riders by route or station.	Allow users to follow an alternative itinerary. Improve user trust in service. Fare adjustment according to user needs. Demand forecasting.
Park & 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 transport network.	Anticipate network extensions.
Trépanier et al. (2009)	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 accuracy of data from both sides. Complete survey with smart card data.

Table 3: Review of studies on smart card systems for strategic transit planning

Conducting strategic planning with the help of smart card data is an improvement over the data collection methods currently used in the industry. The large amount of data collected gives a better understanding of travel behavior, because there are more observations in space and time with this system than with any other means of data collection (Agard et al. 2006, Bagchi & White 2005). For every smart card fare collection transaction, the date, time, and card numbers are available, which facilitates the calculation of ridership statistics at a precise temporal 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 sociodemographic attributes, and so there is a need to enrich them by traditional means of collection, like the household survey (Trépanier et al. 2009). There is also an interesting use of the data for traveler information systems, which helps to provide individual itineraries, as reported by Deakin and Kim (2001) and Utsunomiya et al. (2006).

3.2 Tactical-level studies

On the tactical side, service adjustment is the most frequent topic (see Table 4). That is, most transit authorities will provide a similar schedule for all weekdays. However, there can be large variations in ridership during weekdays, and so a different schedule could be posted for each day. The problem can be tackled route by route, with longitudinal data provided by a smart card system. The maximum loading point can identified more easily, because the load profiles can be derived for each run.

Author(s)	Data used	Analysis/use	Benefits
Bagchi & White (2004)	Trip data and personal data.	Reconstruction of user trips, by identifying bus used and 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 & White (2005)	Origin and destination.	Construct trips made and examine travel pattern.	Service adjustment.
Chapleau & Chu (2007)	Boarding date, time, and location. Estimated alighting point. Card type.	Analyze the boarding passengers variability on a specific route. Detect transfer coincidences. Analyze transfer activities. Identify linked and no-linked itinerary.	Detection of maximum 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.
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 the 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 4: Review of studies on smart card systems for tactical transit planning

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 alighting point. This is done by looking at the next boarding point in the day or by applying 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. When the boarding stop is not known, it is theoretically possible to estimate the boarding location by looking at the time of boarding compared to the bus schedule, but the application of this method was not found in the literature. Another topic of interest here is the study of transfer journeys, as proposed by Hoffman et al. (2009), from 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.

3.3 Operational-level studies

At this level (Table 5), smart card systems can be used to calculate precise performance indicators on a transit network, like schedule adherence, vehicle-kilometers and person-kilometers for each individual run, route, or day (Trépanier et al. 2009). 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. Indeed, smart card time stamps can also help estimate the average boarding time at different stops, and for different types of route and vehicles. Hence, smart cards can indirectly collect data similar to Automated Vehicle Location systems (AVL) (Hickman 2002); however, smart cards can provide these statistics by fare type.

Author	Data used	Analysis/use	Benefits/Potential
Attoh-Okine & Shen (1995)	Personal data, fares.	Payment.	Reduces perception cost.
Chapleau & Chu (2007)	Boarding date, time, and location.	Detect, quantify, and analyze errors and inconsistencies in transaction data.	Improvements can be proposed to system, and corrected data can be obtained.
Deakin & Kim (2001)	History of use and personal data.	Implementation of fare structure permitting time-of-day pricing.	Better flexibility in fare perception.
Morency et al. (2007), Trépanier et al. (2009)	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 & 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 & 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.

Table 5: Review of studies on smart card systems for operational transit planning

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 & Kim 2001). The presence of errors in transaction data can lead to rapidly identifying 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 & Chu 2007).

4 Commercialization

The potential of public transit smart card systems for commercial applications has not yet received intensive focus by researchers, but experiments 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 and volume rebates offered to commuters to promote the use of the smart card payment system (Table 6).

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.	30%increase in bus ridership and 17% in subway ridership in following year.
Washington (Layton, 2000)	10% fare bonuses when more than $15 was loaded on the smart card. Lowest fare program, balance protection, and negative balance.	23% of riders subscribed.
London (SCA 2009)	E-purse on Oyster card Balance protection.	2.1 million cards issued.
Hong Kong (Meadowcroft 2005)	10% fare reduction. Multiple incentive measures: balance protection, negative balance, and auto loading.	N/A
Netherlands (Cheung, 2006)	"Travel first and pay later" program. "Best price principle".	The effects have not yet been calculated.
Seoul (SCA 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 6: Smart-card marketing experiments for fare policies in a public transit context

On the other hand, no special fares are offered, but smart card users will receive a series of benefits from commercial partners (rebates, reductions, or a loyalty program, for example), or will be able to pay for products and services with their card, which may be more convenient than another mode of payment (Table 7).

Place	Experiments	Impacts
Brussels (Belgium), Lisbon (Portugal), Konstanz (Germany), Paris (France), Venice (Italy) (CNA, 2009)	Multi-usage 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 transport-related transactions, e.g. Coca-Cola vending machines, 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 to 70% in buses.
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 (SCA 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 transit agency to improve system reliability and performance .

Table 7: Smart-card marketing experiments for non-fare policies in a public transit context

5 Conclusions

In recent years, justification of the use of smart card fare collection systems has been debated in several countries. The high investment costs needed for implementation (about $30 million dollars Canadian for the Montreal area) and technical difficulties that arose in the early installations have slowed down promoters. However, these days, the technology has improved and the benefits have become evident. Table 8 presents the advantages and disadvantages that were found 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 high implementation costs, technological complexity, and slow social acceptance are seen as possible obstacles. In most cases, external funding seems to be necessary to initiate large implementations (Iseki & al. 2007).

Advantages	Disadvantages
• Minimizes user role in data collection previously obtained by survey (Bagchi & White, 2004). • Trip data combined with personal data improves data quality and increases amount of statistics (Bagchi & White, 2005). • Easier to examine travel behaviors by "reconstructing" user trips than by studying existing data (Bagchi & White, 2005). • Improves feasibility and convenience of a variety of pricing options for road use, parking, and transit fares (Deakin & Kim, 2001). • Provides universal payment method for a number of systems (Deakin & Kim, 2001), integration with other transportation fare collection activities (Cunningham, 1993). • Reduces cost (McDonald, 2000). • Improves service (McDonald, 2000). • Implementation of flexible and creative fare policies (McDonald, 2000). • Improvement in revenue management (McDonald, 2000). • Convenience and system utilization time improved for users (Bagchi & White, 2005). • Improves user perception of public transport by using new technology (Ibrahim, 2003). • Improves payment mechanism and information flow (Blythe, 2004). • Potential for information-sharing offers innovative revenue-earning possibilities (Blythe, 2004). • Smart card life span longer than that of traditional cards (Utsunomiya, Attanucci & Wilson, 2006). • Reduces user boarding time (Chira-Chavala & Coifman, 1996). • Reduces driver's workload (Chira-Chavala & Coifman, 1996).	• Cannot provide information on trip purpose, or on user assessment of service (Bagchi & White, 2005). • Does not provide user's ultimate destination, despite a method to deduce it (Bagchi & White, 2005). • High research and development cost (Deakin & Kim, 2001). • Complexity of introducing new components and processes into systems (Deakin & Kim, 2001). • High implementation cost (Deakin & Kim, 2001). • High risk associated with investment (Deakin & Kim, 2001). • Slow institutional change (Deakin & Kim, 2001). • Slow social acceptance (Deakin & Kim, 2001). • Need for service providers to undertake surveys to confirm analysis of use and assumptions made (Bagchi & White, 2005). • No guarantee of profitability improvement (McDonald, 2000). • Success of implementation often depends on users (McDonald, 2000). • Market penetration needs to be sufficient to provide a representative sample of the entire population (Utsunomiya, Attanucci & Wilson, 2006). • The more complex the card, the less its reliability is guaranteed (Blythe, 2004).

Table 8: The pros and cons of smart card use in public transit

In the 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:

- Data validation. Smart card systems are complex and generate huge quantities of data. In addition to simple database validation logic, more rules are to be developed in order 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, run number) still constitute a day-to-day challenge for transit operators.

- Journey validation. Even though smart cards provide detailed information for each trip, trips must be linked 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 such detailed level of resolution. The first task is to link appropriate sociodemographic 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 to derive 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 taken, planners and researchers will finally have a continuous source of data 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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