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ORIGINAL RESEARCH

Fare evasion in public transport systems: a review of the literature

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Abstract

Fare evasion has become an important issue for public transport companies, especially for those that have adopted proof-of-payment ticketing systems. Recent years have seen strong growth in the publication of studies on fare evasion. This paper reviews 113 studies to identify the characteristics of the research on fare evasion. An overview and classification in five main areas, i.e., fare evader-oriented, criminological, economic, technological, and operational is provided. Next, the *status quo* of these studies is assessed to support possible unifying research development.

Keywords Fare evasion · Proof-of-payment · Pay-on-entry · Fare dodging · Fare evader · Fare dodger · Fraud in public transportation · Fare cheating · Free rider

Abbreviations

AFC	Automatic fare collection
APC	Automatic passenger counting
AVL	Automatic vehicle location
C	Conductor
fBTS	Off-board ticketing systems
GIS	Geographic information system
IT	Information technology
ITS	Intelligent transport systems
nBTS	On-board ticketing systems
NFC	Near field communication
POE	Pay-on-entry
POP	Proof-of-payment

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PTC	Public transport company
QR code	Quick response code
UITP	Union Internationale des Transports Publics

1 Introduction

1.1 Fare payment and fare evasion

Public transport companies (PTCs) adopt one of the three main ticketing systems: proof-of-payment (POP[1]), pay-on-entry (POE) and conductor (C). Table 1 reports them according to the collection and verification of the fare payment. Fare collection (i.e., payment of the fare) can be done off-board or on-board, whereas fare verification (i.e., the confirmation that the fare has been paid) can be performed continuously or occasionally.

In POP_S, passengers must validate tickets to prove the payment by their insertion into validation machines before using the service. Fares are verified via random spot-checks by proper inspectors to ensure that passengers have correctly paid. POP_S is usually applied on nBTS (e.g., bus, tram), but also on fBTS (e.g., subways of Brescia, Vienna).

In POP_B, passengers must have a valid ticket to enter a paid (close) access (e.g., fare gate, ticket barrier). Tickets are validated and verified when they are inserted into a proper validation machine opening the access to the service. POP_B is usually applied in fBTS, but recently also on nBTS (e.g., Moscow).

In POE, passengers can pay via the driver or need to show the proof-of-payment (e.g., a monthly pass) whenever they board the vehicle. Usually, POE is adopted for nBTS and allows continuous monitoring of fare payment.

In C, passengers can pay the fare via conductors on board. C and POE are similar, but C is more traditional and less common, as it involves additional staff.

Malicious passengers can evade fares due to the vulnerability of the ticketing systems. Fare evasion issues increased in the 1960s in Europe and soon after in the USA, because of the relinquishment of conductors (Diebel 1981). Nevertheless, fare evasion is hard to measure due to many reasons. No standard methods exist for estimating fare compliance and fare evasion. PTCs do not agree on what ‘evaders’ are. It is tricky to know how many people skip ticket inspection and/or can be physically checked (e.g., Abrate et al. 2008; Dauby and Kovacs 2007a, b; Larwin and Koprowski 2012a, b; Multisystems et al. 2002). Therefore, the extent of fare evasion is difficult to determine, even if lost revenues and damage to the corporate image are relevant. For instance, official statistics of 31 worldwide PTCs showed that fare evasion costs over 1 billion euros per year (Bonfanti and Wagenknecht 2010). Despite this difficulty, some approaches showed that the magnitude of the evasion depends on ticketing systems.

[1] In this paper, POP occurs when passengers purchase tickets (or passes) in advance and are required to validate before using the service, regardless of the verification of fare payment. According to this definition, POP can be implemented without barriers (or self-service or honour-based or POPs) and with barriers (or POP_B).

Table 1 Fare ticketing systems in public transport

Fare collection	Fare verification	
	Occasional	Continuous
Off-board ticketing systems (fBTS)	POP_S	POP_B
On-board ticketing systems (nBTS)	POP_S	POE, C, POP_B

In fBTS-POP_B, fare evasion is almost absent. It may be observed when passengers pass (under or over) the turnstile, walk through left open gates, etc. (e.g., Multisystems et al. 2002; Reddy et al. 2011). In nBTS-POP_S, fare evasion is more frequent and depends, e.g., on the inspection pattern, fine structure, level of crowding (Multisystems et al. 2002).

In POE, fare evasion is expected to be lower than for nBTS-POPs because of the drivers. Some problems emerged in the past owing to cash evasion, pass evasion, and zone evasion (Peat 1982). Besides, crowded boarding points can instigate fare evasion (Multisystems et al. 2002).

In C, fare evasion may depend on whether the conductors collect/inspect all the tickets. Fare evasion might occur at congested times, but also at uncongested times depending on conductors' behaviour (e.g., Multisystems et al. 2002).

1.2 Fare evasion problems and effects

Nowadays, many PTCs have adopted nBTS-POPs to mainly reduce labor costs and eliminate cash acceptance (e.g., Lorenc and Lutin 2000; Watry and Straus 2000).

On the one hand, nBTS-POPs made possible new fare systems, fast service, spread of the technology, new vehicle design and the physiological wellness of drivers. For instance, nBTS-POPs permits many fare schemes because passengers purchase tickets in advance. Since nBTS-POPs accelerates boarding, PTCs have experienced operational savings owing to the decrease in dwell times. Drivers are less stressed as they must not compute the fare and handle the money.

On the other hand, the removal of systematic monitoring facilitated fare evasion and originated costs for ticket inspection. Moreover, nBTS-POP_s has ingenerated vandalism impacting the apparatus of PTCs. For instance, vandals may insert unallowed items into the validation machine, impairing the ticket validation (e.g., chewing gum, tissue).

Nevertheless, POP_S has led to consequences arising beyond the analysis of the single evasion rate. It has involved policy, deterrence and enforcement issues, operational tasks, and capital (e.g., Multisystems et al. 2002).

Policy issues depend on the specific context where the PTCs operate. POP_S may be implemented whether laws and rules provide the necessary legal framework. The service contract ('net-cost', 'gross-cost', etc.) between a Local Authority and a PTC must also be considered. A 'net-cost' contract should set up specific measures against fare evasion as the PTC makes profit also from ticket sales, which are hindered by fare evasion. As a side effect, paying passengers sustain higher costs to counteract fare evaders (e.g., Abrate et al. 2008). Measuring evasion rate and segmenting (or profiling) passengers help provide a solid knowledge about fare evasion and its actors.

Deterrence and enforcement against fare evasion mainly include the inspection activity (e.g, strategies of inspection, measurement, deployment of inspectors) and the adoption of fines (e.g., setting, structure). These approaches may reduce perceived security levels, because they may trigger violence from fare evaders (Bijleveld 2007; Del Castillo and Lindner 1994; Smith and Clarke 2000).

Operational tasks concern the fare structure planning, the ticket sale and distribution network, the adoption of educational and marketing campaigns, etc. Capital affects the purchase of technology to increase obstacles against fare evaders. For instance, remote commands may turn-off validation machines before the boarding of inspectors to avoid the ticket validation on the spot.

1.3 Motivation of this literature review

Additional reasons motivated this literature review.

Firstly, fare evasion is an old and crucial problem for almost all PTCs worldwide. However, this is a slightly new research area in the transit industry, and, to the best of our knowledge, no review has been made on the different research areas concerning fare evasion. The focus on specific areas resulted in the fragmentation of definitions, problems, and methodologies. Moreover, in our opinion, it perhaps hampered the advancement of an interdisciplinary knowledge in the field. For instance, Smith and Clarke (2000) provided a specific review on crime in public transport and mentioned several offenses, such as fare evasion.

Fare evasion may be considered a *corner* of crime in public transport (Brisman 2016). For instance, Hauber (1980) discovered a positive correlation between the frequency of fare evasion and other minor crimes: the higher the frequencies, the more frequent other crimes. Weidner (1996) stated that many criminals who enter the transit system to commit a serious crime (e.g., robbery) first fail to pay the fare.

Secondly, emerging technologies (e.g., smart cards) and innovative actions (e.g., suitable inspection schemes) need to be investigated to evaluate their viability against fare evasion.

This review aims to answer these questions:

- What are the characteristics of the fare evasion research community?
- Which are the areas of interest studied by experts?
- What is the current knowledge base?
- What are the possible unifying contents of a possible research agenda?

This paper contributes by:

- Providing an overview and a classification of the current knowledge on fare evasion.
- Identifying room for the integration of fare evasion research.
- Inferring a possible research agenda.

1.4 Paper structure

The remaining paper is organised as follows. Section 2 presents the methodology to perform this review, including the search strategy and the type of analysis. Section 3 reports relevant descriptive statistics and the research areas. Section 4 briefly reviews 113 current leading publications. Section 5 provides a possible research agenda. Section 6 concludes this literature review.

2 Methodology

2.1 Design

This paper is designed as a systematic and objective research review according to Cooper (1989) and Moher et al. (2009).

It is organised as follows:

- Statement of problem and research questions.
- Identification of a data search strategy (including multiple channels to avoid bias in coverage).
- Evaluation and selection of retrieved data (including criteria for selection of suitable data).
- Analysis and interpretation of the literature (including statistics about the sources, the number of retrievals and literature finally reviewed).
- Outcomes (including a brief comment on each paper).

2.2 Search strategy

A computerised search is chosen for the sake of fastness and efficiency. Scopus and Web-of-Science were queried as they provide the largest abstract and citation databases of peer-reviewed literature. Since these databases could not contain all references, a separate search on selected web sources followed. Two leading electronic sources are considered: Research Gate, the social network for scientists and researchers, and Google Scholar, a freely accessible web search engine indexing the full text of scholarly literature. Although many academics have Google Scholar profiles,[2] Research Gate is considered owing to its largest academic social network of active researchers worldwide (Van Noorden 2014). Despite providing extensive coverage, the free web search is disregarded due to the abundance of no scientific information.

Nevertheless, electronic sources might limit the coverage. Thus, old and relevant papers were also retrieved by tracking the research cited in the literature that is already obtained (i.e., ancestry approach). Finally, the research already known from

[2] https://101innovations.wordpress.com/, accessed on 21/12/2016.

informal contacts and own research were included in this literature review. It covers studies published from 1980 to 2017.[3]

2.3 Keywords and selection criteria

Search on the title, keywords, abstract and type of source was done. Several search terms are adopted like combinations of keywords to cover different idioms of fare evasion. Studies on ‘Fare Evasion’, ‘Proof-of-Payment’, ‘Pay-on-Entry’, ‘Fare Dodging’, ‘Fare Evader’, ‘Fare Dodger’, ‘Fraud in public transport’, ‘Fare Cheating’ and ‘Free-rider and transit’ were selected. The ‘Free-Rider’ benefits from resources, goods, or services without paying (Baumol 1952). Therefore, the free-rider problem includes a large group of ‘offences’ where people take advantage of doing something illicitly for free. Hence, in order to limit the amount of literature to relevant articles, this review refers only to free riders who are fare evaders.

Unlike Scopus and Web-of-Science, Google Scholar allowed a search based on the title and along the text. Due to the abundance of retrieved papers searching within the text, the only search criteria used in Google Scholar was the title. Moreover, Research Gate was searched for abstracts, keywords, titles and within the text. Therefore, many papers retrieved were sooner neglected after screening as they were not focusing on fare evasion. A few papers of interest in Italian and French were included, because these languages are comprehensible to the authors. Some articles in commercial magazines and press release were excluded because the research background was not provided.

The results are mostly high-quality English publications in scientific journals and conferences.

2.4 Analysis

Some analyses were performed to answer the former research questions.

Firstly, the characteristics of the fare evasion can be quantified according to the geographical area. The adopted geographical indicators are “The country of affiliation” (i.e., the workplace of scientists rather than their nationality) and the “country where the research is applied”. Moreover, “the number of involved scientists per country” and “the number of publications per year” have quantified the impact of the research.

Secondly, the current knowledge base was assessed by analysing the main areas of interest, to provide some possible contents of an integrative research agenda.

[3] An update has been added to the original review due to the publication of recent papers after the first submission of this review. The same search and selection strategy was applied for the years 2018 and 2019. The publications retrieved for these years are listed in Appendix A, but these papers were not reviewed.

3 Summary results

3.1 General statistics about the review

According to Moher et al. (2009), i.e., PRISMA's statement, 373 papers were identified by database searching. An additional 36 papers were collected from ancestry approach, informal contacts and own research. After the removal of multiple copies, 405 papers were used. Next, 230 papers were excluded after the screening of abstracts. In addition, 62 papers were excluded after a full-text assessment, as neither directly focused on fare evasion nor written in a language understood by the authors. Therefore, 113 publications were reviewed: 62 in journals, 33 in conference proceedings, 9 technical reports, 5 dissertations, 2 book chapters, and 2 working papers.

We retrieved 39 unique studies from Scopus and Web-of-Science, 27 from Google Scholar, 25 by the ancestry approach, and 22 from informal contact, Research Gate and authors' research. About 80% of studies came from well-known repositories and ancestry approach. Results do not show significant bias from incorporating our own research: about 4% of the retrieved material.

Fifty-five percent of the studies appeared in journals, whereas the remaining 45% elsewhere. As for journals, 51% covered transportation and economics, 20% criminology and/or security, and 29% additional topics. The most frequent were *Transportation Research Record* (6 times) and *Transportation Research Part A* (five times). Recurrent journals were also *Security Journal* with three publications and *Transportation Research Part B*, *Journal of Transport Economics and Policy*, *The British Journal of Criminology*, *Crime Prevention Studies* and *Transport Policy* with two publications. About 42% of the selected articles appeared in these 8 journals, the remaining 58% in other 37. These different outlets showed the fragmentation of the journals addressing fare evasion for a varied audience.

Figure 1 clearly shows that fare evasion is an emerging research area in public transport in the last 7 years. The number of publications tripled since 2010.

Table 2 shows the geographical publications' distribution.

The first column reports the name of the continent (in bold) and the related countries.

The second column shows that the research was carried out by 78 researchers mainly in North America and Europe. They are about 80% of the total.

The third column reports the number of publications and shows that Europe and North America provided 61 and 47 publications, respectively. Other continents such as Africa, Asia, South America, and Australia are barely or not at all covered. Europe has the largest coverage among the continents. Moreover, in Europe, The Netherlands, France, Germany, and Italy constitute 61% of the selected publications. The number of researchers involved might justify this trend.

The last column reports the number of studies considering the country in which the research was conducted. The distribution of studies is as follows: North America—55%, Europe—about 32% and other continents—13%. This

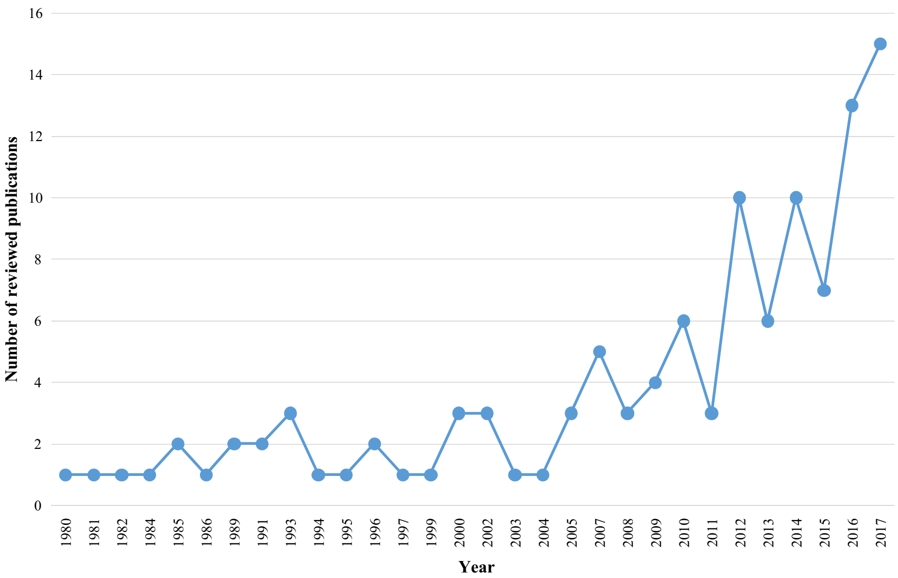

Fig. 1 Number of publications reviewed per year: period 1980–2017

distribution is unbalanced towards North America since our review included some publications involving many countries. For instance, the research of Multisystems et al. (2002) involved 26 North American countries, whereas Nakanishi and Fleming (2011) involved 65 North American countries.

3.2 Common fare evasion definitions

Table 3 presents the main definitions as a result of the reviewed literature. Table 3 reveals that no commonly accepted definition exists. Therefore, all authors seem to use a definition that reflects the scope of their research. Hence, different scopes lead to various definitions. A definition that can be easily understood by a layman may be preferred. This definition integrates those provided in Table 3.

Fare evasion could be defined as *the non-violent act of traveling on public transport in disregard of the law or regulation or contract, having deliberately not purchased, not validated or not correctly adopted the required travel ticket*.

According to this definition, fare evasion includes: (1) freeloading, passengers travel without buying the ticket; (2) overriding, passengers travel several transit zones paying only the base fare and (3) elusion, passengers travel without validating the ticket or with a counterfeit ticket or misuse of existing media, etc.

3.3 Fare evasion research areas

The literature can be classified according to facets, problems, models, methods, etc. However, owing to the interdisciplinary nature of fare evasion, this paper presents a

Table 2 Geographical distribution of the publications reviewed

Country	Number of researchers involved[a]	Number of publications[b]	Country to which research applies[c]
Africa	–	–	**2**
Tunisia	–	–	2
Asia	**15**	**9**	**5**
China	2	1	2
Hong Kong	1	1	1
Iran	3	1	1
Israel	1	2	–
Japan	1	1	–
South Korea	2	1	–
Taiwan	**2**	1	1
Thailand	3	1	–
Australia	**11**	**9**	**7**
Australia	11	9	7
Europe	**78**	**61**	**115**
Austria	2	2	1
Belgium	4	3	5
Czech Republic	1	1	–
Denmark	3	2	4
Finland	3	1	1
France	7	9	15
Germany	13	9	29
Hungary	1	2	2
Italy	11	8	10
Norway	1	1	1
Portugal	1	1	2
Spain	4	2	2
Sweden	2	1	5
Switzerland	9	5	10
The Netherlands	11	11	18
UK	5	3	10
North America	**78**	**47**	**218**
Canada	17	10	15
USA	61	37	203
South America	**17**	**10**	**9**
Chile	17	10	9
Not available	–	–	**13**
			13
Total	**199**	**136**	**369**

–, No data are reported for the considered column

[a]Based on affiliation, not on nationality of the researchers. Authors who wrote more than one paper are counted once

[b]> 113 publications reviewed, because some articles are written by authors from different countries

[c]Some studies refer to many countries. If some studies refer to the same country, it was considered as a separate study

Table 3 Definitions of fare evasion

Source, year	Definitions
Barabino et al. (2013, 2014a, 2015)	Fare evasion is the problem of riding buses when a passenger does not have a valid ticket
Bonfanti and Wagenknecht (2010)	Fare evasion is the violation of rules of law or regulation or contract for whose violation there is a fine, provided that the fact does not represent a crime
Delbosc and Currie (2016a)	Fare evasion is a form of felonious norm infringement: i.e., non-violent criminal acts such as theft, failure to pay for services or rudeness to employees
Diebel (1981)	In the self-service transit, fare evasion means freeloading or riding without paying the fare and overriding or trying to travel several transit zones for only the base fare
Hauber (1980)	Fare dodging refers to the use of transportation systems without having a valid ticket
Leung (2003)	Passengers travelling without tickets or holding invalid tickets are classified as fare evaders without distinguishing whether they are doing so intentionally or not
Li and Min (1985)	Fare evasion is the problem of riding buses without purchasing tickets
Mauri et al. (1984)	Fare evasion occurs when a passenger avoids paying all or part of the fare
Reddy et al. (2011)	Fare evasion occurs when passengers gain access from unpaid to paid areas by interacting with fare controls in manners inconsistent with tariff

classification based on the main areas of interest, without neglecting interrelations among them. More precisely, this paper provides an overview of (1) fare evader-oriented studies, (2) criminology, (3) economics, (4) technological innovations, and (5) operational research.

This classification is motivated by the following reasons. First, fare evasion is a form of *unethical behaviour* of people (e.g., Gneezy 2005; Mazar et al. 2008). A growing literature broadly examines the influence of key determinants affecting the attitude, motivations, and behaviours to evade fares. Second, fare evasion may be considered as a *criminal act*, since fare evaders can trigger other crimes or generate security issues. This research area examines the effectiveness of situation-specific measures facing fare evasion by mostly evaluating deterrence, enforcement, and security. Third, fare evasion could be perceived as an *economic benefit*. Malicious passengers can maximize their benefits without paying the fare. This research area examines determinants, models, methods, and strategies that PTCs can use to protect revenues from fare evasion. Fourth, *technological innovation* pertains to PTCs evolution on ticketing systems. These technologies are applied to simplify travellers' duties and reduce fare evasion. Fifth, a new interest is emerging in the *operational research* field, in which optimisation methods aim to schedule inspection teams' tasks as a planned activity.

This review shows that research is not spread equally between America and Europe. Due to different geographical situations and ways to face fare evasion, the research focus differs. Australian and European researchers dominate the fare evader-oriented area. South Americans dominate the economic area, whereas North Americans dominate the technological one. In the remaining areas, the distinction is not very clear, and a quasi-balanced distribution of studies is observed between American and European teams. This conjunct interest may be due to the relevant implications it generated for all PTCs. Finally, no considerations may be given to Africa and Asia, owing to only six studies.

4 Current knowledge base

This section presents the five areas of interest as depicted in the literature. The focus is on the analysis of issues addressed in the literature and, to a lesser extent, models and methods applied to face them. Because of multiple facets, several publications may be classified according to different areas of interest (and related sub-areas). However, the classification is performed according to the prevailing facet to avoid a double review.

For instance, fare inspection can be perceived as the most profound bridge between PTCs (which aim to provide a valuable service) and evaders (who avoid the fare payment). Moreover, it represents a key control variable in POPs systems. Inspection has three positive impacts. During the day, it primarily serves the business interests of PTCs (i.e., protecting the revenues). During the evening, it increases the sense of security, e.g., reducing aggressive behavior by some passengers (Hansen et al. 2012). As a third impact, it is expected to reduce vandalism against PCTs' apparatus and infrastructures.

The inspection is usually scheduled by spot (random) checks performed daily by inspectors organised in patrols. It is frequent but not continuous. It occurs during boarding, alighting, and on-board (e.g., Abrate et al. 2008; Horizon Research Corporation 2002; Israel and Strathman 2002). The inspection can be performed by uniform and/or plainclothes staff (Dauby and Kovacs 2007a, b). In addition, plainclothes staff may station inside the vehicle next to each door and write down about the number of people evading without being noticed by passengers (e.g., Guarda et al. 2016a). The former contributes to "educate" passengers to pay for trips, whereas the latter aims to "catch" fare evaders.

As a result, fare inspection involves four facets faced from different corners: (1) the significance in explaining the likelihood to evade fares for passengers sensible to the risk of being caught; (2) the evaluation of its effectiveness as a deterrence strategy; (3) the setting of an 'optimal' inspection level (or the setting of the 'optimal' number of inspectors) and (4) the deployment of inspectors along a transit network. According to this classification, they will be investigated in Sects. 4.1.2, 4.2.1 and 4.3.1, 4.3.2 and 4.5, respectively.

The studies on fare evasion, criminological, economic and technological innovation are synthetically summarised by tables encompassing transit mode, type of study, sample size, analytical tool and relevant insights. For instance, the sample size may help understand the impact of the study from a practical perspective. The analytical tool reveals the scientific instruments adopted that may be compared. Relevant insights help understand the inner nature of each study. Moreover, the main findings of each study are briefly reported.

Some studies refer to all transit modes. However, unsurprisingly, many of them refer to trams and buses, which are more suitable to be managed by POPs.

Qualitative, quantitative, descriptive, and theoretical studies are distinguished. Qualitative studies analyse the attitude and motivation behind fare evasion. Quantitative studies discover segment of fare evaders and the related key determinants. They also emphasise the problem size, determinants of fare evasion and fare inspection, advantage/disadvantage of the ticketing systems, etc. Descriptive studies discuss general information on how to face fare evasion. Theoretical studies formulate models without experimentation in real case studies.

Qualitative studies use data collected interviewing selected individuals in workshop-style methodology. Quantitative studies include aggregate official data on historical trends of inspection and evasion rates, number of citations and fines, programme audits, etc. Moreover, other data came from surveys (e.g, web, mails, at home/work and intercept with staff and passengers) and lab experiments. Descriptive and theoretical studies do not use data.

The analytical tools include synthesised and coded text interview in qualitative studies. Descriptive models (simple percentages, cluster analysis, etc.), inferential models (linear, logistic, probit regressions, structural equation models, etc.) and optimisation methods are used in quantitative studies. Descriptive studies adopt a qualitative description, whereas theoretical studies present several kinds of models.

Conversely, the operational research area is arranged in a proper structure including specific facets: problem modelling, objective function, constraints, network type, and resolution methods.

4.1 Fare evader-oriented studies

Twenty-one studies examine the passenger's perspective. They contribute to figure out the evader portrait and discover segments, by investigating the characteristics, attitudes, motivations and behaviours of fare evaders.

4.1.1 Socio-demographics, travel determinants and situational factors of fare evaders

Table 4 summarises seven studies of socio-demographics, travel behaviour determinants, and situational factors identifying a 'one-size-fits-all' profile of fare evaders. Socio-demographics include gender, age, level of education, activity, nationality, car availability, and reasons for using the bus. Travel behaviours embrace trip purpose, time of day, in-vehicle time, other transit system use, transit use frequency, trip

Table 4 Studies on socio-demographics and travel determinants of fare evaders

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Abrate et al. (2008)	Italy, 12 cities	n/a	Quantitative	Intercept (stop) interviews	16,000 passengers	Logistic regression	Socio-demographic profiling by the measured evasion (ticketholder)
Barabino et al. (2015)	Italy, Cagliari	Bus and Trolley	Quantitative	Intercept (on-board) interviews	2177 passengers	Logistic regression	Socio-demographic, travel and situational profiling by the stated evasion
Bucciol et al. (2013)	Italy, Reggio Emilia	Bus	Quantitative	Intercept (stop) interviews	544 passengers	Probit regression	Socio-demographic, travel and situational profiling by the measured evasion (ticketholder)
Cools et al. (2018)	Belgium, Flanders	Train, subway, tram and bus	Quantitative	Web-based questionnaire	638 passengers	Logistic regression	Socio-demographic and situational profiling by the revealed evasion
Dai et al. (2016, 2017, 2018)	France, Lyon	Tram and bus	Quantitative	Intercept (stop) interviews and lab experiment	279 passengers	Descriptive statistics and logistic regression	Travel profiling by the measured evasion (ticketholder)
Eddy (2010)	Australia, Melbourne	Train	Quantitative	Intercept (stop) observations	288 passengers	Descriptive statistics	Socio-demographic profiling by the observed evasion (incognito)

origin and destination, travel frequency, travel alternatives. Situational factors regard the previous ticket violations, the knowledge of the fine amount, the probability of being detected, and attitude towards norms. All these determinants may affect fare evasion in all its forms (i.e., observed, measured, revealed or stated).

Although these studies used different approaches to data processing, the key determinants are quite similar despite some conflicting findings as follows.

Abrate et al. (2008) showed that young, unemployed and non-Italian were more likely to evade.

Bucciol et al. (2013) observed that young, male and non-European immigrants are more likely to evade. Moreover, occasional passengers taking short trips are more likely to evade. Besides, the group's affiliation affects the likelihood to evade fares, even if its effect depends on who the passenger and the others are. For instance, travelling with relatives is shown to increase the likelihood of being a paying passenger. Conversely, travelling with friends from 12 pm to 2 pm is shown to increase the likelihood of being a fare evader.

Barabino et al. (2015) showed the intention to evade fares increases among young males, those with low education, unemployed and/or students. Moreover, travelling shorter than 15 min, being dissatisfied users, and without an alternative to buses increase the intention to evade fares as well. In addition, situational determinants such as the level of inspection, the knowledge of fines and being already fined favour the intention to evade.

Dai et al. (2016, 2018) verified that people cheat more on shorter distances. Moreover, people already fined in the field behave more honestly in the lab.

Cools et al. (2018) observed that younger and male passengers have the highest likelihood to evade. Furthermore, perceptions of ticket prices and the probability of being inspected directly impact evasion rates.

Eddy (2010) found that most evaders were males over 25 years old, indicating that fare evasion is not just a youth issue.

4.1.2 Motivational determinants and behaviour towards fare evasion

In Table 5, 14 studies show how segments of fare evaders differently respond to fare evasion. Usually, fare evasion follows the rules of economic rationality, even if these rules are not always right. These studies pointed out largely five clusters of passengers: (1) honest (always purchase a ticket); (2) not paying the fare and/or the fine, despite high chances of being caught; (3) opportunists (evaluate the specific situation to buy the ticket; (4) respondents to economic reasons and (5) non-respondents to *economic* reasons (social norms concerning the self-image, social stigma, political ideology). To be specific, cluster (5) includes fare evaders that may use a political justification for their behaviour. Indeed, they consider public transportation as a public service that everybody should use freely.

In the area of qualitative studies, Suquet (2008, 2010) showed that fare evaders could be classified into six categories: (1) people who have no choice; (2) gamblers who are not likely to meet inspectors; (3) ideological opponents who challenge the inspectors; (4) dissatisfied users about service quality; (5) cheaters pretending to

Table 5 Studies on motivational determinants and behaviour toward fare evasion

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Currie and Delbosc (2017)	Australia, Melbourne	Train, Tram and Bus	Quantitative	Web-based questionnaire	1561 residents	Structural equation modelling	Analysis of unintentional and deliberate evaders (revealed evasion)
Delbosc and Currie (2015, 2016a)	Australia, Melbourne	Train, tram and bus	Qualitative	At home/work and/or online focus group interviews	67 passengers	Synthesis and coding of interview text	Analysis of attitudes towards and motivations behind fare evasion (revealed evasion)
Delbosc and Currie (2016b)	Australia, Melbourne	Train, tram and bus	Quantitative	Web-based questionnaire	1561 residents	Cluster analysis	Analysis of attitudes towards and motivations behind fare evasion (revealed evasion)
Hauber (1980)	Germany, Great Britain, Scandinavia, Switzerland and The Netherlands, 100 cities	Train, tram and bus	Quantitative	Intercept (stop) and at home/work interviews	8673 passengers; more than 100 PTC	Descriptive statistics	Analysis of motivations behind fare evasion (revealed evasion)
Leischnig and Woodside (2017)	Germany	n/a	Quantitative	n/a	390 respondents	Fuzzy-set qualitative comparative analysis	Analysis of multiple causal determinants of corrupted consumer behaviour, including fare evasion
Mehlkop et al. (2007)	Germany, Dresden and Switzerland Berne	Tram and bus	Quantitative	n/a	3869 passengers	Logit regression	Analysis of multiple determinants of the intention to evade fares

Table 5 (continued)

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Perrotta (2017)	USA, New York	Train, Subway, Bus	Qualitative	At home/work interviews	15 transportation and social service experts, 25 low-income residents	Synthesis and coding of interview text	Analysis of transit affordability. How low income leads to afford public transit. How transit planners understand public transport
Salis et al. (2017)	Italy, Cagliari	Bus and Trolley	Quantitative	Intercept (on-board) interviews	850 fare evaders	Cluster analysis	Analysis of attitudes towards fare evasion (revealed evasion)
Schwerdtfeger (2016)	Germany, Frankfurt-Rhine-Main	n/a	Qualitative	At home/work interviews	31 passengers	n/a	Analysis of attitudes towards and motivation behind fare evasion
Sterner and Sheng (2013)	Stockholm, Sweden	Subway	Quantitative	At home/work questionnaire	293 students	Linear regression	Analysis of social stigma associated with inspection
Suquet (2005)	n/a	Bus	Qualitative	At home/work interviews	6 fare evaders	Synthesis and coding of interview text	Analysis of the relationship between moral standards and social order
Suquet (2008, 2010)	France, Val d'Oisi	Bus	Qualitative	At home/work interviews	n/a	Synthesis and coding of interview text	Analysis of attitudes of fare evaders from the inspector's viewpoint

pay the fine, but never pay; (6) people having difficulties in understanding the fare structure.

Delbosc and Currie (2015, 2016a) discovered four segments of evaders: (1) the accidental evader having a strong view against fare evasion. (2) The unintentional evader who would pay, but sometimes s/he evades (e.g, when the validation machine is out of order). (3) The calculated risk-related–evader who deliberately evades if s/he thinks not to be caught. (4) The career evader who always evades.

Perrotta (2017) showed that low-income people are often unable to pay for trips of daily necessity. They travel by evading the fare, abusing free transfers, forgoing goods, borrowing and using a free fare card provided by welfare agents.

Schwerdtfeger (2016) discussed that fare evasion is the last way out of being socially excluded for some people. Conversely, other people see fare evasion as an opportunity to save money owing to the drawback of the ticket system (e.g., low inspection). Thus, financial reasons may lead people to evade, and fare evasion can have links with social exclusion.

In the area of quantitative studies, Hauber (1980) showed that many people evade due to economic, social (desire to emulate other evaders) and political reasons. Hence, he classified evaders into four groups: (1) 'naïve', not real offenders, accidentally forget to buy or validate a ticket; (2) 'conscientious', commit fraud only in some circumstances (financial restrictions at the end of the month); (3) 'regular', often practice fraud and usually include the political fare evaders. (4) 'cunning[4]', commit the offense as often as possible, and save money for their profit.

Delbosc and Currie (2016b) refined their previous segmentation and merged fare evaders into deliberate, unintentional, and never-evaders. Salis et al. (2017) obtained a similar result.

The remaining studies pointed out determinants of evaders, including adherence to norms, moral standards, and social stigma.

In Suquet (2005), fare evasion seems a social issue strongly related to the moral standard. For instance, some caught evaders may experience an internal reward for behaving in a manner consistent with their values: they pay when fined.

Mehlkop et al. (2007) linked the attitude to evade with the benefits of evading, the severity of fines, the probability of being caught, attitude towards norms and risk-taking. They showed that most passengers agree to the norms, even if somebody is inclined to risk, avoiding the payment of the fare.

Sterner and Sheng (2013) observed that fare evaders experienced almost no significant difference between an ordinary and an embarrassing inspection. Thus, the social stigma is likely not to be a determinant in deciding whether to evade or not.

Currie and Delbosc (2017) showed that honesty and permissiveness towards fare evasion were common determinants explaining intentional and unintentional evasion. Conversely, ticket competence and perceived ease of evasion were specific determinants explaining unintentional and deliberate fare evasion, respectively.

[4] To the best of our knowledge, there are groups of fare evaders that may deal with the elusion of fares by astute tricks. They are clever and well informed about the mazes in the system, or have become experienced in that no harm will come if they adapt their behaviour to the change of the fare system control.

Leischnig and Woodside (2017) found that combining deterrence (e.g., perceived likeliness of detecting fare dodging), personality (e.g., opportunistic behaviour), norms (e.g., obedience to law) and socio-demographic factors may explain also fare evasion.

4.2 Criminological studies

Eighteen studies consider fare evasion as a 'criminal' act. They are usually data-driven and based on real experiments. These studies show the effectiveness of situation-specific measures to face crimes in general and fare evasion in particular. They contribute to shed light on issues of deterrence, enforcement, and security.

4.2.1 Deterrence

Eleven studies deal with deterrence against fare evasion. Deterrence can be defined as "*the use of threats by one party to convince another party to desist from criminal actions*" (Huth 1999). Two key assumptions characterise deterrence. Firstly, specific measures against offenders will prevent further acts. Secondly, the apprehension of specific punishment will prevent similar crimes.

A body of literature on crimes in public transport is associated with the system itself—e.g, fare evasion, vandalism-employees—e.g., assaults on drivers or ticket collectors—and passengers—e.g., robbery (Smith and Clarke 2000). Thus, a specific approach to crime allows managers to tailor specific measures. Most of the criminological literature also deals with measures to prevent fare evasion, according to 'situational crime prevention' theory (Smith and Clarke 2000). According to this theory, fare evasion is committed because many opportunities are available. Therefore, preventive measures would help make public transport trickier to non-paying passengers.

Table 6 points out two main preventive measures against fare evasion: physical and psychological.

Physical measures concern the system design by impediments to reinforce the access (and/or the exit) to it. Although the entry is not impossible, it is much trickier if more obstacles must be overcome. For instance, barriers at subway entry impede access without a valid ticket and could discourage criminals from committing a theft. A passenger may have a limited time to exit and avoid loitering.

Psychological measures are impediments producing relevant chances of apprehension by intensive supervision at the entry and some inspection at exit in fBTS-POP_B or by specific inspection in nBTS-POP_S. For instance, checking the tickets electronically also at the exit can double the risks of apprehension of being caught.

The main results are summarised below.

As for physical measures, Clarke (1993) concluded that the introduction of automatic ticket collection in 63 central business stations reduced the incidence of fare evasion by two-thirds. Moreover, these results support the logic of installing these devices in other critical stations.

Table 6 Studies on deterrence

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Clarke (1993)	UK, London	Subway	Quantitative	Intercept (on-board) measurement; tickets sales	12,500 checked passengers; 1150 cars	Descriptive statistics	Automatic ticket collections: before and after evaluation of fare evasion rate
Clarke et al. (2010)	Canada, Edmonton	Light rail transit, bus	Quantitative	Intercept (at alighting stop) measurement	163 weekly checks on passengers	Descriptive statistics	Reduced inspection activities and increased fining rate: before and after evaluation of fare evasion rate
Dai et al. (2017)	France, Lyon	Light rail transit	Quantitative	Intercept (at alighting stop) interviews and lab experiment	279 passengers	Descriptive statistics and probit regression	Crackdown policies: evaluation of efficiency and effectiveness
Del Castillo and Lindner (1994)	USA, New York	Subway	Descriptive	n/a	n/a	Qualitative description	Discussion of three strategies against fare evasion
Des Champs et al. (1991)	Canada, Vancouver	Light rail transit, bus, trolleybus, ferry	Quantitative	Audit programme	75,000 checked passengers/audit	Descriptive statistics	Fare system design: before and after evaluation of fare evasion rate
Hauber (1993)	23 European City	Urban train, subway, tram, bus	Quantitative	Observation of passengers and staff and personal interviews	600–1200 observations per cities	Descriptive statistics	Survey on inspection and evasion rates
Hauber et al. (1996)	The Netherlands, Amsterdam, Rotterdam, Utrecht and Den Haag	Subway, tram, bus	Quantitative	Direct observation and Intercept (on-board) interview	170 passengers	Descriptive statistics	Inspectors with their own right: before and after evaluation of fare evasion rate

Table 6 (continued)

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Killias et al. (2009)	Switzerland, Zurich	Train	Quantitative	Working hours of checks	Average of 100,000 h/month	Descriptive statistics	Attendants during night hours: before and after evaluation of fare evasion rate
Smith and Clarke (2000)	n/a	All	Descriptive	n/a	n/a	Qualitative description	Review of facets of crime e.g., fare evasion, assault on ticketing collectors, vandalism, pick pocketing
Van Andel (1989)	The Netherlands, Amsterdam, Rotterdam and The Hague	Subway, tram, bus	Quantitative	Data on fare evasion, Intercept (on-board) interview with staff and passengers	900 passengers	Descriptive statistics	Get-on-board procedures and increased inspection activities: before and after evaluation of fare evasion rate
Weidner (1996)	USA, New York	Subway	Quantitative	Fare evasion arrests, summonses, Intercept (at-station) interview	200–2500 arrests and summonses; 380 passengers	Descriptive statistics	'High-wheel' turnstiles: before and after evaluation of fare evasion rate

Weidner (1996) showed that ‘high-wheel’ turnstiles were somewhat effective in reducing fare evasion. However, they were not a complete success in enhancing the perception of safety on passengers: they can create a prison-like environment.

As for psychological measures, despite conflicting results, ‘inspection’ activities by human presence (at the entry/exit or on-board) and technology were a powerful tool against fare evasion.

Hauber (1993) concluded that increasing the frequency of inspections reduces fare evasion and produces more benefits as opposed to the higher penalty or a lesser fare than the current. Nevertheless, he found that the frequency of inspections did not reduce fare evasion beyond a certain level: some people may remain unaffected.

Similar conclusions are reported in other studies besides other improvements.

Van Andel (1989) observed that changing the procedure to get on-board effectively contrasted the fare evasion (i.e., passengers must walk close to the driver who checked their tickets).

Des Champs et al. (1991) emphasised that the redesign of a simple fare structure may reduce fare evasion for many passengers.

Del Castillo and Lindner (1994) concluded that token attendants, police presence and minisweeps are effective in reducing fare evasion, even if token attendants have not the police power.

Hauber et al. (1996) observed that the increase in the effectiveness of inspectors (in their own right) resulted in less fare evasion despite more conflicts between inspectors and passengers.

Killias et al. (2009) showed that the introduction of attendants on the suburban train of Zurich reduced fare evasion at night and during daytime hours. Nevertheless, even if fare evaders are discovered, the certainty of being fined works as deterrence in a non-linear way. Moreover, they observed that inspections should be concentrated at critical hours and areas.

Clarke et al. (2010) concluded that reducing the inspection activities and issuing more fines for evading fares provided no clear trends in the weekly evasion rate.

Dai et al. (2017) evaluated crackdown policies and concluded that: (1) random inspections are better than concentrated crackdowns; (2) prolonged crackdowns reduce fare evasion during intense monitoring, but they increase fare evasion as soon as they are withdrawn; (3) pre-announced inspections cause more fare evasion.

4.2.2 Enforcement

Enforcement can be defined as a system where some organisations act in a systematised way to enforce the law when people are discovered violating it (New Law Journal 1974). In this paper, the enforcement is a tool to discourage a ‘non-criminal’ violation of the law by the imposition of some consequences (e.g., a fine).

Table 7 summarises three studies. They contribute to the evaluation of two types of enforcement: ‘administrative’ and ‘managerial’.

Administrative enforcement studies focus on the effects of the application of fines on fare evaders, because only a proportion of fined passengers pay them (Bijleveld 2007; Clarke et al. 2008).

Table 7 Studies on enforcement

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Bijleveld (2007)	The Netherlands, Amsterdam and Dordrecht	Train	Quantitative	Data on penalty	24739 penalties	Descriptive statistics and tests	Evaluation of standard (civil law) and penalty collection procedures
Bratton (1999)	USA, New York	Subway	Descriptive	n/a	n/a	Qualitative description	Description of managerial strategies against crimes including fare evasion
Clarke et al. (2008)	Australia, New South Wales	Train and bus	Descriptive	n/a	n/a	Qualitative description	Description of the impact of the fine on disadvantaged people

Managerial enforcement focuses on the effects of the application of 'human' strategies to contrast fare evasion.

In the case of administrative enforcement, in a controlled experiment, Bijleveld (2007) evaluated two procedures to recover the cost of the unpaid ticket. In the "standard procedure", when fare evaders are discovered, they are asked to buy a ticket from the inspector at an increased price. Next, following regular civil law, the debt collection procedure is applied. In the "penalty collection procedure", the efforts of the PTC are followed by a penalty collection procedure. It is managed by the fine collection agency of the national Ministry of Justice. She concluded that the standard procedure is more effective than the penalty collection one.

Clarke et al. (2008) observed that socially or economically disadvantaged people (e.g., homeless, mentally ill, young, recently released from prison, low incomes) are more vulnerable than others to being fined. Moreover, they are not able to pay the fine. Barriers to paying include the high amount, the inability to manage the fine processing system, the difficulties in accessing the court, in seeking legal advice and specific situations.

In the case of managerial enforcement, Bratton (1999) concluded that a well-managed and highly directed police department could provide a reduction in crimes, including fare evasion. This was possible by changing criminals' perceptions of their chances of success. These results are contrary to the classical approach, where an increase in crime could depend on an increase in arms, drugs, and others.

4.2.3 Security

Security is the degree of protection when a separation between the 'asset' and the threats is created. This concept is applied to whichever vulnerable or valuable 'asset' such as a person, an organisation, etc. Extensive literature exists on the analysis and categorisation of security in different areas (information technology, political, infrastructures, etc.). As for fare evasion, we can borrow this concept and interpret it as the protection from assaults[5] against ticket inspectors and bus drivers. A recent survey showed that 67% of factors contributing to the assaults of bus drivers were because of fare enforcement (Nakanishi and Fleming 2011).

Four studies are summarised in Table 8 and provide details on security strategies against assaults.

Mace (1997) observed that a situation of insecurity may be originated by low-economic classes (e.g., young, sulky, and aggressive passenger) and drivers when their resentments meet inside a bus. These resentments may lead to assaults.

Bonfanti and Wagenknecht (2010), Mauri et al. (1984) and Nakanishi and Fleming (2011) concluded that assaults could be faced by technological devices and 'human' activities. The former includes e.g., video-surveillance, radio alarm, protected driver cabin, or windows. The latter considers a partnership with police, on-site security staff, and training. These actions would also reduce fare evasion.

[5] An assault is a physical/verbal act against the mission of the staff by passengers. It may depend on time, location and crowding.

Table 8 Studies on security

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Bonfanti and Wagenknecht (2010)	Worldwide	All modes	Quantitative	n/a	31 operators	Descriptive statistics	A survey on fare evasion and aggression
Mace (1997)	France, Paris	Bus	Descriptive	n/a	n/a	Qualitative description	Description of lower-class suburbs passengers' interaction with drivers
Mauri et al. (1984)	USA	Heavy rail, Light Rail Transit, Bus	Quantitative	At work interview	13 transit agencies	Descriptive statistics	Description of security problems and strategies against crime including assaults
Nakanishi and Fleming (2011)	USA and Canada	Bus	Quantitative	Telephonic interviews	66 transit agencies	Descriptive statistics	Description of policies and practices to deter and mitigate assaults

4.3 Economic studies

Forty-one studies approach fare evasion from an ‘economic’ perspective. They focus on control parameters, system aspects and strategies against fare evasion. Five different sub-areas are considered: (1) measuring and managing fare evasion, (2) inspection, (3) fines, (4) ticketing systems and (5) miscellaneous.

4.3.1 Measuring and managing fare evasion

Twenty-three studies are summarised in Table 9. They include general surveys and case studies, encompassing all public transit modes. These studies have stressed the topics of measurement, determinants (e.g., time period, low-income neighborhoods) and strategies against fare evasion besides economic estimation. Usually, these topics are faced individually. Several studies just described the strategies, whereas few others provided cost–benefit evaluations of them. Some others showed how to estimate lost revenues.

Fare evasion needs to be quantified even if just the measure is not adequate to draw conclusions. It should be used with other parameters. The most common include warning passengers (unintentional evaders, first time forgiven), citation passengers (passengers who received a fine), and inspected passengers (passengers with a checked ticket). These parameters help estimate both the Fare Evasion rate and the Inspection rate (e.g., Dauby and Kovacs 2007a, b; Larwin and Koprowski 2012a, b; Multisystems et al. 2002).

The fare evasion rate is the *ratio* between *evaders* and *inspected passengers* in a predefined time window. However, while calculating the fare evasion rate, PTCs do not agree on what ‘evaders’ are. Some PTCs consider the total warnings issued as well as the citations, others consider the citations only, and some also consider the passengers escaped when inspectors get on board. Therefore, a comparison among fare evasion rates could be biased. Fare evasion rate measures the trend of the phenomenon along years and might represent a key parameter of efficiency. Indeed, low values of the fare evasion rate could represent a weak control activity rather than a ‘comply-with-rules behavior’ of passengers. The inspection rate is the ratio between *inspected* and *carried passengers* in a predefined time window.

The fare evasion rate is expected to vary according to the fare inspection rate, even if this relationship is not clear-cut. Dauby and Kovacs (2007a, b) showed significant negative trends between the evasion rate and inspection rate. These trends were not observed elsewhere, both at an aggregate (Multisystems et al. 2002) and disaggregated level (Cummins et al. 2012), respectively.

From a descriptive viewpoint, fare evasion measurement depends on some determinants.

Lee (2011) showed that route, time period, back-door boarding, vehicle occupancy and level of inspection affected fare evasion.

In Reddy et al. (2011) fare evasion depended on system entries, time periods, seasonality, and income. They showed that busy time and stations have a lower amount of evasion per hour, but a higher number of passengers per hour. Moreover, evasion occurred more often in low-income neighbourhoods.

Table 9 Studies on measuring and managing fare evasion

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Buneder and Galilea (2017)	Chile, Santiago	Bus	Quantitative	Intercept (at stop)—unobtrusive—official data of Ministry of Transport	91 months	Autoregressive, linear and non-linear regression models	Determinants of fare evasion
Cosby (1985)	UK, Manchester	Bus	Quantitative	Intercept (on-board) observation	239 duties	Descriptive statistics	A method to estimate lost revenues by aggregate data
Cummins et al. (2012)	USA, Seattle	Light Rail Transit	Quantitative	Official data on historical trends of fare evasion and fare inspection	> 1 million passengers	Descriptive statistics	A pool of strategies against fare evasion
Dauby and Kovacs (2007a, b)	Worldwide	Light Rail Transit	Quantitative	N/A	18 worldwide transit agency/operators	Descriptive statistics	Measurements and strategies against fare evasion
Fürst (2012)	Germany, Switzerland and Austria	All transit	Qualitative	E-mail personal interviews	55 experts	Synthesis and coding of the text	A pool of strategies against fare evasion
Guarda et al. (2016a)	Chile, Santiago	Bus	Quantitative	Intercept (on-board)—unobtrusive—official data of Ministry of Transport	21244 observations	Multiple linear regression, Poisson and Negative binomial	Determinants of fare evasion
Guarda et al. (2016b)	Chile, Santiago	Bus	Quantitative	Intercept (on-board) unobtrusive	13,912 observations	Negative Binomial Regression Model and Heuristic	Cost–benefit evaluations to locate fare inspectors
Guarda et al. (2015)	Chile, Santiago	Bus	Theoretical	N/A	N/A	Negative Binomial Regression Model and formulas	Theoretical cost–benefit evaluation of three strategies against fare evasion

Table 9 (continued)

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Hansen et al. (2012)	Canada, Calgary	Light Rail Transit, Bus, community shuttle	Quantitative	Intercept (on-board) interview	33499 customers and 1496 fare evaders	Descriptive statistics	A pool of strategies against fare evasion
Horizon Research Corporation (2002)	USA, South California	Subway	Quantitative	Intercept (at boarding station) interviews	4985 checked and 485 interviewed passengers	Descriptive statistics and Binomial regression model	Determinants of fare evasion; A pool of strategies against fare evasion
Israel and Strathman (2002)	USA, Portland	Train and Bus	Quantitative	Intercept (at stop) measurement	1331 trips	Descriptive statistics	A method to estimate lost revenues by disaggregated data
Larwin and Koprowski, (2012a, b)	USA	All transit	Quantitative	Online survey	33 North American agencies	Descriptive statistics	Measurements and strategies against fare evasion
Lee (2011)	USA, San Francisco	Light Rail Transit, Tram and Bus	Quantitative	Intercept (on board and at stop) observation	41,239 passengers and 1141 Trips	Descriptive statistics and GIS	A pool of strategies against fare evasion
Li and Min (1985)	China, Shanghai	Bus	Descriptive	Official data on Shanghai buses and interviews	N/A	Qualitative description	Reasons, effects, and strategies against fare evasion
Multisystems et al. (2002)	European and American agencies	Heavy rail, commuter rail, Bus and Bus Rapid Transit, Ferry	Quantitative	Telephonic interview	4 European and 26 American public transit agency/operators	Descriptive statistics	Survey of self-service ticketing systems
Prokosch and Gartsman (2017)	USA, Boston	Light Rail Transit	Quantitative	Intercept (at stop)—observation	110 trips, 1532 passengers	Descriptive statistics	Methods for estimating lost revenues from POE to nBTS-POPs
Reddy et al. (2011)	USA, New York	Subway	Quantitative	Intercept (at stop)—unobtrusive	255,436 observations	Descriptive statistics	A pool of strategies against fare evasion

Table 9 (continued)

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Sánchez-Martínez (2017)	USA, Boston	Light Rail Transit	Quantitative	Intercept (at stop) observation	777,001 transaction data	Stochastic model	A framework for estimating fare non-interaction and evasion
Torres-Montoya (2014)	Chile, Santiago	Bus	Descriptive	Official data on historical trends of fare evasion	N/A	Qualitative description	A pool of strategies against fare evasion
Troncoso and de Grange (2017)	Chile, Santiago	Bus	Quantitative	Intercept (at stop)—unobtrusive—official data of Ministry of Transport	86 months	Cointegration analysis	Determinants of fare evasion

From a modelling viewpoint, Horizon Research Corporation (2002) showed that the fare evasion rate depended on the knowledge of the transit systems, access to ticket vending machines and passengers' characteristics (e.g., demographics, travel patterns, and fare media type). Conversely, some situational factors (e.g, perceived likelihood of being caught, ticket inspected in the past) had no significant effect in explaining fare evasion.

Guarda et al. (2016a) pointed out that there was more evasion during rush hours when buses had more doors and were crowded. Besides, fare evasion rates increased when passengers experienced longer headways than the scheduled, and many passengers boarded/alighted at a given door, particularly by a rear door. Moreover, fare evasion was significantly higher at bus stops located in low-income neighbourhoods.

In Buneder and Galilea (2017) fare evasion was driven over time by a time trend, possibly due to sociological group-behaviour effects. In addition, they showed that a spatial-distribution pattern existed. This pattern demonstrated how the most vulnerable neighbourhoods had higher evasion rates than the less vulnerable ones.

Troncoso and de Grange (2017) observed that increasing 10% of the fare would increase by a 2% evasion rate, whereas an increase of 10% in the inspection rate would lead to a decrease of 0.8% in the evasion rate. Also, they highlighted a negative correlation between unemployment and evasion rates.

Sánchez-Martínez (2017) showed that the estimations of fare noninteraction and fare evasion could be used by agencies to target fare inspection and off-board validation resources effectively. These estimations may improve the accuracy of scaling for inferred origin–destination matrices.

Measurement results are an input for management strategies against fare evasion. Strategies should be embraced not only by physical and technological devices but also by cultural and political changes. Management strategies are largely classified into five main categories: System design, Legal framework policy, Inspection activity, Advertisings and informative campaigns and Transit environment strategies.

System design aims at improving the accessibility to transit systems for paying passengers and increasing difficulties for non-paying ones. As in Dauby and Kovacs (2007a, b), Fürst (2012), Horizon Research Corporation (2002), Larwin and Koprowski (2012a, b), Multisystems et al. (2002), Reddy et al. (2011) and Torres-Montoya (2014), these strategies mainly include: (1) a clear-cut, simple, understandable, transparent and integrate fare system with a variety of tickets and loyalty programmes; (2) a high degree of closure; (3) the adoption of technological devices for safety and security (e.g, video monitoring at the entry) to identify and capture fare evaders; (4) the increase in off-board payment structures; (5) the use of electronic tickets.

Legal framework aims at enforcing the fare payment by 'administrative' tools (e.g, the fine). According to Dauby and Kovacs (2007a, b), Hansen et al. (2012), Larwin and Koprowski (2012a, b), Li and Min (1985), Reddy et al. (2011) and Torres-Montoya (2014), these strategies mainly include: (1) the change of the offence from civil to criminal (e.g, failure to pay warrant for the arrest); (2) the increase of the fine amount for both ordinary and repeating offenders; (3) the improvement of the fine collection procedure to avoid a climate of perceived impunity; (4) the provision of the 'police' power to inspectors to check the identity of passengers; (5) the adoption of a joint fast-track justice procedure for payment of fines together with the PTC.

Inspection aims at deterring and capturing fare evaders. In Cummins et al. (2012), Dauby and Kovacs (2007a, b), Fürst (2012), Hansen et al. (2012), Horizon Research Corporation (2002), Larwin and Koprowski (2012a, b), Li and Min (1985), Multisystems et al. (2002), Reddy et al. (2011) and Torres-Montoya (2014), many examples of these strategies are available. They include: (1) selection and training of inspectors to adopt a customer-oriented approach to resolve conflicts; (2) announcement and intensification of inspections to remember a constant inspection activity; (3) inspection on board and on the platform. This activity may be refined by locating well-recognised inspectors' vehicles in highly visible locations to ensure that passengers know that inspectors are operating; (4) education or punishment of fare evaders by warnings or citations; (5) audits as a tool in reviewing the work of inspectors. Nevertheless, Reddy et al. (2011) concluded that observing staff presence does not reduce fare evasion. Conversely, empowering the legal framework by increasing fines and arrests seems to provide better results.

Advertisements and informative campaigns aim at providing changes in the behaviour of passengers by psychological actions. As in Horizon Research Corporation (2002), Lee (2011), Li and Min (1985) and Torres-Montoya (2014), these actions mainly include: (1) educational campaigns to change the collective psyche (e.g, fear of social rejection, embarrassment, the desirability of recognition) and (2) effective communication to show improvement in the system (e.g, commend 'civilised' paying passengers as opposed to fare evaders, educate passengers, dissuade evaders).

Transit environment strategies aim at improving some operational characteristics of the service. Fürst (2012) suggested a rise in quality of service that could also have positive effects on fare evasion: some people do not perceive the value for money. Guarda et al. (2016a) advised increasing the bus fleet, improving service regularity, and the bus design.

Usually, no benefit–cost models have validated these strategies though Dauby and Kovacs (2007a, b) reported that the return rate ranges between 17 and 72%. Hence, the extra revenues collected are seldom enough to cover the extra costs. Conversely, two recent papers by Guarda et al. (2015, 2016b) provided analytical evaluations of some strategies to help reduce fare evasion for nBTS-POPs. Guarda et al. (2015) provided theoretical benefit–cost models of: (1) more off-board payment stations, (2) more inspection and (3) more bus capacity. Guarda et al. (2016b) concluded that the inspection strategy may be cost-effective when inspectors are located on selected bus stops, time periods, and bus routes. Besides, inspectors reminded passengers to pay the fare while getting on board instead of giving fines.

Finally, fare evasion produces lost revenues, which need to be quantified.

Cosby (1985) estimated the total lost revenues due to all types of evasion by both passengers and employees. It included a measurement of the average revenue on duties where evasion was prevented; the total number of duties and the total on-vehicle revenues were also considered in the study.

Israel and Strathman (2002) estimated lost revenues, including the passenger volumes, the type of evasion, the average originating fare, and the weighs of each type of evasion.

Prokosch and Gartsman (2017) estimated a fare evasion rate of approximately 22% at the rear door. Moreover, evasion rates are higher in the afternoon.

4.3.2 Setting the inspection

Six studies, summarised in Table 10, concern the setting of an 'optimal' inspection level. They stressed three different approaches to set the optimal inspection level by using: (1) exact optimisation methods; (2) game theory-based modelling and (3) a data driven-model linking the probability of being caught and the amount of the corresponding fine. The main results are described below.

The first approach was adopted in Boyd et al. (1989) and Barabino et al. (2013, 2014a).

They formulated profit models to establish the inspection. These models included the probability that a passenger is checked and the probability that a passenger feels to be checked, respectively. Moreover, they included the monetary value of a fine and the level of risk aversion, among others.

Boyd et al. (1989) provided a theoretical formulation of it.

Barabino et al. (2013) adjusted the previous model by including several terms dependent on the PTC (e.g, the cost of a reminder) and used real data to calibrate each term of the profit. Both models maintain the hypothesis of an established perception of inspection though it varies during different time windows according to the level of inspection. Moreover, the number of caught passengers is equal to the number of collected fines without distinguishing between caught and fined passengers and caught but not fined ones.

Barabino et al. (2014a) addressed these drawbacks recognising that the passenger perception of being inspected varies along the time and sometimes fare inspectors cannot capture (fine) all evaders. They concluded that the optimum inspection level is 3.8%.

As for the second approach, Jankowski (1991) showed that, in the case of complete information about the deterrence policy set by the PTC, the level of inspection could be set considering the fare-to-fine ratio. Conversely, in the case of incomplete information, it could incur higher inspection costs without reaching a lower evasion rate.

Avenhaus (2004) provided advices on how frequently passengers should be controlled when the fare and the fine have been established. He concluded that if a passenger chooses its equilibrium strategy (behaving legally) for any control probability, "*the investment of control is just being compensated by the amount of fines taken in*".

The latter approach was adopted by Kooreman (1993). By manipulating specific utility functions, he found that the evasion elasticity regarding the inspection rate was approximately -1, while the elasticity regarding the fare-to-fine ratio was just below -0.5. He concluded that passengers behave like people who maximise the expected utility.

Table 10 Studies on the setting of inspection

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Avenhaus (2004)	n/a	n/a	Theoretical	n/a	n/a	Game theory	Analysis of the 'optimal' level of inspection through non-cooperative inspection games
Barabino et al. (2013)	Italy, Cagliari	Bus and Trolleybus	Quantitative	Intercept (on-board and stop) observations	Checked passengers (8853); interviewed Passengers (3659)	Exact optimisation method	Extending a profit maximisation model for setting the 'optimal' level of inspection
Barabino et al. (2014a)	Italy, Cagliari	Bus and Trolleybus	Quantitative	Intercept (on-board and stop) observations	Checked passengers (27,514); interviewed Passengers (10,586)	Exact optimisation method	A framework setting the 'optimal' level of inspection in a long-time window
Boyd et al. (1989)	n/a	n/a	Theoretical	n/a	n/a	Exact optimisation method	The first model for setting the 'optimal' level of inspection
Jankowski (1991)	n/a	Bus	Theoretical	n/a	n/a	Game theory and Exact optimisation methods	Analysis of the 'optimal' level of inspection through cooperative inspection games
Kooreman (1993)	Europe and Canada	n/a	Quantitative	Official data on fare evasion and fare inspection	7 operators	Log-regression model	A data-driven model of the 'optimal' level of inspection and the amount of the corresponding fine

4.3.3 Setting the fine

This category includes three studies. Together with the inspection, fines represent a crucial 'administrative' element to enforce fare payment. While raising the level of inspection by human presence and/or technological devices could be costly, this is not right for the fine. Fines increase the fear of paying penalties if passengers are caught evading fares.

A monetary fine for undertaking an illegal activity should be set as high as possible (Becker, 1968). Nevertheless, sometimes, this hypothesis does not hold. Thus, some studies endeavoured to find an optimum level of fines to discourage fare evasion by considering the value of fine, fare, and inspection cost.

Table 11 reports the three studies where different approaches were employed to set the level of fines by using some forms of modelling.

Bootheway (2009) concluded that an increased fine might reduce the overall percentage of fare evaders. The remaining evaders will fight to avoid the higher fine, because they would have paid the lower fine.

Buehler et al. (2014, 2017) showed that fines higher than usual do not necessarily reduce fare evasion. Besides, fare evasion allows the PTC to charge a high price to paying passengers. Moreover, a PTC could not have incentives to fully deter fare evasion because profit increases provided that detection 'technology' is available (e.g, video surveillance).

4.3.4 Ticketing systems comparison

While the detail of each ticketing system may always differ in each case, some attempts were done to understand which one is more profitable against fare evasion by three studies. They are summarised in Table 12 and stressed different comparisons.

Leung (2003) showed that neither fBTS-POP$_B$ nor nBTS-POPs are particularly vulnerable to fare evasion provided that adequate control measures are adopted. More precisely, nBTS-POPs have the highest expenditures as percentages of revenues and the quasi-lower percentages of lost revenues. To strengthen deterrence and enforcement, passengers suggest increasing the fine to the notorious offender for fBTS-POP$_B$ and increasing platform announcements (e.g., reminders for a valid ticket before boarding) for nBTS-POPs.

Sasaki (2014) concluded that the optimal choice of the ticketing system may be described as a sub-game solution. By specifying the profit equations, he calculated the difference in profits for each ticketing system. If the morality of passengers is supposed to be high enough, the PTC should choose fBTS-POP$_B$ if the equilibrium-profit is >0 when the optimal fine for nBTS-POPs is considered. Conversely, it should choose nBTS-POPs with the setting of the optimal fine. Both systems are indifferent if the difference is 0.

Currie and Reynolds (2016) showed that nBTS-POPs performed better than nBTS-POE. Despite the recovery of lost revenues through fare evasion, the cost owing to additional stop dwell time was more significant than benefits of the nBTS-POE. Moreover, nBTS-POE resulted in lower passenger volumes, additional

Table 11 Studies on the setting of fines

Source (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Bootheway (2009)	USA	Bus	Theoretical	n/a	n/a	Simple mathematical model	Analysis of the 'optimal' fine
Buehler et al. (2014, 2017)	Switzerland, Zurich	Train, Tram, Bus, Ferry	Quantitative	Official data	> 46,000,000 paying passengers; > 600,000 payment evaders	Exact optimisation method	Analysis of the 'optimal' fine considering the 'optimal' price

Table 12 Studies on ticketing systems comparisons

Source (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Currie and Reynolds (2016)	Australia, Melbourne	Light Rail Transit	Quantitative	Official data on cost and benefits for POPs and POE	n/a	Descriptive statistics	Cost–benefit analysis between nBTF-POPs and nBTS-POE
Leung (2003)	Asia, Honk Kong	Train, Subway, and Light Rail Transit	Quantitative	Interview with operators and intercept (mail)	3 railway operators and 150 passengers	Descriptive statistics	Cost–benefit analysis between nBTF-POPs and fBTF-POP_B
Sasaki (2014)	n/a	Heavy rail, commuter rail, Light Rail Transit, Bus rapid transit	Theoretical	n/a	n/a	Game theory and Exact models	Comparison between nBTF-POPs and fBTF-POP_B

vehicles, and higher operational costs. In order to increase revenues, they conclude that other methods will be more effective than changing the nBTS-POPs to nBTS-POE.

4.3.5 Miscellaneous

Six studies cannot be classified elsewhere, and thus are summarised in Table 13. These studies mention three types of facets: (1) service product design, (2) policy ticketing innovations, and (3) service contracts and fare reform.

Dong and Taik (2014) suggested to include the social capital in the budget needs for running the product/service. The budget included the estimated percentage of fare evasion. This is because for designing a product/service system, designers need to set assumptions for understanding the expected behaviour and the abuse of the system.

Nahuis (2005, 2007) showed that the effectiveness of decisions taken by the PTCs on the innovation of the ticketing systems was not a complete success. Indeed, even if the PTCs set a programme of actions expected to be followed by passengers, it crashed due to different anti-programmes, in *primis* fare evasion. He concluded that these anti-programmes posed a political problem for the public authority.

In Nahuis (2009), PTCs did not achieve the stabilisation (i.e., whether passengers accept the innovation). This is because they unsuccessfully tried to correct passengers' misbehaviour (i.e., configure the passenger) confiding his/her morality and honesty. He concluded that configuring the passengers and adjusting the technology are combined strategies suggested to achieve stabilisation. For instance, the PTCs should obligate all passengers stamping their travel document without distinguishing from tickets and passes.

Tamblay et al. (2017) showed that various contractual mechanisms transferred risks to the transit authorities. These mechanisms were shown to reduce revenue risk from 70% to around 25%. Nevertheless, this fact contributed to the persistence of buses skipping stops and fare evasion.

Chung and Chiou (2017) observed a positive association between willingness to pay and attitudes from a stage-based towards a distance-based bus fare scheme. This fact highlighted the importance of communicating with people about the bus fare scheme reform, especially considering that free riders significantly less supported this reform. Nevertheless, they referred to free riders who have tried to benefit by showing a lower willingness to pay for the bus. Moreover, these respondents are not necessarily fare evaders.

4.4 Technological innovation studies

This section focuses on technology innovations for accessing public transport and preventing fare evasion. The focus is on the ticketing systems evolution from traditional fare collection, such as nBTS-POE, to nBTS-POPs. Moreover, attention is devoted to AFC technologies such as smart cards and e-ticketing.

Table 13 Studies on miscellaneous

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Chung and Chiou (2017)	Taiwan, Taipei	Bus	Quantitative	Telephonic interview	2000	Multinomial and nested logit models	Evaluation of bus fare reform by measuring travellers' willingness to pay for bus travel
Dong Hoon and Talk (2014)	USA, UK, Finland and Korea	Subway	Theoretical	n/a	n/a	Simple mathematical model	Analysis of social capital effects on the product-service system
Nahuis (2005, 2007)	The Netherlands, Amsterdam	Tram	Descriptive	Newspapers and interviews	n/a	Qualitative description	Analysis of ticketing innovation from nBTS-C to nBTS-POPs
Nahuis (2009)	The Netherlands, Amsterdam	Tram	Descriptive	Newspapers and interviews	n/a	Qualitative description	Evaluation of the stabilisation from nBTS-C to nBTS-POPs
Tamblay et al. (2017)	Chile, Santiago	Bus	Descriptive	n/a	n/a	Qualitative description	A framework grouping the risks inherent in each transit system

4.4.1 Ticketing systems evolution

Table 14 reports five studies on the advantages of moving towards nBTS-POPs against fare evasion.

Diebel (1981) discussed the advantages of nBTS-POPs: (1) increased productivity (dwell time reduction); (2) more flexible fare policies; (3) reduced driver workloads (they are not responsible for handling money); (4) enhanced system security and (5) reduced friction between drivers and passengers.

Peat (1982) showed that fare evasion occurred owing to cash evasion, pass evasion, and zone evasion depending on the fare structure. They concluded that nBTS-POPs is expected to reduce fare evasion, even if cash-paying passengers will continue to pay the fare and may attempt to defraud the fare box as well.

Wagner et al. (1986) showed that some problems need to be overcome to obtain a successful nBTS-POPs. Some of these problems are the increase in fare evasion, high inspection costs, little or any improvements on travel time (unlike some European bus operators), low surcharge/fine collections (27%), overburdened courts, and the increase in vandalism.

In Lorenc and Lutin (2000) fare evasion is considered an offense like motor vehicle infractions and it is faced by appropriate legislation (e.g, the creation of fare paid areas, the establishment of a suitable penalty). Moreover, they reported that inspectors are more customer-oriented than enforcer-oriented in the case of an unclear fare structure.

Watry and Straus (2000) claimed that the transition to nBTS-POPs was complicated due to POPs and non-POPs routes. Nevertheless, the authors concluded that the PTC has been successful in this conversion, mainly owing to the reassignment of the second operator to make duties elsewhere. In addition, the fare inspection was assigned to civilian inspectors directly managed by the company. Unlike nBTS-POPs in USA Light Rail Transit, this system had a low inspection rate and a low fare evasion rate.

4.4.2 Smart card

Table 15 summarises seven studies on smart cards, which are plastic memory cards with microprocessor-like credit cards. Smart cards contain an embedded integrated circuit (or chip) on which fare data are electronically stored. Moreover, while printed-paper tickets are discarded when expired, smart cards can be reloaded with a new fare. In this paper, the focus is on the evaluation of smart cards for preventing and/or reducing fare evasion, even if their use must not be overvalued (Dauby and Kovacs 2007a, b). Although smart cards are the most advanced medium of software and hardware for ticketing, they do not prevent a passenger without a valid ticket to access POPs (Barabino et al. 2014b).

Two main facets emerged: security and implementation.

From a security viewpoint, Attoh-Okine and Shen (1995) studied the fraudulent manipulation of software, hardware, and communication. Many advancements in the security of credit cards could be applied to smart cards. They also highlighted

Table 14 Studies on ticketing systems evolution

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Diebel (1981)	USA, Virginia	Light rail transit, bus	Descriptive	n/a	n/a	Qualitative description	Advantages and disadvantages of nBTS-POPs
Lorenc and Lutin (2000)	USA, Newark	Light rail transit	Descriptive	n/a	n/a	Qualitative description	Evaluation of moving from nBTS-POE to nBTS-POPs
Peat (1982)	USA, Portland	Bus	Quantitative	Mail and intercept (on-board) operators and passengers	5% bus trips; 4% on-board passengers	Descriptive statistics	Evaluation of nBTS-POE
Wagner et al. (1986)	USA, Portland	Bus	Quantitative	Mail and intercept (on-board) operators and passengers; at home passengers and not; panel survey	9,800 on-board passengers; 500 passengers and 500 non-passengers 800-panel survey	Descriptive statistics	Evaluation of moving towards nBTS-POE, and from nBTS-C to nBTF-POPs
Watry and Straus (2000)	USA, San Francisco	Light rail transit	Quantitative	Official data on historical trends of fare evasion	> 90,000 monthly average inspections; > 240 monthly average citations	Descriptive statistics	Evaluation of moving from nBTS-POE to nBTF-POPs

Table 15 Studies on smart cards

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Attoh-Okine and Shen (1995)	n/a	n/a	Descriptive	n/a	n/a	Qualitative description	How smart cards could reduce fare evasion
Bucknell et al. (2015, 2016a, b)	Chile, Santiago	Bus	Quantitative	Official data on smart card validations	2,060,522 trips without time extension; 1,985,957 trips with extension	Descriptive statistics	Evaluation of smart cards loading network
Khoeblal et al. (2015)	Europe, The Netherlands	Train, tram	Descriptive	n/a	n/a	Qualitative description	An experimental technology combining RFID distance scan with APC
Kinisky et al. (2005)	Canada, Vancouver	Train, bus, sea bus	Descriptive	n/a	n/a	Qualitative description	How smart cards could reduce fare evasion
Mayes et al. (2009)	n/a	n/a	Descriptive	n/a	n/a	Qualitative description	Technological problems affecting smart cards
Pollan (2013)	USA, Canada	Commuter rail transit, light rail transit, bus rapid transit commuter	Descriptive	Direct survey	15 American public transport agencies honouring POP and smart cards	Qualitative description	POPs evolution towards a new electronic environment
Pourmonet et al. (2015)	Canada, Montreal	Bus	Quantitative	Official data on smart card validations and boardings	10,502,628 transactions; 782,765 boardings	Descriptive statistics and GIS	Linking smart cards and APC for analysing fare evasion

that smart cards are affected by relevant costs of equipment, production, and maintenance.

Kinisky et al. (2005) argued that smart cards have the potential to rapidly process passengers and reduce fare evasion due to original magnetic passes. Moreover, they listed ten fundamental security principles embedded in smart cards: least privilege, fail-safe defaults, the economy of mechanism, complete mediation, open design, separation of privilege, least common mechanism, psychological acceptability, defense in depth, and question assumptions.

Mayes et al. (2009) highlighted the issue of technical fraud due to illegal access to computers. Therefore, information security, cryptographic algorithms, protocols and implementations should be based on widely reviewed designs according to the best practices.

From an *implementation* viewpoint, Pollan (2013) emphasised the need of handling card readers (to show the encoded fare data) and the challenge of overriding in the case of distance-based fare. Besides, clear advantages were more accurate tracking and reporting on inspection and evasion rates, and a smaller likelihood of counterfeit tickets.

Khoeblal et al. (2015) showed that the integration of different system architectures helps locate and catch evaders. More precisely, a RFID-based distance reading can be used to capture potential evaders with unchecked smart cards and an APC can be adopted to detect passengers without smart cards as well.

Pourmonet et al. (2015) concluded that the integration between smart cards and APC can quantify estimated and ‘real-time’ observed fare evasion. Indeed, the ratio between validations and boardings is 1 when all passengers pay the fare. A GIS-based map helps to show the most critical points of the network to enforce checks, when this ratio is lower than 1.

Bucknell et al. (2015, 2016a, b) noticed that the loading network of smart cards is a critical issue and can favour fare evasion. Unintentional fare evasion can be reduced by credit to passengers with positive but insufficient funds, to complete one additional trip.

4.4.3 E-ticketing

Table 16 summarises three papers on e-ticketing. It is a key element of ITS and aims at replacing paper-based tickets with electronic media. E-ticketing offers several advantages: the redundancy of the networks of sale and loading, ease and speed of creating new tickets. The identification of e-tickets requires verification tools equipped with a QR code scanner and a NFC[6] reader.

These studies provided an overview and some perspectives on NFC adoption and e-ticketing environments. The results are described below.

Juntunen et al. (2010) showed that NFC allows mobile phones to emulate smart cards and provides benefits for both passengers and service providers.

[6] NFC is wireless short-range communication technology.

Table 16 Studies on e-ticketing

Authors (year)	Location, city	Transit mode	Type of study	Type of survey	Sample size	Analytical tool	Relevant insights
Juntunen et al. (2010)	n/a	n/a	Descriptive	n/a	n/a	Qualitative description	Analysis of NFC mobile ticketing
Mirbaha et al. (2016)	Iran, Tehran	Bus	Descriptive	n/a	n/a	Qualitative description	Analysis of e-ticketing in the Tehran bus network
Puhe (2014)	EU	All	Descriptive	n/a	n/a	Qualitative description	A systemic perspective of the e-ticketing environment

Mirbaha et al. (2016) demonstrated that the diffusion of e-ticketing would reduce the dwell time. Payment with mobile phones can be made by SMS or other secure and comfortable methods. Change in the fare payment might also provide a reduction in fare evasion.

Puhe (2014) emphasised the European Union viewpoint in implementing integrated e-ticketing services. The most recent technological innovation is the e-ticketing by mobile phones. Fare evasion and fraud resulting from cash handling can be minimised by alternative fare media services which are more attractive for users.

4.5 Operational research studies

The last area of this review covers studies in the Operational Research on the planning of inspection tasks. Eighteen studies are classified according to five sub-areas: (1) fare inspection patrols scheduling; (2) security crew scheduling; (3) resources allocation; (4) allocation of inspectors on a transit network and (5) fare inspection strategies.

4.5.1 Fare inspection patrols scheduling

Eight studies provide models and algorithms to address temporal and spatial fare inspection and are summarised in Table 17. These studies analyse one or two routes without interchanges and the massive transit mode (e.g, subway), as it is simpler than the collective to be experimented.

Mostly, these studies model the problem as Leader (or the defender, i.e., PTC)–Follower (or the attacker, i.e., fare evader) Stackelberg game. The defender commits to an inspection policy (e.g, it moves on routes to check passengers), and the attacker displays the best response to this policy.

All these studies face this problem in the case of on-board and off-board inspection. These models consider different objective functions, including the viewpoints of the leader and the follower as well as several realistic constraints. Most studies adopt transition graphs as a network type: a pair of stations and time points represent nodes, whereas actions are modelled by arcs (i.e., the inspection activity). Matyášek (2013) adopt a directed graph where stations represent nodes and their connections are weighted arcs.

Linear Programming reformulations are adopted to exactly solve the model by off-the-shelf solvers. Conversely, Matyášek (2013) adopts heuristic methods such as hill-climbing, beam search, recursive depth search and greedy algorithms.

The main results follow.

Jiang et al. (2012) concluded that increasing patrol hours decreased the percentage of fare evaders and increased ticket revenues.

Yin et al. (2012a, b) presented the application 'TRUSTS' for scheduling randomized patrols for fare inspection in transit systems. A basic and an extended formulation of this problem were considered. They concluded that TRUSTS computed near-optimal strategies against fare evasion and ensured a high level of revenues with few patrol hours.

Table 17 Studies on fare inspection patrols scheduling

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Delle Fave et al. (2014a)	USA, Los Angeles	Subway	Stackelberg game	Total revenue maximisation	The sum of the marginal probabilities is equal for each state	Transition graph	Linear Programming	Modelling the uncertainty in the execution of patrol by the Markov Decision Process on real-world experiments
Jiang et al. (2012)	USA, Los Angeles	Subway	Stackelberg game	Total revenue maximisation	Upper bound on total patrol units and time limits—minimum and maximum number of inspections along arcs—cost of inspection per passenger between threshold values	Transition graph	Linear Programming	Modelling the domain of patrol scheduling by representing the leader's mixed strategies as flows
Jiang et al. (2013)	USA, Los Angeles	Subway	Stackelberg game	Total revenue maximisation	The sum of the marginal probabilities is equal for each state	Transition graph	Linear Programming	Modelling the uncertainty in the execution of patrol by the Markov Decision Process, such that small fractions of execution uncertainty can have a dramatic impact

Table 17 (continued)

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Krogvig (2014)	Norway, Oslo	Train	Master and dual problem	Total revenue maximisation	Selecting joint patrols exactly once—upper bounds on the passenger type	Transition graph	Linear programming (master-column generation)—mixed integer programming (sub problem)—heuristic (sub problem)	A heuristic method dealing with the computational complexity of finding optimal solutions
Matyášek (2013)	USA, Los Angeles	Subway	Constrained Optimization Problem	Total passengers checked maximisation	Feasibility of paths in time and space—the assignment of patrolling is forbidden at the initial station—long staying and waiting are allowed only in the last station	Directed graph	Heuristic (hill climbing, beam search, recursive depth first search, greedy)	Modelling a constrained optimisation problem investigating heuristics techniques

Table 17 (continued)

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Thorlacius and Clausen (2010)	Denmark, Copenhagen	Subway	n/a	Net revenue maximisation	Available number of inspectors and duty per time and week, minimum and maximum number of inspectors on duty, maximum number of inspectors having a break and maximum number of inspectors starting their duty in a time interval	n/a	Linear Programming	A decision support system based on historical data of fares and the schedules of inspectors

Table 17 (continued)

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Yin et al. (2012a, b)	USA, Los Angeles	Subway	Stackelberg game	Total revenue maximisation	Upper bound on total patrol units and time limits—minimum and maximum number of inspections along arcs—cost of inspection per passenger among threshold values—upper bound on switches	Transition graph	Linear programming	A randomised Stackelberg game for tactical randomization for urban security in transit systems (TRUST)

Krogvig (2014) compared optimal and heuristic methods. He concluded that using the heuristic method was a viable option, especially for small time windows. Joint patrols can be generated for a small portion of the local network with realistic levels. However, this method may not work for the entire network or a complete working day.

Jiang et al. (2013) and Delle Fave et al. (2014a) showed that their approach outperformed the schedules generated by 'TRUSTS' and improved them by real-time knowledge of uncertain data during the execution (e.g., the time to issue a fine).

Matyášek (2013) showed that the hill climbing algorithm provided good performance both in time and resource management in evaluating and optimising the schedules.

Thorlacius and Clausen (2010) provided an IT tool that determined new schedules for ticket inspectors by mathematical models.

4.5.2 Security crew scheduling

Table 18 summarises three studies facing the security crew scheduling problems, in which the ticket inspection is a component.

This problem is addressed in mass transit mode. Two studies model this problem as Leader–Follower Stackelberg game, whereas Snijders and Saldanha (2016) adopt the shortest path and set covering models. All these studies address the case of on-board and in-station inspection. Several constraints are adopted to account for realistic conditions. Snijders and Saldanha (2016) adopt two graphs for job generation and assignment, respectively. In the first graph, nodes are stations and arcs are train control jobs and waiting times at stations. In the second graph, nodes are tasks, and arcs represent two consecutive tasks to be performed in the same duty. Linear programming and heuristics are adopted.

Delle Fave et al. (2014b, c) developed the Multi-operation Patrol Scheduling System (MOPSS). Three experiments on fare evasion, terrorism and crime demonstrated that schedules by MOPSS outperformed current human counterparts. In the case of fare evasion, e.g., MOPSS schedules led to 16 captures against the 10 obtained by the random inspection approach refined by human intelligence.

Snijders and Saldanha (2016) concluded that an increase of 50% in crew's capacity gets an increase of about 71% in security value and 81% in gains for the PTC against fare evasion.

4.5.3 Resources allocation

Two studies propose models to allocate security resources to face different threats such as fare evasion at multiple sites (stations in the train transit mode). These studies are summarised in Table 19.

They are based on the Leader–Follower Stackelberg game model. The objective functions maximise the expected utility to find the optimal security plan against one or several threats. The main constraints include the available budget for the resources and the fact that some strategies can be modelled by binary variables (i.e., to assign or not assign a resource at a specific site).

Table 18 Studies on security crew scheduling

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Delle Fave et al. (2014b, c)	USA, Los Angeles	Subway	Stackelberg game and Markov processes	Maximise the expected utility function of the leader	Leader's payoff against passengers less than the probability that the Leader will overlap with a fare evader playing an action	Transition graph	Linear programming	Three-game modules on three threats: fare evasion, terrorism and crime
Snijders and Saldanha (2016)	The Netherlands, Randstad Noord	Train	Shortest path problems and set covering problem	Minimise total cost of the duties and the uncovered tasks	Coverage of one duty for each team and transit in all network segments—coverage of all mandatory tasks of duty—coverage or neglect of all optional tasks of duty Duty length	Direct graph for job generation and assignment	Lagrangian relaxation heuristic and column generation	Modelling security guards scheduling in platform and on-board

Table 19 Studies on resources allocation

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Insua et al. (2014)	Spain, Barcelona	Train	Stackelberg game	Utility maximisation	Available budget	n/a	Enumeration	Modelling a standard and adversarial risk analysis to calculate the amount of intentional and unintentional fare evaders
Insua et al. (2016)	Spain, Barcelona	Train	Stackelberg game	Utility maximisation	Available budget	n/a	Enumeration and genetic algorithms	Modelling of an adversarial risk analysis to calculate numbers of multiple threats (fare evasion and pickpocketing) in multi-sites, when attackers are uncoordinated

Insua et al. (2014) provided a methodology to set up an optimal portfolio of resources for security. A portfolio included inspectors, control access points, new secured automatic access doors, ticket clerks, and patrol along with the facility. When intentional and unintentional fare evaders were faced separately, little resources were invested by the operator. The opposite result was obtained when both types of evaders were considered simultaneously.

Insua et al. (2016) enriched the former methodology enlarging the portfolio of resources with trained guards and security dogs, cameras, and awareness campaigns. They showed that in a real case study, investing in control access points, cameras and awareness campaigns seem not worthwhile for the PTC.

4.5.4 Allocation of inspectors on a transportation network

Two general models are presented on motorways. However, they are not limited to these networks as these models can be adopted when passengers are checked during their travel along transit routes. These studies are summarised in Table 20.

These models may be applied to the overall transit modes. The problem is modelled as Leader–Follower Stackelberg and Nash games. The objective functions maximise the toll revenues and minimise the number of fare evaders or the shortest paths for users. Constraints include an upper bound on the average cost for the user on the link, an upper bound on the number of controlled passengers and the inspection probability on a link, the maximum length of shortest paths, etc. All these studies adopt a complex directed graph where nodes represent junctions and links travel times.

These models are solved by linear programming methods and differ on the main hypotheses on the routes chosen by passengers. While in Borndörfer et al. (2012) the user does not freely choose the route between origin and destination, in Borndörfer et al. (2013) s/he does.

Results showed that both models could lead to significant improvements as opposed to the strategy of proportionally controlling each section according to the traffic volumes. An increase in controls per hour showed a significant decrease of the fare evasion rate.

4.5.5 Fare inspection strategies

Three studies face the optimal inspection strategy problems in transit networks. They are summarised in Table 21.

All these studies refer to transit modes managed with nBTS-POPs. They model the problems as Leader–Follower Stackelberg game or by a Nash Game. In the first game, the leader sets up probabilities of inspecting passengers at some locations; the follower responds by deciding which route to take, according to her/his knowledge of inspection probabilities and travel times (adaptive strategy). In the latter, game random probability-distribution-valued payoffs among players are used to allow playing spot-checking games.

The objective functions focus on revenues and logistic aspects such as shortest paths, employed inspectors on a route, and the number of penalties. A directed

Table 20 Studies on allocation of inspectors on a transportation network

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Borndörfer et al. (2012)	Germany, Berlin-Brandenburg and North Rhine-Westphalia	All	Stackelberg game	Toll revenue maximisation; Fare evaders minimisation	In the maximisation: average cost lower than the product between fare and a control probability; upper bound on checked passengers In the minimisation: fine-to-fare ratio lower than a control probability and a variable depending on the probability of being controlled	Directed graphs	Linear Programming, mixed integer program, column generation	A spatial allocation model that considers the network topology and the spatial distribution of inspectors
Borndörfer et al. (2013)	Germany, Berlin-Brandenburg	All	Stackelberg and Nash games	Toll revenue and penalty maximisation	Length of shorter paths, feasibility strategies for inspectors, links to the best path	Directed graphs	Linear programming	Similar to the previous paper; the model handles the case where each user freely chooses the path in the network

Table 21 Studies on fare inspection strategies

Author, year	Location, city	Transit mode	Problem modelling	Objective function	Main constraints	Network type	Resolution methods	Relevant insights
Alshawish et al. (2017)	Test network	Suburban rail, subway, tram and bus	Nash game	Multiple objectives: (1) maximisation of inspections per inspectors on a route; (2) inspection costs minimisation; (3) penalties fare maximisation	n/a	Directed graphs	Expert-based evaluations of strategies and search for a Nash–Pareto equilibrium	A multi-objective theoretical model of different ticketing inspection strategies
Bahamondes et al. (2017)	n/a	n/a	Stackelberg game	Leader: maximisation of the minimum expected follower costs; collected fines maximisation Follower: Expected cost minimisation	Sum of probability to place checkpoint on each link = 1	Directed graphs	Polynomial time algorithms, Shortest paths, Linear programming	Optimisation model for fare inspection with: (1) inspection performed in a single link of the network; (2) modelling of the followers' behaviour
Correa et al. (2014)	Germany and The Netherlands	Train and subway	Stackelberg game	Leader: total revenues maximisation Follower: route path minimisation	n/a	Directed graphs	Polynomial time algorithms, Shortest paths, linear programming and local search frameworks	Optimisation model for fare inspection with (1) probabilities for inspection at different locations; (2) modelling of the followers' behaviour

graph is used to represent all the networks: nodes are stations and arcs are travel times or passenger volumes between consecutive stations (Alshawish et al. 2017). Polynomial-time algorithms, shortest paths, linear programming, and local search were adopted.

These methods are implemented by CPLEX and some real experiments are performed. Conversely, a Nash–Pareto equilibrium strategy is obtained in a theoretical network (Alshawish et al. 2017).

The main results are as follows.

Correa et al. (2014) proved a tight bound of 3/4 on the ratio of optimal cost between adaptive and non-adaptive strategies. In the non-adaptive variant, passengers a priori select a route and continue along it throughout the trip. In the adaptive strategy, passengers gain information along the way and use it to update their routes. Moreover, in the case of the leader's optimization problem, they modelled the cases of rigid fares and flexible fares. Using a local search procedure, they showed that the rigid fare is within 95% of the upper bounds on the average, whereas it is within 97.5% in the other case.

Bahamondes et al. (2017) noticed that the non-adaptive strategy was reduced to the standard shortest path problem, whereas a cycle free path can always represent the adaptive strategy. Moreover, they concluded that the follower's best non-adaptive strategy is within a ratio of 4/3 of the optimal adaptive strategy. This ratio decreases when the follower is almost close to the shortest path.

Alshawish et al. (2017) discovered that the most effective strategies have the largest number of inspectors who work individually on the most crowded routes.

5 Towards research development on fare evasion

Current research has led to insights into the complex relationships governing fare evasion. It has also provided ideas on how to improve the strategic, tactical and operational planning of PTCs affected by fare evasion. However, so far, the research on fare evasion has provided ideas in separate areas of interest, because studies were stand-alone undertakings. In our opinion, this fact has resulted in the fragmentation of the knowledge and perhaps hampered its growth. This literature review helps define some unifying research perspectives.

In the *fare evader-oriented area*, further research is desirable regarding the segmentation of passengers by using quantitative methods. Many current studies are limited to 'one-size-fits-all' models of fare evaders. Little is still known about the relationships among segments, modes of transport and reasons why people evade and their geographical coverage. Different surveying methods and other models would provide rooms to identify other segments. These may help PTC's managers tailor specific countermeasures such as patrol inspection strategies and educational campaigns. Nevertheless, the moral acceptability of segmenting passengers to set up inspection strategies is a significant ethical concern. Indeed, inspection strategies should be equitable and not targeting some individuals over others. Besides, the segmentation should be addressed within the legal framework of geographic contexts because it may differ.

Research is desirable on the *criminological area* regarding the evaluation of the effectiveness of deterrence and enforcement strategies. So far, deterrence studies are based on a retroactive examination of already implemented preventive measures. New studies could be introducing scientific experiments (e.g., condition control). Moreover, there is a need for quantitative research on the reasons that impede evaders from paying the fine, because segments of evaders respond differently to fines. Some segments react as predicted by theory: the more severe the punishments, the higher the compliance to rules. Other segments seem unaffected by the increased certainty of punishment (and the related increase in the severity). Therefore, an analysis of the reasons why the certainty of punishment does not apply needs to be done. Inferential models could empower the evaluation of all these strategies using data collected from surveying passengers, staff, and authority. Further research would evaluate the characteristics and effectiveness of different legal frameworks. For instance, the legality of POPs depends on the legal framework, and it appears a promising research area.[7]

Research would be useful in the *economic area* to further characterise, measure, and manage fare evasion. The current knowledge is poor regarding standard methods for estimating fare evasion and fare compliance and the feasibility of all strategies. For instance, mystery shopper surveys might help collect all data on fare evasion covered by the definition in Sect. 3.2 and provide a unifying method of data collection among PTCs. What strategies are more effective for reducing fare evasion? The relationships among the evasion rate, the inspection rate, and the fine amount look still unclear and need to be investigated. The setting of inspections could be further investigated. All previous studies considered fare evaders as rational actors who maximise their utility by evaluating a trade-off between the fare and the fine if caught without a ticket. There are other segments that do not stick to this pattern. Therefore, new studies would be valuable to include these segments. The setting of fines requires more research as well. For instance, how should a fine be set? Which is the effect of pushing people from not paying to paying a fine for real? What is the real percentage of passengers who could leave public transport when fines increase? In addition, the cost-effectiveness of enforcement methods for the payment of fine appears a new challenge (e.g., local agency vs court-oriented approaches). All these facets might help PTC to understand why only a proportion of fined passengers pay the fine.

The *technological area* could be further investigated on the interrelations among payment methods, inspections, and automatic counting of passengers. For instance, smart cards and mobile apps will enhance willingness for buying tickets, and, thus, travelers' comfort. New research will be fostered using smart cards against fare evasion. The most robust technological medium could be detected by analysing the type of fare evasion in comparative studies. Nevertheless, it would be interesting to evaluate the propensity of fare evasion by forcing all passengers to validate their ticket

[7] Recently, there have been court cases in the USA surrounding the ability of police to act as inspectors or ask passengers to show Proof of Payment. For instance, in Cleveland (Ohio), a judge has ruled that police cannot act as inspectors because they do not have probable cause to detain passengers (Groves 2017).

or pass while boarding: this *modus operandi* is expected to reduce the fare evasion rate avoiding the copycat syndrome.[8]

Research would be valuable on models and methods of *Operational Research* to plan the inspection in integrated POPs networks. More research would be useful on segmenting passengers along routes for socio-demographic, travel behaviour, attitude against fare evasion, etc. This research would help refine the models that were usually based on the 'one-size-fits-all' demand model. New models will be valuable in tram and bus networks that represent the most widespread networks adopting POPs, where the inspection is crucial. New models could incorporate the impact of transfers among routes, the visit of the most crowded stations or stops, and the different perspectives of transit operators and passengers. Finally, new instances of modelling benchmarks will be welcome as they are missing in specific problems.

6 Conclusions

Fare evasion produces relevant economic loss, social inequity and increased levels of violence affecting individual security. Thus, PTCs are genuinely interested in addressing fare evasion. The scientific community has grown considerably tripling the studies on fare evasion in the last 7 years. Although much more literature exists (including unpublished scientific studies, scientific literature in many national languages and professional reports), an extensive search is made to retrieve English studies. One hundred and thirteen publications were reviewed to investigate the characteristics of research on fare evasion.

This review classified these studies in five (possibly overlapping) areas: fare evader-oriented, criminological, economic, technological, and operational research. It has shown that research evolved owing to the problem's awareness in PTCs and the availability of related data. Nowadays, the most advanced PTCs own specific departments contrasting fare evasion, whereas it was hidden in the past, being perceived as internal inefficiencies.

Fare evader-oriented studies were largely conducted in Australia and Europe. They were devoted to the examination of the characteristics and the psychology of fare evaders. The motivations of fare evasion were also analysed and endeavoured to segment fare evaders. In this case, studies are evolving from 'one-size-fits-all' models to specific—post hoc—segmentations.

Criminological studies were mainly made in America and Europe. Oldest studies provided descriptions of deterrence, enforcement and security strategies against crime (and fare evasion). More recent studies are investigating the effectiveness of strategies using before and after evaluations.

Economic studies were conducted more often in America than in Europe. Initially, this research focused on prediction models addressing specific issues (e.g, the

[8] The copycat syndrome refers to a person who adopts, imitates, mimics, or follows the same behaviour of someone else (i.e., fare evaders may follow the behaviour of pass holders that in many worldwide transit systems are not required to tap in/out their tickets).

inspection on POPs). Later, prediction models largely identified patterns of fare evasion and shed light on understanding the effects of some determinants. Next, some cost–benefit evaluations of a few strategies and ticketing systems have been studied in recent years.

Technological studies were faced mainly in America. Several studies examined the evolution of ticketing systems. More recent studies investigated the implementation of smart cards as a tool for automatic fare payment. Recently, others examined the effects of electronic ticketing as a substitute for paper-tickets on the transit network.

Operational Research studies were conducted in America and Europe. This research presented models and optimisation methods for scheduling and deploying inspectors along transit networks.

Although this literature review revealed five separate areas of interest, many overlapping research issues emerged. For instance, the inspection and fines involved almost all areas. Some possible research perspectives are mentioned, and common issues arise in segmentation, new inspection models, and the setting of fines.

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Appendix: Overview of publications for 2018 and 2019—not reviewed

Allen J, Muñoz JC, Ortúzar JD (2019) On evasion behaviour in public transport: dissatisfaction or contagion? Transp Res Part A 130:626–651. https://doi.org/10.1016/j.tra.2019.10.005

Ayal S, Celse J, Hochman G (2019) Crafting messages to fight dishonesty: a field investigation of the effects of social norms and watching eye cues on fare evasion. Organ Behav Hum Decis Process. https://doi.org/10.1016/j.obhdp.2019.10.003 **(in press)**

Barabino B, Salis S (2019) Moving towards a more accurate level of inspection against fare evasion in *proof-of-payment* transit systems. Netw Spat Econ 19:1319–1346. https://doi.org/10.1007/s11067-019-09468-3

Dai Z, Galeotti F, Villeval MC (2019) Fare-dodging in the lab and the moral cost of dishonesty. In: Dishonesty in behavioral economics. Academic Press, pp 245–265. https://doi.org/10.1016/B978-0-12-815857-9.00004-2

Delbosc A, Currie G (2019) Why do people fare evade? A global shift in fare evasion research. Transp Rev 39(3):376–391. https://doi.org/10.1080/01441647.2018.1482382

González F, Busco C (2019) Fare evasion in public transport: grouping Transantiago users' behavior. Sustainability 11(23):6543. https://doi.org/10.3390/su11236543

Fabbri M, Nicola Barbieri P, Bigoni M (2019) Ride your luck! A field experiment on lottery-based incentives for compliance. Manag Sci 65(9):4336–4348. https://doi.org/10.1287/mnsc.2018.3163

Hughes P, Maroske K (2019) Fare evasion in Queensland-compounding inequity and the need to improve social inclusion on public transport. Parity 32(4):18–19

Tan ES (2019) "Paying" the way for a better BART future: a call for better enforcement of fare evasion policies and strategic planning at BART. Scholarship repository, University of San Francisco

Delfau JB, Pertsekos D, Chouiten M (2018) Optimization of control agents shifts in public transportation: tackling fare evasion with machine-learning. In: 2018 IEEE 30th international conference on tools with artificial intelligence (ICTAI). IEEE, pp 409–413

Keuchel S, Laurenz K (2018) The effects of a higher ticket inspection rate in a medium-size public transportation system. Transp Res Procedia 31:56–66

Fürst E, Herold D (2018) Fare evasion and ticket forgery in public transport: insights from Germany, Austria and Switzerland. Societies 8(4):98

Kulkarni V, Chapuis B, Garbinato B, Mahalunkar A (2018) Addressing the free-rider problem in public transport systems. arXiv preprint, arXiv:1803.04389

References

Abrate G, Fraquelli G, Meko E, Rodia G (2008) L'Evasione Tariffaria nel Trasporto Pubblico Locale: un'Analisi Empirica. Conferenza Società Italiana di Economia Pubblica, XX Riunione Scientifica, Pavia, 25–26 Settembre 2008

Alshawish A, Abid MA, Rass S, de Meer H (2017) Playing a multi-objective spot-checking game in public transportation systems. In: Proceedings of the 4th workshop on security in highly connected IT systems. ACM, pp 31–36

Attoh-Okine NO, Shen LD (1995) Security issues of emerging smart cards fare collection application in mass transit. In: Vehicle navigation and information systems conference, 1995. Proceedings. In conjunction with the Pacific Rim Trans Tech Conference, 6th International VNIS.'A Ride into the Future', IEEE, pp 523–526

Avenhaus R (2004) Applications of inspection games. Math Model Anal 9(3):179–192

Bahamondes B, Correa J, Matuschke J, Oriolo G (2017) Adaptivity in network interdiction. In: International conference on decision and game theory for security. Springer, Cham, pp 40–52

Barabino B, Salis S, Useli B (2013) A modified model to curb fare evasion and enforce compliance: empirical evidence and implications. Transp Res Part A 58:29–39

Barabino B, Salis S, Useli B (2014a) Fare evasion in *proof-of-payment* transit systems: deriving the optimum inspection level. Transp Res Part B 70:1–17

Barabino B, Di Francesco M, Mozzoni S (2014b) An offline framework for handling automatic passenger counting raw data. IEEE Trans Intell Transp Syst 15(6):2443–2456

Barabino B, Salis S, Useli B (2015) What are the determinants in making people free riders in proof-of-payment transit systems? Evidence from Italy. Transp Res Part A Policy Pract 80:184–196

Baumol W (1952) Welfare economics and the theory of the state. Harvard University Press, Cambridge

Becker GS (1968) Crime and punishment: an economic approach. In: The economic dimensions of crime. Palgrave Macmillan, London, pp 13–68

Bijleveld C (2007) Fare dodging and the strong arm of the law. J Exp Criminol 3(2):183–199

Bonfanti G, Wagenknecht T (2010) Human factors reduce aggression and fare evasion. Public Transp Int 59(1):28–32

Bootheway GBP (2009) On the optimality of fines when enforcement is risky. ASBBS E-J 5(1):33–39

Borndörfer R, Omont B, Sagnol G, Swarat E (2012) A Stackelberg game to optimize the distribution of controls in transportation networks. Game theory for networks. Springer, Berlin, pp 224–235

Borndörfer R, Buwaya J, Sagnol G, Swarat E (2013) Optimizing toll enforcement in transportation networks: a game-theoretic approach. Electron Notes Discrete Math 41:253–260

Boyd C, Martini C, Rickard J, Russell A (1989) Fare evasion and non-compliance: a simple model. J Transp Econ Policy 23(2):189–197

Bratton WJ (1999) Great expectations: how higher expectations for police departments can lead to a decrease in crime. In: Measuring what matters: proceedings from the policing research institute meetings. National Institute of Justice, Washington, DC, pp 11–26

Brisman A (2016) The corners of crime: an introduction. In: Geometries of crime. Palgrave Macmillan, London, pp 1–33

Bucciol A, Landini F, Piovesan M (2013) Unethical behaviour in the field: demographic characteristics and beliefs of the cheater. J Econ Behav Organ 93:248–257

Bucknel, C, Muñoz JC, Schmidt A, Navarro (2015) The impact on fare evasion of a credit-based fare system in Transantiago. In: Conference on advanced systems in public transport, July 2015
Bucknell C, Muñoz JC, Schmidt A, Navarro M, Simonetti C (2016a) Impact of a loan-based public transport fare system on fare evasion: experience of Transantiago, Santiago, Chile. Transp Res Rec 2544:20–27
Bucknell C, Muñoz JC, Schmidt A, Navarro M, Simonetti C (2016b) The impact on fare evasion of a loan-based fare system in Transantiago. In: Transportation Research Board 95th annual meeting (No. 16-4009)
Buehler S, Halbheer D, Lechner M (2014) Payment evasion. Working Paper, University of St. Gallen
Buehler S, Halbheer D, Lechner M (2017) Payment evasion. J Ind Econ 65(4):804–832
Buneder C, Galilea P (2017) Temporal and spatial analysis of fare evasion in Transantiago. Transportation Research Board Annual Meeting, Washington, DC
Chung YS, Chiou YC (2017) Willingness-to-pay for a bus fare reform: a contingent valuation approach with multiple bound dichotomous choices. Transp Res Part A 95:289–304
Clarke RV (1993) Fare evasion and automatic ticket collection on the London underground. Crime Prev Stud 1:135–146
Clarke S, Forell S, McCarron E (2008) Fine but not fair: fines and disadvantage. Justice Issues 3:1
Clarke RV, Contre S, Petrossian G (2010) Deterrence and fare evasion: results of a natural experiment. Secur J 23(1):5–17
Cools M, Fabbro Y, Bellemans T (2018) Identification of the determinants of fare evasion. Case Stud Transp Policy 6(3):348–352. https://doi.org/10.1016/j.cstp.2017.10.007
Cooper HM (1989) Integrating research: a guide for literature reviews. In: Applied Social Research Methods Series, vol 2. SAGE Publications, Newbury Park
Correa JR, Harks T, Kreuzen VJ, Matuschke J (2014) Fare evasion in transit networks. arXiv preprint, arXiv:1405.2826
Cosby S (1985) A method for measuring the revenue loss due to fraud within a public transport undertaking. Traffic Eng Control 26(2):59–61
Cummins K, Porter B, Durham J, Heinrichs J (2012) Seattle sound transit's experiences with proof-of-payment fare collection. Sustaining the Metropolis, 96
Currie G, Delbosc A (2017) An empirical model for the psychology of deliberate and unintentional fare evasion. Transp Policy 54:21–29
Currie G, Reynolds J (2016) Evaluating pay-on-entry versus proof-of-payment ticketing in light rail transit. Transp Res Rec 2540:39–45
Dai Z, Galeotti F, Villeval MC (2016) Cheating in the lab predicts fraud in the field. An experiment in public transportations. Working paper
Dai Z, Galeotti F, Villeval MC (2017) The efficiency of crackdowns: a lab-in-the-field experiment in public transportations. Theor Decis 82(2):249–271
Dai Z, Galeotti F, Villeval MC (2018) Cheating in the lab predicts fraud in the field. An experiment in public transportations. Manag Sci 64:1081–1100
Dauby L, Kovacs Z (2007a) Fare evasion in light rail systems. Transp Res E-Circ E-C112
Dauby L, Kovacs Z (2007b) Fare evasion in light rail systems. Public Transp Int 56(2):6–8
Del Castillo V, Lindner C (1994) Fare evasion in New York City transit system: a brief survey of countermeasures. Secur J 5(4):217–221
Delbosc A, Currie G (2015) Qualitative segmentation of fare evasion attitudes and behaviours. In: Transportation Research Board 94th annual meeting (No. 15-0808)
Delbosc A, Currie G (2016a) Four types of fare evasion: a qualitative study from Melbourne, Australia. Transp Res Part F 43:254–264
Delbosc A, Currie G (2016b) Cluster analysis of fare evasion behaviours in Melbourne, Australia. Transp Policy 50:29–36
Delle Fave FM, Jiang AX, Yin Z, Zhang C, Tambe M, Kraus S, Sullivan JP (2014a) Game-theoretic patrolling with dynamic execution uncertainty and a case study on a real transit system. J Artif Intell Res 50:321–367
Delle Fave FM, Brown M, Zhang C, Shieh E, Jiang AX, Rosoff H, Sullivan J (2014b) Security games in the field: an initial study on a transit system. In: Proceedings of the 2014 international conference on autonomous agents and multi-agent systems. International Foundation for Autonomous Agents and Multiagent Systems, pp 1363–1364

Delle Fave FM, Brown M, Zhang C, Shieh E, Jiang AX, Rosoff H, Sullivan JP (2014c) Security games in the field: deployments on a transit system. In: International workshop on engineering multi-agent systems. Springer International Publishing, pp 103–126
Des Champs S, Brantingham PL, Brantingham PJ (1991) The British Columbia transit fare evasion audit: a description of a situational prevention process. Secur J 2:211–218
Diebel LE (1981) The introduction of European fare collection techniques in the United States. J Adv Transp 15(1):55–60
Dong Hoon B, Taik W (2014) Social capital as a design parameter for product-service system design. J Digit Des 14(3):43–51
Eddy D (2010) Fare evasion—is it a youth issue? Transit Aust 65(12):1–7
Fürst E (2012) Free riders and ticket fraud in public transport: a Delphi analysis. In: European transport conference 2012
Gneezy U (2005) Deception: the role of consequences. Am Econ Rev 95(1):384–394
Groves E (2017) Cleveland municipal court. https://p.clevescene.com/media/pdf/groves_rta_fareenforcement.pdf
Guarda P, Ortúzar J de D, Handy S, Galilea P, Munoz JC (2015) Optimal mixed strategies for dealing with fare evasion in public transport. In: Proceeding of conference on advanced systems in public transport, Rotterdam
Guarda P, Galilea P, Paget-Seekins L, de Ortúzar JD (2016a) What is behind fare evasion in urban bus systems? An econometric approach. Transp Res Part A 84:55–71
Guarda P, Galilea P, Handy S, Muñoz JC, de Ortúzar JD (2016b) Decreasing fare evasion without fines? A microeconomic analysis. Res Transp Econ 59:151–158
Hansen S, Whitelaw B, Leong JD (2012) Tackling fare evasion on Calgary transit's CTrain system. Sustaining the Metropolis, 84
Hauber AR (1980) Daily life and the law: discrepancies in behavior. Int J Law Psychiatry 3(2):187–192
Hauber AR (1993) Fare evasion in a European perspective. Stud Crime Crime Prev 2:122–141
Hauber AR, Hofstra B, Toornvliet L, Zandbergen A (1996) Some new forms of functional social control in the Netherlands and their effects. Br J Criminol 36(2):199–219
Horizon Research Corporation (2002) Metropolitan transit authority: fare evasion study. Horizon Research Corporation, Los Angeles
Huth PK (1999) Deterrence and international conflict: empirical findings and theoretical debate. Ann Rev Polit Sci 2:25–48
Insua DR, Cano J, Pellot M, Ortega R (2014) From risk analysis to adversarial risk analysis. In: Upadhyay SK, Singh U, Dey DK, Loganathan A (eds) Current trends in Bayesian methodology with applications. CRC Press, Boca Raton, pp 311–334
Insua DR, Cano J, Pellot M, Ortega R (2016) Multithreat multisite protection: a security case study. Eur J Oper Res 252(3):888–899
Israel SI, Strathman JG (2002) Analysis of transit fare evasion in the rose quarter. Technical report. Center for Urban Studies, College of Urban and Public Affairs, Portland State University, Portland
Jankowski WB (1991) Fare evasion and noncompliance: a game theoretical approach. Int J Transp Econ 38:275–287
Jiang AX, Yin Z, Johnson MP, Tambe M, Kiekintveld C, Leyton-Brown K, Sandholm T (2012) Towards optimal patrol strategies for fare inspection in transit systems. In: AAAI Spring symposium: game theory for security, sustainability, and health
Jiang AX, Yin Z, Zhang C, Tambe M, Kraus S (2013) Game-theoretic randomization for security patrolling with dynamic execution uncertainty. In: Proceedings of the 2013 international conference on autonomous agents and multi-agent systems. International Foundation for Autonomous Agents and Multiagent Systems, pp 207–214
Juntunen A, Luukkainen S, Tuunainen VK (2010) Deploying NFC technology for mobile ticketing services—identification of critical business model issues. In: 2010 Ninth international conference on mobile business and 2010 ninth global mobility roundtable (ICMB-GMR). IEEE, pp 82–90
Khoeblal R, Laohapensaeng T, Chaisricharoen R (2015) Passenger monitoring model for easily accessible public city trams/trains. In: 2015 12th International conference on electrical engineering/electronics, computer, telecommunications and information technology (ECTI-CON). IEEE, pp 1–6
Killias M, Scheidegger D, Nordenson P (2009) The effects of increasing the certainty of punishment: a field experiment on public transportation. Eur J Criminol 6(5):387–400
Kinisky TD, Hewitt MD, Kwei D, Qin C (2005) Analysis and design of a smart card transit security system. UBC Engineering

Kooreman P (1993) Fare evasion as a result of expected utility maximisation. Some empirical support. J Transp Econ Policy 27(1):69–74
Krogvig LB (2014) Fare inspection optimization in train networks. Dissertation Norwegian University of Science and Technology
Larwin TF, Koprowski Y (2012a) Off-board fare payment using proof-of-payment verification, vol 96. Transportation Research Board
Larwin TF, Koprowski Y (2012b) Off-board fare payment using proof-of-payment verification. Transit Cooperative Research Program, Synthesis 96. Washington, D.C.
Lee J (2011) Uncovering San Francisco, California, Muni's proof-of-payment patterns to help reduce fare evasion. Transp Res Rec 2216:75–84
Leischnig A, Woodside AG (2017) Who approves fraudulence? Configurational causes of consumers' unethical judgments. J Bus Ethics 158:713–726
Leung LC (2003) A study of fare evasion in railway systems in Hong Kong. Degree thesis
Li S, Min J (1985) Riding public buses without tickets results in numerous problems. Chin Sociol Anthropol 17(3):49–61
Lorenc JM, Lutin JM (2000) Conversion of Newark City subway from conventional fare payment to proof of payment fare system. In: Light rail: investment for the future. 8th Joint conference on light rail transit
Mace E (1997) Public service and lower-class suburbs, a coproduction on crime: the Parisian Transit Authority's bus network. Sociol Travail 39(4):473–498
Matyášek M (2013) Optimization of ticket inspection in public transport networks. Degree thesis. Czech Technical University, Prague
Mauri R, Cooney NA, Prowe GJ (1984) Transit security: a description of problems and countermeasures (No. UMTA-MA-06-0152-84-2). United States Urban Mass Transportation Administration
Mayes KE, Markantonakis K, Hancke G (2009) Transport ticketing security and fraud controls. Inf Secur Tech Rep 14(2):87–95. https://doi.org/10.1016/j.istr.2009.06.003
Mazar N, Amir O, Ariely D (2008) The dishonesty of honest people: a theory of self-concept maintenance. J Mark Res 45(6):633–644
Mehlkop G, Becker R, Imhof R (2007) Extending the rational action theory of crime: success, norms and risk-taking. An empirical re-assessment of the theory of subjective expected utility. In: Proceedings of the international conference on rational choice and social institutions, Zurich, 6–8 Sep
Mirbaha B, Foroshani HA, Amirpashaei N (2016) Technical and economical evaluation of e-ticketing in Tehran bus network. WCTRS 2016
Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 6(6):e1000097. https://doi.org/10.1371/journal.pmed.1000097
Multisystems, Inc., Mundle and Associates, Inc., and Parsons Transportation Group, Inc. (2002) A toolkit for self-service, barrier-free fare collection. Transit Cooperative Research Program, Report 80. TRB, Washington, D.C.
Nahuis R (2005) The politics of innovation: self-service on the Amsterdam trams. Technol Soc 27(2):229–241
Nahuis R (2007) The politics of innovation in public transport. Issues, settings and displacements, vol 357. KNAG
Nahuis R (2009) The rise and fall of self-service in Amsterdam trams: user–technology relations in a case of service innovation. Technol Anal Strateg Manag 21(2):233–247
Nakanishi YJ, Fleming WC (2011) Practices to protect bus operators from passenger assault, vol 93. Transportation Research Board
New Law Journal (1974) Volume 123, part 1, p 358
Peat M (1982) Portland self-service fare collection evaluation implementation technical memorandum: pre-implementation data collection and analysis
Perrotta AF (2017) Transit fare affordability findings from a qualitative study. Publ Works Manag Policy 22(3):226–252
Pollan EB (2013) Smart cards and proof-of-payment: a marriage of necessity. Sustaining the metropolis. Transp Res Circ E-C177: 110–122
Pourmonet H, Bassetto S, Trépanier M (2015). Vers la maîtrise de l'évasion tarifaire dans un réseau de transport collectif. 11e Congrès International De Génie Industriel, Québec

Prokosch A, Gartsman A (2017) All-door boarding without proof-of-payment: revenue impacts and operational implications (No. 17-06500). Transportation Research Board 96th annual meeting compendium of papers

Puhe M (2014) Integrated urban e-ticketing schemes—conflicting objectives of corresponding stakeholders. Transp Res Procedia 4:494–504

Reddy AV, Kuhls J, Lu A (2011) Measuring and controlling subway fare evasion. Transp Res Rec 2216:85–99

Salis S, Barabino B, Useli B (2017) Segmenting fare evader groups by factor and cluster analysis. WIT Trans Built Environ 176:503–515

Sánchez-Martínez GE (2017) Estimating fare noninteraction and evasion with disaggregate fare transaction data. Transp Res Rec 2652:98–105

Sasaki Y (2014) Optimal choices of fare collection systems for public transportations: barrier versus barrier-free. Transp Res Part B 60:107–114

Schwerdtfeger S (2016) Fare evasion: the last resort of social exclusion or simply a way to save money? In: RGS-IBG annual international conference 2016. 10.13140/RG.2.2.18674.50889

Smith MJ, Clarke RV (2000) Crime and public transport. In: Tonry M (ed) Crime and justice. A review of research, vol 27. University of Chicago Press, Chicago, pp 169–233

Snijders H, Saldanha RL (2016) Decision support for scheduling security crews at Netherlands Railways. Publ Transp 9:193–215

Sterner A, Sheng S (2013) The effect of social stigma on fare evasion in Stockholm's public transport. J Transp Lit 7(4):50–74

Suquet JB (2005) Moral standards: underpinning or (re) constructing social order? The case of fraud in a french collective transportation service. In: 17th Annual meeting of the Society for the Advancement of the Socio-Economics (SASE)

Suquet JB (2008) The professional dynamics of the service encounter. An inquiry into RATP's approach to fare evasion. PhD thesis

Suquet JB (2010) Drawing the line: how inspectors enact deviant behaviors. J Serv Mark 24(6):468–475

Tamblay S, Gschwender A, Dragicevic M, Muñoz JC (2017) Risks involved in transit provision of bus contracts: case study of Transantiago, Chile. Transp Res Rec 2649:89–96

Thorlacius P, Clausen J (2010) Scheduling of inspectors for ticket spot checking in urban rail transportation. DSB S-tog (Copenhagen). 2008 Trafikdage på Aalborg Universitet

Torres-Montoya M (2014) Tackling fare evasion in Transantiago: an integrated approach. In: Transportation Research Board 93rd annual meeting (No. 14-4641)

Troncoso R, de Grange L (2017) Fare evasion in public transport: a time series approach. Transp Res Part A 100:311–318

Van Andel H (1989) Crime prevention that works: the care of public transport in the Netherlands. Br J Criminol 29(1):47–56

Van Noorden R (2014) Online collaboration: scientists and the social network. Nature 512(7513):126–129

Wagner D, Harper W, Schueftan O (1986) Self-service fare collection on buses in Portland, OR

Watry DJ, Straus P (2000) Muni metro goes POP: implementing proof of payment fare collection on Muni Metro. In: Light rail: investment for the future. 8th joint conference on light rail transit

Weidner RR (1996) Target-hardening at a New York City subway station: decreased fare evasion–at what price? Crime Prev Stud 6:117–132

Yin Z, Jiang AX, Johnson M, Tambe M, Kiekintveld C, Leyton-Brown K, Sandholm T, Sullivan J (2012a) TRUSTS: scheduling randomized patrols for fare inspection in transit systems. In: Proceedings of the twenty-fourth AAAI conference on innovative applications of artificial intelligence (IAAI). AAAI Press, Menlo Park

Yin Z, Jiang AX, Johnson M, Tambe M, Kiekintveld C, Leyton-Brown K, Sandholm T, Sullivan J (2012b) TRUSTS: scheduling randomized patrols for fare inspection in transit systems using game theory. AI Mag 33(4):59–72