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Abstract

Purpose – *The purpose of this paper is to devise a crowdsourcing methodology for acquiring and exploiting knowledge to profile unscheduled transport networks for design of efficient routes for public transport trips.*

Design/methodology/approach – *This paper analyzes daily travel itineraries within Mexico City provided by 610 public transport users. In addition, a statistical analysis of quality-of-service parameters of the public transport systems of Mexico City was also conducted. From the statistical analysis, a knowledge base was consolidated to characterize the unscheduled public transport network of Mexico City. Then, by using a heuristic search algorithm for finding routes, public transport users are provided with efficient routes for their trips.*

Findings – *The findings of the paper are as follows. A crowdsourcing methodology can be used to characterize complex and unscheduled transport networks. In addition, the knowledge of the crowds can be used to devise efficient routes for trips (using public transport) within a city. Moreover, the design of routes for trips can be automated by SmartPaths, a mobile application for public transport navigation.*

Research limitations/implications – *The data collected from the public transport users of Mexico City may vary through the year.*

Originality/value – *The significance and novelty is that the present work is the earliest effort in making use of a crowdsourcing approach for profiling unscheduled public transport networks to design efficient routes for public transport trips.*

Keywords *Knowledge creation, Data collection, Knowledge-based systems*

Paper type *Research paper*

1. Introduction

Some metropolises like Mexico City provide their inhabitants with uncertain, unscheduled public transport services (Stereocarto, 2001), consisting of subway, trolleybus, urban train and bus transport networks. Due to the lack of planning and organization, in addition to the complexity, size and heterogeneous nature of such public transport services (Schteingart, 1989), explicit knowledge (namely, bus route maps, bus frequencies, subway frequencies, etc.) is commonly undefined (Kash and Hidalgo, 2014). Only public transport users that have lived in a metropolis (like Mexico City) for a considerably long time, have deep knowledge of the underlying structure of its public transport network, the dynamics of its different public transport systems and their interconnectivity. Given that the different public transport services are provided by different entities (e.g. the city government and/or private companies), acquiring and integrating knowledge from distributed, independent sources is a challenge. Even more complex is to design efficient routes for public transport trips based on heterogeneous, unscheduled public transport services.

In this paper, we propose a crowdsourcing approach for the acquisition and consolidation of knowledge of unscheduled public transport services from their users whose knowledge is integrated to design efficient routes for public transport trips.

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Crowdsourcing is the act of outsourcing a large, complex task, e.g. profiling unscheduled public transport networks, to a generally undefined group of people or crowd (Howe, 2008), e.g. public transport users. Crowdsourcing, as a problem-solving model (Brabham, 2008, 2009), has been used in a wide range of applications, from translation systems (Eagle, 2009), validating land cover maps (Fritz *et al.*, 2009) and answering queries (Franklin *et al.*, 2011), to planning urban projects (Brabham, 2009). With respect to crowdsourcing applications in the transport domain, Zambonelli (2011) highlighted that crowdsourcing initiatives can improve public transport systems. Following this idea, Schnitzler *et al.* (2014) implemented a crowdsourcing approach to complement information from real-time urban sensors to resolve sensor disagreements about traffic congestions. Furthermore, crowdsourcing has been proposed as a mechanism to empower citizens in making decisions about public transport policies (Filippi *et al.*, 2013).

This paper makes use of crowdsourcing to acquire and consolidate knowledge about public transport networks (namely, rush hours and quality of service of a myriad of public transport services) from expert public transport users. The consolidation of the knowledge of the public transport users then becomes a profile of the public transport network that can be used to design efficient routes for public transport trips even in the total absence of official information from the public transport providers. Knowledge is acquired from public transport users by conducting surveys providing information about waiting times, average speed of public transport services and transfer times between different types of public transport services of Mexico City. It is worth mentioning that, to the best of the authors' knowledge, the public transport providers of Mexico City do not make this type of information publicly available. From the knowledge of the expert public transport users, we characterize the public transport network of Mexico City. In addition, we have devised and implemented a heuristic search algorithm to design efficient routes for public transport trips in the characterized public transport network. Moreover, we have ported this knowledge and heuristic to a public transport navigation system that can be installed in mobile phones.

The structure of this paper is as follows. In Section 2, we review related work. Subsequently, in Section 3, we describe our data collection mechanism. Afterwards, in Section 4, we explain the knowledge acquisition process from expert public transport users and consolidate the knowledge. Then, in Section 5, we describe the *expert user heuristic*, a heuristic search algorithm for finding efficient routes for public transport trips. In Section 6, we present SmartPaths, a mobile application to travel on the public transport system of Mexico City. Finally, in Section 7, we provide some concluding remarks and future research directions.

2. Knowledge acquisition, knowledge management and public transport

Knowledge acquisition should be considered a cognitive process that involves understanding language, learning, reasoning, problem-solving, decision-making, knowledge modeling and knowledge conversion. Knowledge acquisition should be seen as a spiral of epistemological and ontological content that grows upward by transforming tacit knowledge into explicit knowledge, which in turn becomes the basis for a new spiral of knowledge generation (Cairó and Guardati, 2012).

Knowledge is undoubtedly a fluid mix of framed experience, values, expertise, contextual information and insight that provides a suitable environment and a structure for evaluating and incorporating new information and experiences. We know it is the knowledge, the ability to create, to use and to transfer it, which may allow the creation or improvement of new products or services. But knowledge is often tacit, meaning it lives in the minds of individuals (e.g. expert public transport users) and, therefore, it is difficult to transfer knowledge to another person by means of the written word or verbal expression. This is precisely one of the main obstacles. While the problem is clear, the solution is hard to implement. The conversion of tacit knowledge into explicit knowledge is indeed critical because it is a prerequisite to the knowledge amplification process wherein knowledge becomes part of a knowledge network (Herschel *et al.*, 2001).

Knowledge management is the process of capturing, developing, sharing and effectively using organizational knowledge. Knowledge management encompasses the managerial efforts in facilitating activities of acquiring, creating, storing, sharing, diffusing, developing and deploying knowledge by individuals and groups (Rowley, 2000; Soliman and Spooner, 2000). We must emphasize that this is precisely the main idea of our work on public transport. We mainly focus on two processes that have received the most consensus: knowledge acquisition and knowledge utilization. We are looking for the efficient transformation of tacit knowledge of unscheduled public transport networks into explicit knowledge to design efficient routes for public transport trips. We do think that when tacit knowledge is crystallized, knowledge can be shared and used for others and can be connected to a knowledge system.

The evolution of navigation applications on public transport has been accelerated in the past years (Quddus *et al.*, 2007). Many new public transport navigation applications have flooded the market for mobile devices. The mobile applications can allow you to view service times, use the journey planner and set your favorite stops throughout the city for faster access to public transport information on the go. These applications definitely help people to save time and money using the appropriate public transport and the best route. Moovit (2014), TriMet (2014), RTA (2014) and PTV (2014) are some of them. This also has brought a lot of attention into algorithms that can find optimal routes in a map (i.e. a node network) given certain conditions and restrictions like traffic, trip time and users' preferences.

The problem of finding the fastest path between two stations is generally modeled as a shortest path, minimum delay problem in a graph (Chuang and Kung, 2005; Hart *et al.*, 1968; Orda and Rom, 1990). The nodes of the graph represent the transport stations, the edges represent the connections among the stations and the weights (of the edges) represent the distance between stations.

Google has also made a considerable amount of research in the area. They developed navigation systems for walking, car and public transport. Nevertheless, Google's public transport navigation systems are only available in a small number of highly developed cities. This is because they calculate public transport routes using real-time data that is uploaded by third-party companies in a standardized format called general transit feed specification. This specification format requires many parameters, e.g. location of stops, frequencies and transfers. This information is available only in some cities that believe in open data, and many developers use it to create accurate routing algorithms (Ludwig, 2009).

To speed-up computer processing Jariyasunant *et al.* (2011) proposed pre-generating all possible paths from station *i* to *j*, and after that, looking for the optimal path in the result set, instead of calculating the optimal path each time the user requires it. A similar method has been already used in some train navigation systems in The Netherlands (Tulp and Siklóssy, 1991). Liao *et al.* (2007), Froehlich *et al.* (2009), and Ferris *et al.* (2010) have also contributed to this issue on public transport and mobile applications.

Although many of these solutions are widely proven and efficient, they cannot be applied to the public transport system of Mexico City. This is because the transport system lines are not properly regulated, i.e. they are unscheduled, and there is no source of real time data of any of them. Besides, the transports' speed is highly variable and arrival and departure times are not scheduled for any of them. This is the main reason why we decided to build a crowdsourcing model to acquire, consolidate and exploit knowledge of multiple, heterogeneous knowledge sources.

3. Collecting data via crowdsourcing

Our *crowd* consisted of an overall of 610 public transport users that were surveyed about the three major public transport systems in Mexico City: the subway (hereafter *metro*), the bus rapid transit system (hereafter *metrobus*) and the public transport bus system. The surveyed public transport users were composed of 400 bus users, 100 metrobus users (20 metrobus users for each line) and 110 metro users (10 metro users for each metro line). We surveyed considerably more bus users because the public transport bus system is considerably more chaotic than the metro or metrobus transport systems. Both the metro and the metrobus, although unscheduled, are considered to be successful public transport systems (Wright and Fjellstrom, 2003; Mejía-Dugand *et al.*, 2013). Hence, surveying a few metro and metrobus users was sufficient to draw conclusions about waiting times, average speeds and transfer times.

The public transport users were provided with a timetable (see Figure 1) to indicate their daily travel itineraries, the type of public transport system they use the most and the route. In addition, the public transport users were asked three questions with respect to the quality of service of the public transport system they use the most. The quality-of-service questions were:

1. *On average, how fast is the {metro, metrobus, bus} transport system?* The possible answers were: 1 (very slow), 2, 3, 4 or 5 (very fast).
2. *On average, how long do you wait for the {metro, metrobus, bus} to arrive?* The possible answers were: 1 (too long), 2, 3, 4 or 5 (too short).
3. *On average, how long does it take to transfer between {metro, metrobus, bus} routes?* The possible answers were: 1 (too long), 2, 3, 4 or 5 (too short).

4. Knowledge acquisition from expert, public transport users

From the survey results (Figures 2-12), we extracted knowledge about the rush-hour period per day on an hourly basis of each type of public transport system and route. In addition, we also extracted knowledge about three main quality-of-service parameters of public transport systems: the average speed, average waiting time and average transfer time between (metro/metrobus) lines and/or bus routes. It should be noted that whereas the public transport users provided detailed daily travel itineraries, the questions regarding the quality-of-service parameters were general, e.g. *on average, how fast is the metro?* In doing so, the users were not overwhelmed by numerous and specific questions, e.g. *on average, how fast is the metro on Tuesdays at 10 a.m.?*

Figure 1 Timetable provided to transport users to register travel itineraries

Please indicate the type of public transport system (and the route) you use the most.

☐ Metro ☐ Metrobus ☐ Bus

Route:_______

Please indicate your travel itineraries for the public transport system and the route you have selected.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
6:00-7:00							
7:00-8:00							
8:00-9:00							
9:00-10:00							
10:00-11:00							
11:00-12:00							
12:00-13:00							
13:00-14:00							
14:00-15:00							
15:00-16:00							
16:00-17:00							
17:00-18:00							
18:00-19:00							
19:00-20:00							
20:00-21:00							
21:00-22:00							
22:00-23:00							
23:00-24:00							

Figure 2 Bus-related data: rush hours on weekdays

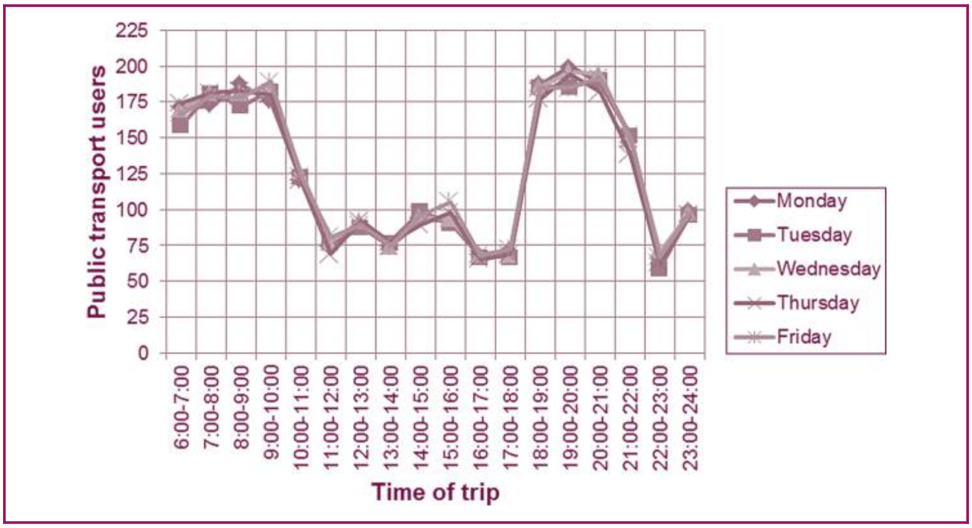
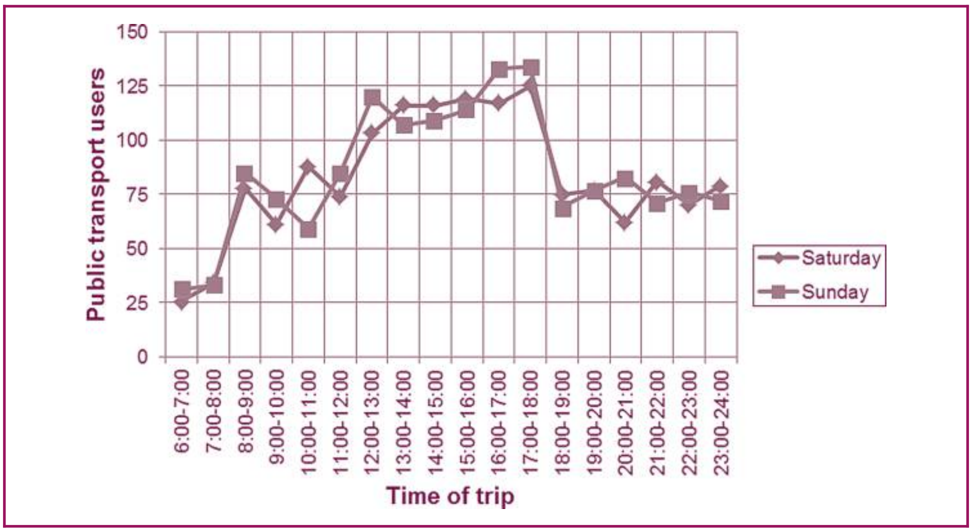


Figure 3 Bus-related data: rush hours on weekend days



We classified the survey results into three categories: bus-related results (Figures 2-4), metrobus-related results (see Figures 5-10) and metro-related results (see Figures 11-12). From the survey results, we have drawn seven observations.

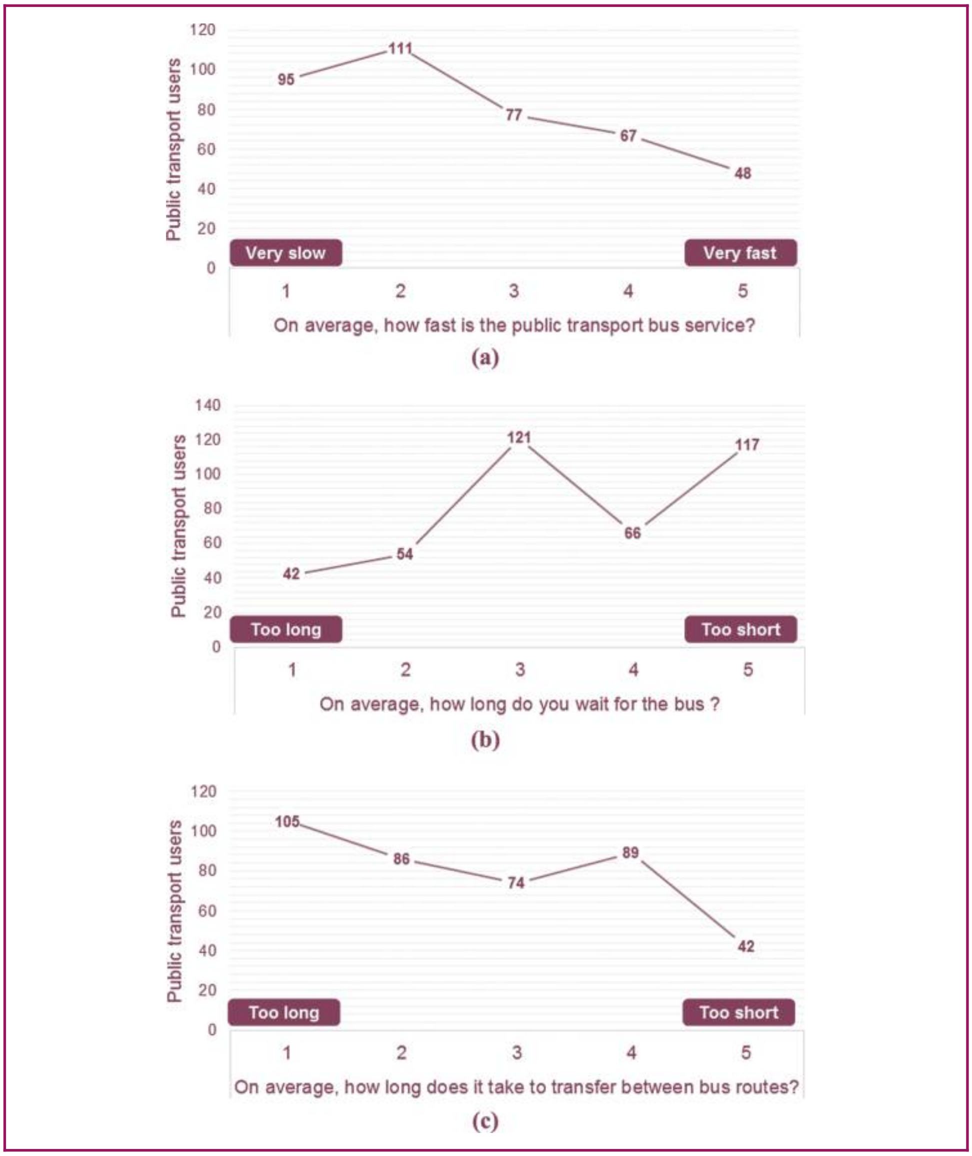
4.1 Observation 1

The rush hours on weekdays of all the public transport systems, metro, metrobus or the public transport bus system, highly differ from the rush hours on weekend days. As observed in Figures 2 and 3, 5-9, and 11, the majority of the public transport trips occur during the weekdays most likely due to students' and workers' daily mobility in Mexico City. Then, the design of efficient routes for unscheduled public transport trips should take into account whether the trip is made in weekdays or weekend days.

4.2 Observation 2

The rush hours of public transport systems, namely, the metro and the public transport bus system, are slightly different. Whereas Figure 11 shows that the dominant peak rush hour

Figure 4 Bus-related data: quality of service



of the metro happens between 1,900 and 2,000 hours, the peak rush-hour period of the public transport bus system happens between 1,800 and 2,100 hours, see Figure 2. A possible cause of this difference is that metro stations are located in highly urbanized areas, which may be close to locations (e.g. schools and offices) with scheduled activities. This, in turn, may generate more scheduled public transport trips than the trips of the public transport bus system, which is more geographically extended. Then, the design of efficient routes for unscheduled public transport trips should simultaneously take into account both the type of public transport system and the time of the trip.

4.3 Observation 3

The rush hours of the metrobus lines are different among each other. As shown in Figures 5-9, each metrobus line has a different rush-hour period. This may be due to the different social and demographic characteristics of the regions of Mexico City where the metrobus stations are located at. Then, the design of efficient routes for

Figure 5 Metrobus-related data: rush hours of Line 1

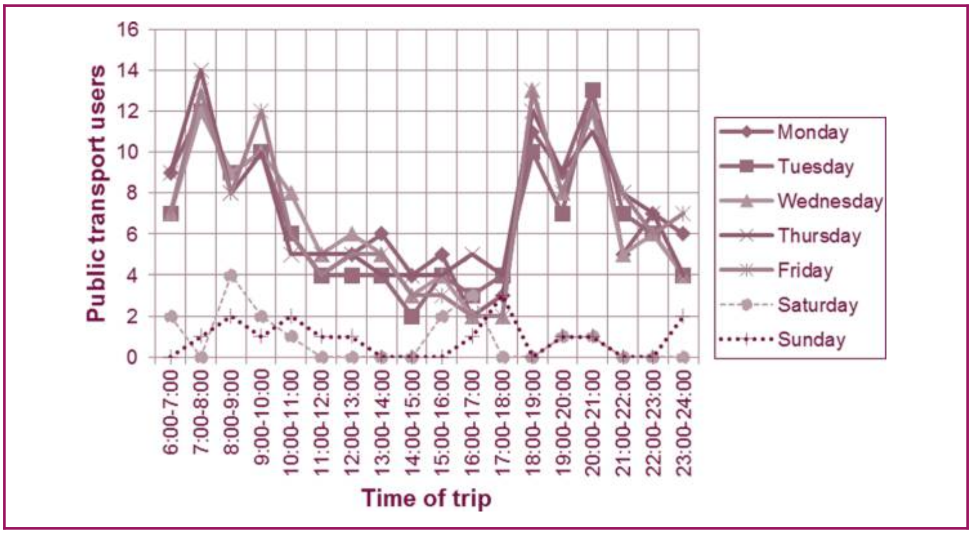
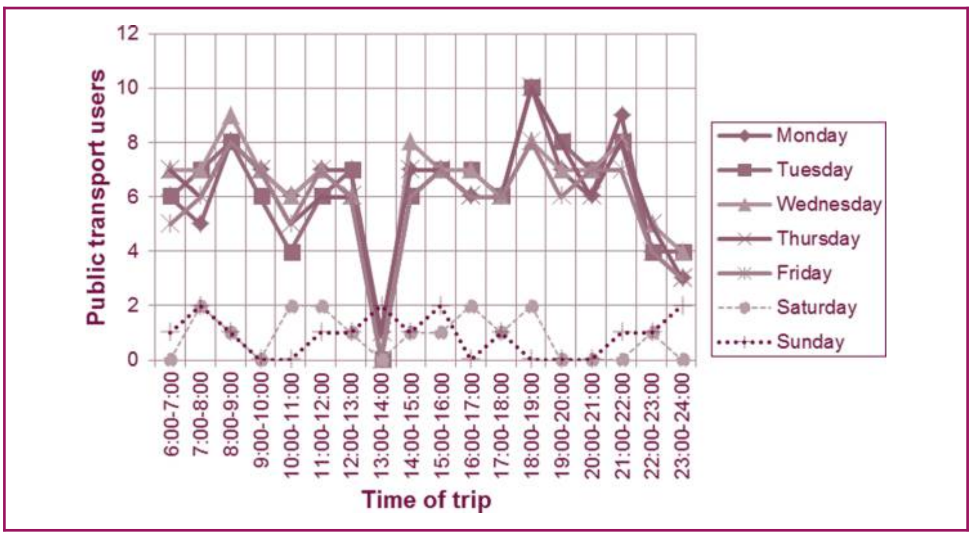


Figure 6 Metrobus-related data: rush hours of Line 2



unscheduled public transport trips should take into account the line (or route) of the public transport system.

4.4 Observation 4

In general, the rush hours of the public transport systems of Mexico City are relatively stable during weekdays. As the variations on the number of people using a particular line (or route) and a particular public transport system through the week is relatively stable (see Figures 2, 5-9, and 11), no distinction should be made when designing routes for public transport trips for a particular weekday.

4.5 Observation 5

The answers of public transport users to the question: *on average, how fast is the {metro, metrobus, bus} transport system?* suggest that the fastest public transport system is the metro (see Figure 12(a)), followed by the metrobus (see Figure 10(a)). In addition, the majority of the users think that the transport bus system is very slow (see Figure 4(a)). Then, when possible,

Figure 7 Metrobus-related data: rush hours of Line 3

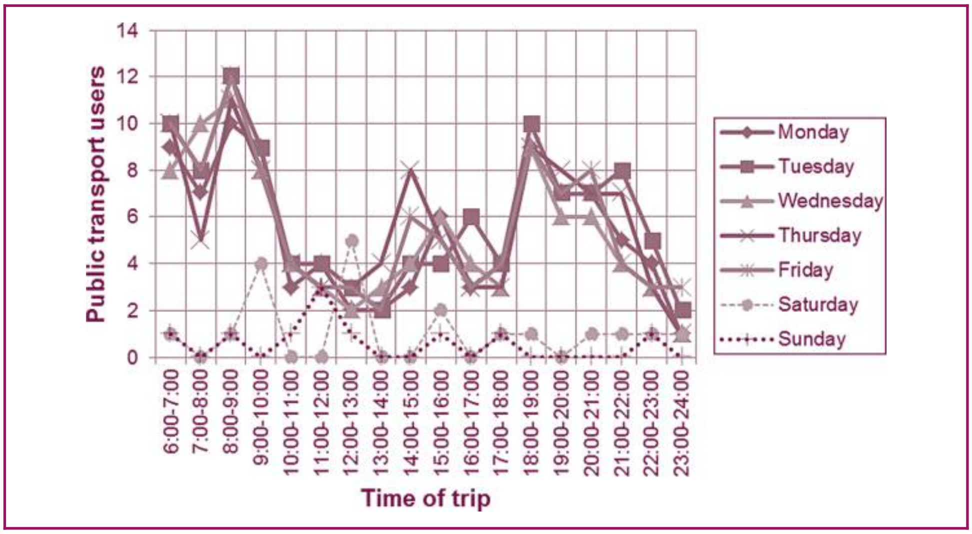
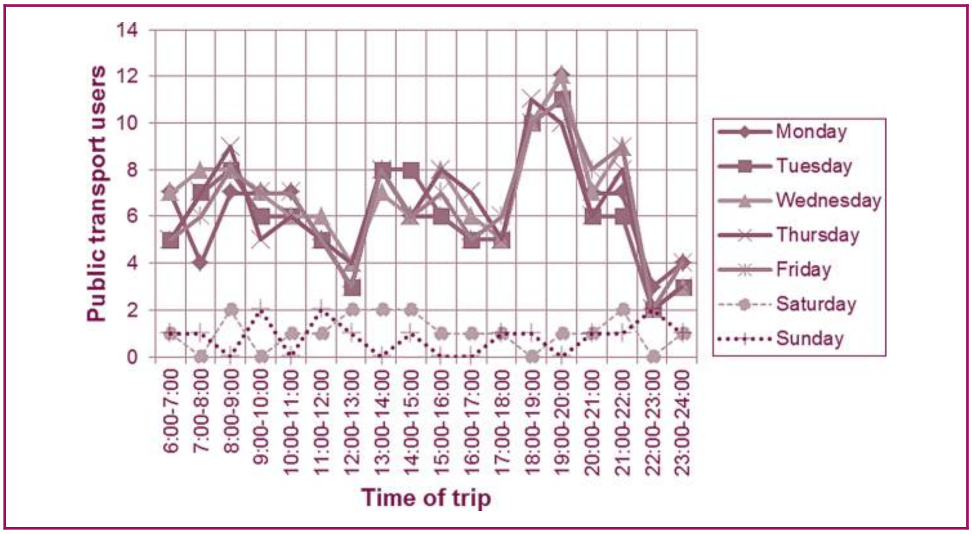


Figure 8 Metrobus-related data: rush hours of Line 4



public transport trips should be made by using the metro. If no metro station is nearby, then, using the metrobus is a good option. Moreover, if we take into account only the speed of the public transport system, the public transport bus system should be avoided.

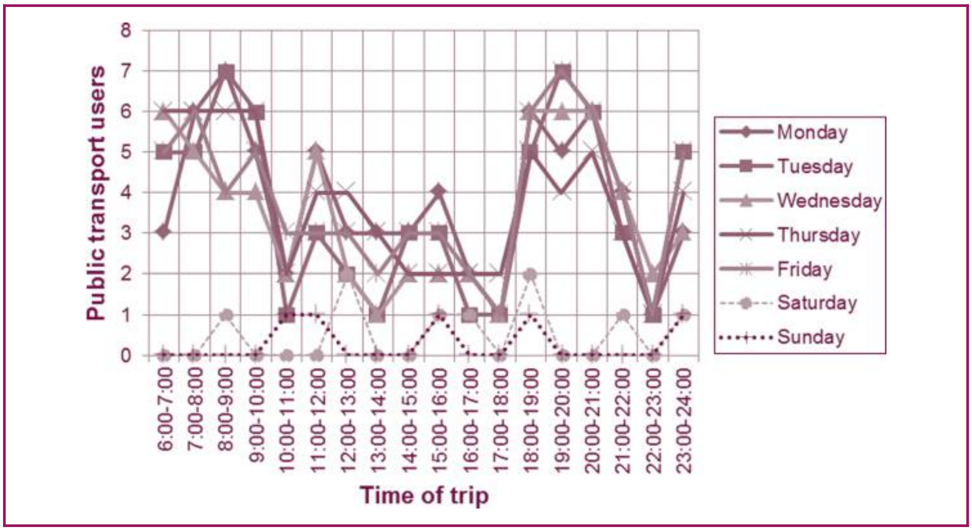
4.6 Observation 6

With respect to the *waiting time*, all public transport systems are relatively efficient, as pointed out by a majority of responses, indicating that waiting times are from average [see Figure 4(b) of the bus system] to too short [see Figures 10(b) and 12(b) of the metrobus and metro transport systems, respectively]. These survey results indicate that the public perception of the frequency of the public transport systems in Mexico City is relatively very good.

4.7 Observation 7

With respect to *transfer time*, the users indicated that both the metro and metrobus transport systems have too short transfer times and that the average transfer time of the transport bus system is too long. As shown in Figures 10(c) and 12(c), when using the metro and/or

Figure 9 Metrobus-related data: rush hours of Line 5



metrobus, transferring between lines is, at least, not considerably time-consuming. On the other hand, when referring to the public transport bus system, the transfer times are time-consuming [Figure 4(c)], which seems to suggest that the frequency of the public transport bus system is bad, contradicting *Observation 6*. However, a possible reason that can explain this result is that transfers between bus routes may require walking several blocks to another bus stop.

In summary, from the above analysis of the seven observations, we have acquired knowledge about the unscheduled public transport services of Mexico City. In addition, we have obtained quality-of-service profiles for each public transport system of Mexico City. We are now able to exploit this knowledge for the design of routes for unscheduled public transport trips.

5. The expert user heuristic

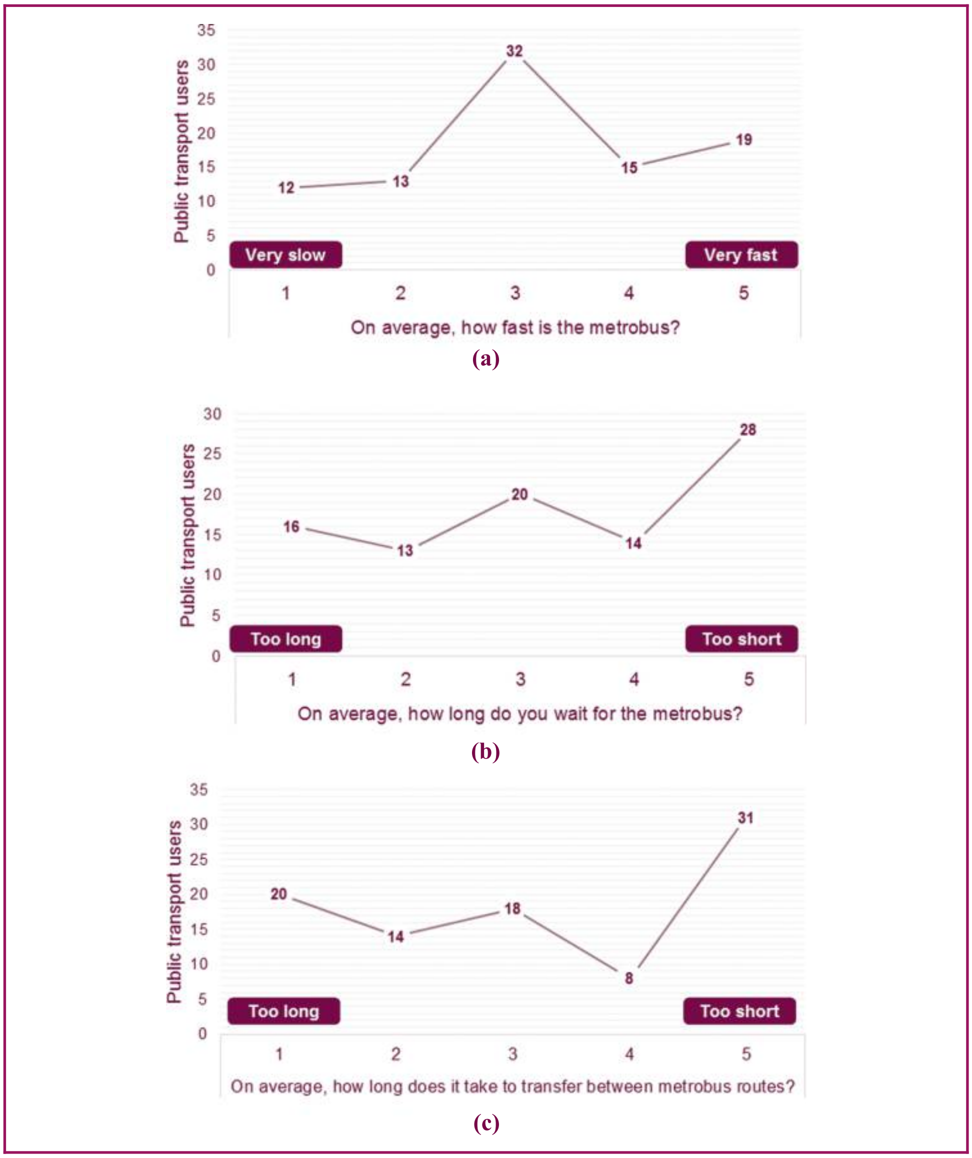
We have designed and implemented the *expert user heuristic*, a heuristic that exploits the knowledge of expert public transport users of Mexico City. The *expert user heuristic* takes into account the following: distance from origin to destination, transfer times, waiting times and speed of public transport services.

The *expert user heuristic* computes the distance from a departure transport station either a metro, metrobus or bus station to a final destination, which may not be a transport station, by using the A* search algorithm. See (Zeng and Church, 2009) for a detailed description of the A* search algorithm. Then, the distance to destination is the sum of the distance from the departure transport station *i* to the closest transport station *j* to the final destination *k*, and the walking distance from transport station *j* to the final destination *k*. To do this, the whole transport network of Mexico City was modeled as a graph whose nodes are metro, metrobus and bus stations, and the edges indicate the distance between stations. The graph of the transport network, the origin and the final destination of the public transport trip are the inputs of the A* search algorithm, which finds the shortest path to a given destination.

The *expert user heuristic* also takes into account that public transport trips in Mexico City are commonly composed of one or more transfers between the same public transport system and/or several public transport systems. Then, given that transfers take some time, the *expert user heuristic* takes into account the number of transfers.

Whereas waiting for a bus (or the metro) does not consume a considerably amount of time (as analyzed in *Observation 6* of Section 4), accumulated *waiting times* of a relatively long public transport trip may consume a considerable amount of time. For this reason, the

Figure 10 Metrobus-related data: quality of service



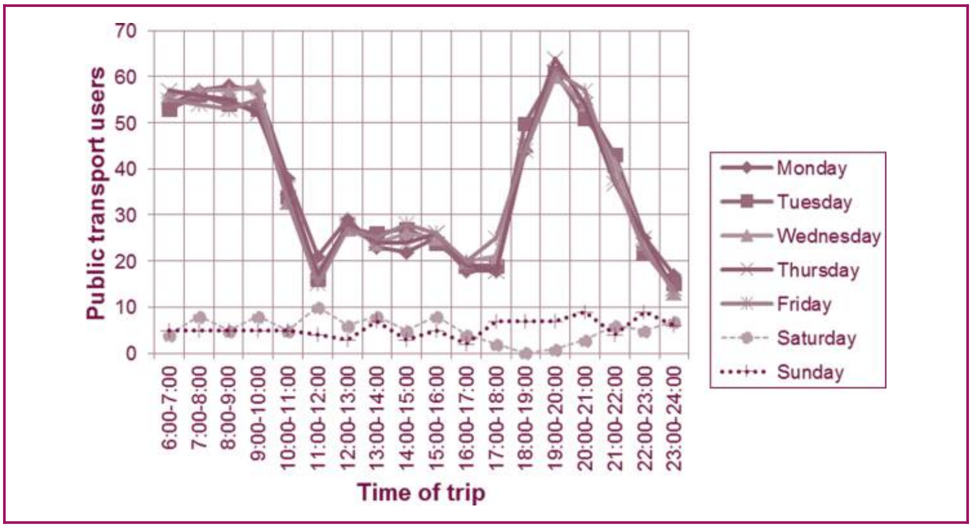
expert user heuristic takes into account accumulated waiting times to determine suboptimal routes for public transport trips.

It is acknowledged that the *expert user heuristic* was firstly presented by Sendra and Cairó (2014), who presented it as a conference paper whose sole contribution is the design of the *heuristic*. Please refer to Sendra and Cairó (2014) for details of the *expert user heuristic*.

6. SmartPaths: a public transport navigation system

SmartPaths is a mobile application whose objective is to design efficient routes for unscheduled public transport trips for users of the public transport network of Mexico City. SmartPaths is the result of exploiting knowledge of expert public transport users. SmartPaths makes use of the *expert user heuristic* to generate routes for public transport trips in Mexico City, which takes into account waiting times, transfer times and average speed of the public transport services. SmartPaths is available for download at Sendra (2014). As of November 20, 2014, the current version of SmartPaths is rated by

Figure 11 Metro-related data: rush hours



users of a popular online store with 4 out of 5 stars (where 5 stars is the highest user satisfaction rating). This relatively high rating validates the appropriate exploitation of knowledge to profile unscheduled transport networks for the design of efficient routes for public transport trips in Mexico City. Please see Sendra (2014) for user reviews.

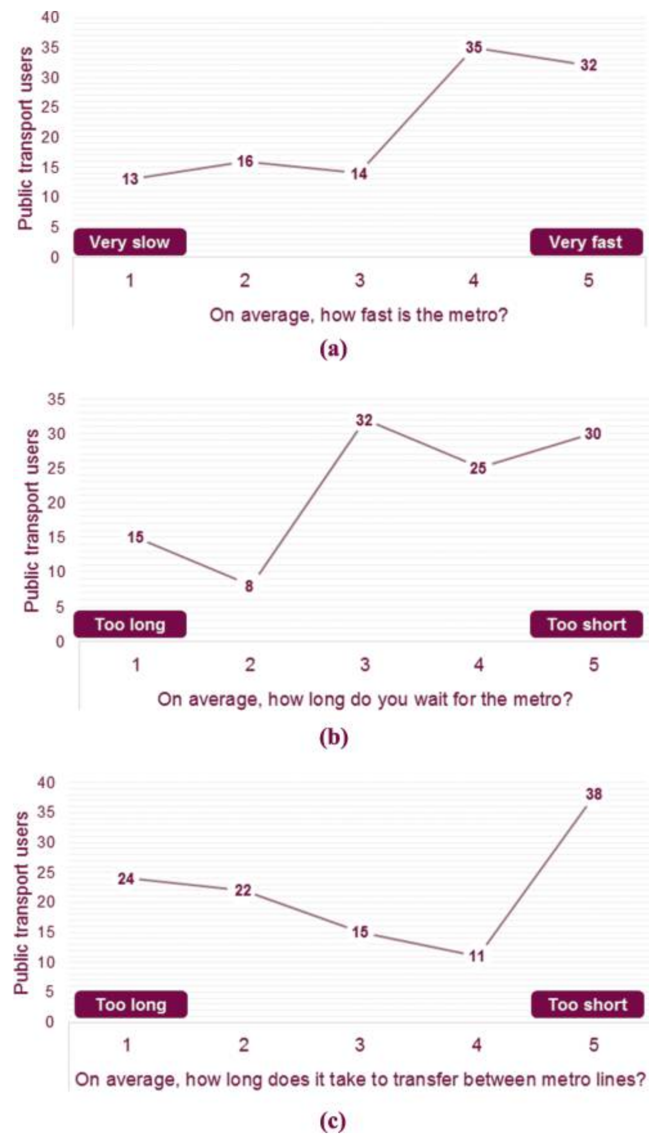
7. Conclusion and future work

The significance and novelty of this work is that, to the best of the authors' knowledge, the present work is the earliest effort in making use of a crowdsourcing approach for profiling unscheduled public transport networks to design efficient routes for public transport trips. The contributions of this work are as follows:

- Developing a crowdsourcing methodology for characterizing unscheduled transport networks.
- Providing the first, to the best of the authors' knowledge, profile of the unscheduled public transport network of Mexico City composed of heterogeneous transport networks, namely, metro, metrobus and bus transport systems.
- Devising and implementing SmartPaths, a mobile application for public transport navigation in Mexico City.

From the observations analyzed in Section 4, we can conclude that the design of efficient routes for unscheduled public transport trips in Mexico City should take into account whether the trip is made in weekdays or weekend days (see Observation 1). In addition, it should take into consideration both the type of public transport system and the time of the trip (see Observation 2) as well as the particular route (or line) of the public transport system (see Observation 3). Moreover, from the analysis presented in Section 4, we can conclude that no distinction should be made when designing routes for public transport trips for a particular weekday (see Observation 4). Furthermore, the analysis revealed that the majority of the trips should be made by using the metro. If no metro station is nearby, then using the metrobus is a good option and, as a last resort, using the transport bus system (see Observation 5). The results analyzed in Section 4, also indicated that the frequency of the public transport systems in Mexico City is relatively very good (see Observation 6). Finally, from the analysis of Observation 7, we can conclude that whereas the transfer times of both the metro and metrobus are acceptable, the transfer times of the public transport bus system are unacceptable.

Figure 12 Metro-related data: quality of service



Knowledge management, in particular knowledge management in transport, can influence the efficiency of public transport systems when knowledge management is aligned with the structure and strategy of a city. Knowledge management tools and knowledge management initiatives for public transport systems help transfer the impact of public transport resources to the bottom line (Zheng *et al.*, 2010), i.e. users of the public transport services.

Our future research direction is focused on designing a flocksourcing (Kennedy, 2012) methodology for profiling the routes of the public transport bus system of Mexico City, which has no formal, documented routes, i.e. the routes of the bus system are only known to some users, but no official routes are available publicly. Flocksourcing consists of providing a group of people with sensors, e.g. smartphones and instruct them to explore a (public transport) system to profile it. Another future research direction includes implementing an automated mechanism to allow continuous feedback from public transport users.

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