ANALYSIS OF SKIP-AND-STOP PLANNING USING SMART CARD DATA

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Introduction

Transportation is one of the first sectors to use information communication technologies (ICT) to improve services and performance. In this context, the automated fare collection card, later called ‘smart card’, was developed to automate ticketing and increase the efficiency of the payment process by replacing the ticket purchase for all public transport modes within most of the cities around the world (Blythe, 2004; Trépanier et al., 2007).

However, smart cards, and the data they store, enabled several new opportunities, such as customer behaviour analysis, transportation evaluation and assessment, transportation planning, and platforms for efficient revision of fare structures (Trépanier & Morency, 2010; Schmöcker et al., 2017, pp. 1–11; Briand et al., 2017; Zhao et al., 2018; Chen & Fan, 2018; Espinoza et al., 2018; Medina, 2018). The big data collected by smart card use is now widely used in planning, as identified in the overview chapter (see also Chapter 33), at three levels: the strategic level or long-term planning, tactical level for informing service adjustment and network development, and the operational level where the smart card is used to analyse ridership statistics and performance indicators.

In Seoul, the smart card was first implemented in 1996, and at first it was only used on urban buses. The aim was to enhance the management transparency of bus operators, to simplify the payment process for users, and reduce delays caused by paying processes (Park & Kim, 2013). Later, in 2004, Seoul extended the smart card system, then called T-money, to enhance the convenience for modal transfer as well as facilitating payment and fare collection process, improving the transparency of bus operator behaviour, and analysing public transportation usage (Audouin et al., 2015). In 2020, Korean cities are known for their high rate of smart card usage, with a penetration reaching 96% in Seoul in 2009 (Park & Kim, 2013).

In this chapter, the focus is on the exploitation of smart card data in schedule optimisation of express and normal trains in the city of Seoul. It is a case study of schedule optimisation of the skip-and-stop mechanism of train services using smart card data. The structure of the chapter is as follows: the next section gives an overview of the Seoul case study. Then, the modelling and calculation of the optimised schedule are explained before turning to the main results. The final section summaries the research, its limitations and pointers for further research.
Case study modelling

Skip-and-stop strategy

Improving the quality of service is the principal way of maintaining or increasing patronage (Currie & Wallis, 2008) so that public transport can compete with the private car. Alongside this, an understanding of passenger behaviour and preferences is also necessary. Improving quality means focusing on: waiting time, travel time, in-vehicle congestion, and transfers.

In this study, the in-vehicle speed is considered a key characteristic that should be improved, as it influences other characteristics while reducing the overall door-to-door journey time. The focus is on real-time scheduling optimisation, and many different operational schemes aiming to increase the speed and reducing travel time, through rescheduling strategies, have been advocated. For instance, the dead running strategy, which means running an empty train from the dispatching station through a number of the first stations with the aim of saving overall running time (Hassannayebi et al., 2016); an express service strategy; and stop skipping (Wang et al., 2015).

The skip-and-stop strategy is an operational strategy in which stops are spread out among alternating route-stop patterns (Kittelson & Associates, 2003). In general, a skip-and-stop strategy permits an increase in public transport average speed and a reduction in the overall travel time. It can also reduce in-vehicle congestion and improve the travel experience of public transport passengers.

More specifically, a skip-and-stop strategy classifies stations into three categories: A, where only trains of type A stop, B where only B type trains stop, and AB stations that are labelled as busy stations, where all trains stop. To consider implementing a skip-and-stop scheme, it is important to first determine whether a skip/stop scheme is more beneficial than regular operation and second to find the optimal A, B, and AB station distribution, considering the optimal distance and the time gap between those stations. Generally, a skip/stop plan is highly affected by passengers’ route choice and behaviour; therefore, a deep understanding of travel behaviour is needed.

The subway line 9 in Seoul is designed to enhance the accessibility of central Seoul and already operates two trains: express and regular, using a skip-and-stop policy. However, the line suffers from heavy congestion, being the main link that connects the south-eastern part to the rest of the city. This congestion has reached 240% of the rail vehicle’s overall capacity. It is hoped that this issue could be solved without the need either to build new infrastructure or to buy new trains with higher vehicle capacity. To avoid any expansion that would only induce more demand, schedule optimisation was chosen as the best approach in terms of cost-benefit efficiency. The optimised schedule aims to minimise congestion while optimising both operator and passenger costs. Mathematical programming in the form of mixed-integer linear programming (MLIP) and agent-based modelling using the software MATSim were used in the optimisation process.

Model building

The Seoul smart card fare collection system is a “closed” system that requires a tap on for entering and a tap off for leaving the system. The data from the smart card permits a range of planning activities (estimating travel demand, measuring travel time and transfer time, managing schedules, adjusting routes, and services) as well as the analysis of travel behaviour, the
development of origin-destination matrices, and the route load profile of each run within the public transport offering. The Seoul smart card data was calibrated with the national household travel survey given by the Korea Transport DataBase (KTDB) and the national Vehicle Kilometres Travel (VKT) data information database.

The preliminary process includes five steps to build the MILP model: station classification, objective function setting, constraint setting, OD matrix building, and calculation of the optimal solutions (as shown in Figure 38.1).

Station classification

First, stations were classified into express and regular groups, considering the skip and stop service provided. The express train stops only at express stations, while the regular one stops at all stations.

Origin destination matrices and congestion identification

The MILP allows building an optimised model while considering different aspects, like relieving congestion and reducing passenger and operator costs. Therefore, OD matrices were generated for each station using smart card data. Each OD matrix represented the number of in and out passengers at each station. Then, the prepared OD matrices were imputed into the model to estimate the in-vehicle overall congestion, as well as identifying congestion at each station. The OD matrices permitted a reflection of the real demand at each station, thereby allowing finer analysis of the in-vehicle congestion.
Objective function setting

This step involves choosing the solution to be implemented which has the best cost-benefit efficiency. Rescheduling was chosen here, as it is more efficient in terms of flexibility and cost/benefit. Therefore, the objective function is a function that minimises both passenger costs and operator costs.

Passenger costs are estimated using the user travel time and waiting time at the stations. Operator cost is estimated considering the train capital and operation costs.

Constraint setting

In the third step, the constraints were determined and the assumptions identified. This included demand saving, ensuring the total traffic volume does not change and that the category of travellers was unchanged (some classes of travellers, such as the older population, enjoy free rides in Korea). The assumptions included allowing a train to carry up to 150% of its capacity, a value of time per capita assumed to be 4907 KRW, and holding dwell time per station constant at 20 seconds to facilitate calculation and operating hours set as 1170 minutes per day.

Optimal solution calculation

To develop the MILP model, this research used the general algebraic modelling system (GAMS), a sophisticated high-level mathematical optimisation tool to formulate and solve mathematical models and implementing mathematical equations without the need of high-programming skills. GAMS not only has an intuitive data interface, but its strength comes from having separated interfaces into independent layers so that model, solver, data, platform, and user interfaces are all separate. This separation and independency simplifies the switch between interfaces, the use of multiple datasets, the running of the of the process on multiple platforms, and the integration of the tool into existing applications and workflows. The solver CPLEX is used within GAMS to solve the model and find the optimised schedule of skip-and-stop planning. The use of this solver permitted multiple runs of the model in a short time, as it provides faster manipulation and handling of the calculations.

Case study results

The schedule optimisation results, obtained from GAMS and based on the MILP method, are presented in two diagrams showing the schedule before (Figure 38.2) and after (Figure 38.3) optimisation, for the time period 7 am to 8.20 am. The optimised schedule suggested more express trains, with the then operating ratio in 2015 of 1:1 of express trains to regular trains being increased to 1.6:1.

However, the ratio of 1.6:1 is unrealistic (the ratio must be an integer). To resolve this, manual adjustments were added to avoid accidents between express and regular trains by ensuring a sufficient safety gap between them. These adjustments are included in the optimisation diagram.

This optimisation was followed by a further investigation using an agent-based model using MATSim in order to run simulations of potential ratios of express to regular trains, especially where manual adjustments were included, and to visualise and measure passenger satisfaction through the estimation of travel, waiting, and transfer times. The research exploited an existing model (Ali et al., 2016) to do this. The MATSim model considered three ratios: 1:1 (the current ratio), 1.6:1 (the optimum ratio, according to the MILP model), and 2:1, as these were the
Skip-and-stop planning

Figure 38.2  Express (black) and regular (grey) train operation diagram of Line 9
Source: Lee & Park, 2015

Figure 38.3  Scenario 1.6:1’s optimum express (black) and regular (grey) train schedule diagram of line 9
Source: Lee & Park, 2015

Figure 38.4  Percentage of trips per distance using MATSim
Source: Lee & Park, 2015
best results obtained from the MILP model. The main outputs from the MATSim modelling are used for the evaluation of the best scenarios in congestion, travel time (or passenger costs), and operator costs.

These outputs are illustrated by Figures 38.4 and 38.5. MATSim estimates the percentage of trips for each OD (Figure 38.3) and the number of loading passengers per station (Figure 38.5) so that travel time, travel distance, and loading volume can be estimated which, in turn, are used as optimisation parameters in the MATSim model.

The MATSim model results shown in Table 38.1 confirm that the best scenario is of the ratio 1.6:1 but that the ratio 2:1 also provides a good outcome. In addition, the model provides

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*Source: Lee & Park, 2015*

![Figure 38.5](image)

Figure 38.5 Line 9 loading volume per station

*Source: Lee & Park, 2015*
the travel pattern between stations with estimates of passengers entering and leaving at each station, which then permits an assessment of the optimised solution (scenario 1.6:1).

Conclusion

This chapter exploits smart card data to undertake a skip-and-stop schedule optimisation using mixed integer linear programming and agent-based models to evaluate the best schedule for express and regular trains. The goal was to relieve severe in-vehicle crowding, while avoiding more infrastructure spending, by optimising both operator and passenger costs.

The study does have some limitations: First, a manual adjustment for avoiding accidents was needed, and second, the study period was only for the peak time, and the results might be different if a whole-day operation was considered. In addition, whilst a ratio of 1.6:1 express to regular trains was identified as the optimum in the calculations, this required more analysis to be conducted to identify an operational ratio of skip-and-stop that was close to this calculated optimum.

In future, a more in-depth study is recommended, where accidents and other constraints could be added automatically, without need for manual adjustment. Also, the used data should be for a whole weekday and a weekend day, not only peak hours, so as to get more accurate results.

The recent COVID-19 pandemic has shown the importance of this study as the service level of public transport needs to be improved, especially in term of crowdedness, to respect recommended social distancing. The best way forward to identify the needed capacity for both rail and bus systems involves the need for rescheduling, which is best modelled using available big data.

References

Audouin, M., Razaghi, M., & Finger, M. (2015, December 17–19). How Seoul used the ‘T-money’ smart transportation card to re-plan the public transportation system of the city; Implications for governance of innovation in urban public transportation systems. 8th TransIST Symposium.


