Passenger Flow and Station Facilities Modelling for Metro Station Layout Design

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Abstract

This paper presents the simulation model development of passenger flow in a metro station. The model allows studies of passenger flow in stations with different layouts and facilities, thus providing valuable information, such as passenger flow and density of passenger at critical locations and passenger-handling facilities within a station, to the operators. The adoption of the concept of Petri nets in the simulation model is discussed. Examples are provided to demonstrate its application to passenger flow analysis, train scheduling and the testing of alternative station layouts.

Keywords: Passenger flow, simulation modelling, Petri nets

Introduction

Train stations are the passenger hubs in railway systems and proper station layout enables full advantage of the designed capacity to be taken. Utilisation of capacity is of particular importance for main stations in which line inter-changes, service inter-changes or transfer to other modes of transportation is possible. For metro stations, which are mostly underground, passenger throughput during peak hours, quick evacuation upon incidents and access to major streets or buildings are the additional consideration. A simulation-based station layout evaluation tool is essential for layout design, in which a model on passenger flow is required (Goodman, 2001).

A passenger flow model should be able to denote passenger flow rates, origins and destinations of passengers and their selections of routes (Ross, 2000). However, a complete simulation tool cannot go without the modelling of the station facilities, such as escalators, lifts, corridors, concourses, platforms, fare collection gates etc., through

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which the passengers are conveyed within the station. Because of their different attributes and passenger carrying capabilities, components of a station should be modelled independently whilst a generic framework is provided to facilitate easy modifications of station layout. Besides, the station facility model must allow simple integration with the passenger flow model so that passenger movement through the facilities can be neatly represented.

Passenger movement at a train station can be described as a number of concurrent processes flowing through a set of fixed servers. The processes have their own routes to go through and their rates of arrival may vary. The servers are in specific order of services and they are of different capacities. The concept of Petri net has been employed in this study to model both passenger flow and to denote the station facilities.

A Petri net consists of places, transitions, tokens and arcs (Brauer, 1985). The places denote the stationary physical locations and tokens are movable entities which may go from one place to another. The arcs indicate the connections, usually with direction, between places and hence the links on which tokens may transfer between places. The transitions exert control between places and determine, according to certain rules, if the tokens are allowed to move on. Thus, station facilities and passengers can be represented by places and tokens in a Petri net respectively while the arcs denote the relationships among the facilities and the transitions regulate the flow.

This paper presents the Petri net model for the metro station layout design tool and discusses the advantages and limitations of this approach. Tests have been carried out on a typical metro station and simulation results illustrating the passenger flow under a few scenarios will be given to demonstrate applicability of the models.

Railway Stations

Railway stations are places of arrivals and departures, for both trains and passengers. They must be designed in such a way that they are convenient and safe for passengers. Station design is a continuous process involving many professional disciplines. A basic requirement is that the station should allow for free flow of passengers to and from the trains during peak hours at the required capacity. The design of a station should be simple and straightforward to implement and follow, providing facilities that passengers need. A station can be divided into different walking routes. Each route is a sequential string of station elements. Each element has its own characteristics. The capacities of elements in a station should be sufficient to handle the designated passengers at peak hours. The number of stairways and escalators at platform, for example, must be more than sufficient to allow a trainload of alighting passengers to clear a platform before the next trainload arrives.

Station design should also ensure optimal use of spaces, such as shared routes to different areas. The walking routes should be able to lead passengers through the facilities in a logical order. In order to ensure passengers to circulate freely when moving between different elements, the routes should be free from obstructions and capacity of the routes should be as uniform as possible along their length (Ross, 2000). Last but not least, there must be adequate exit routes and clear indications in cases of necessary evacuation upon emergency or incidents.

A station can be divided into a number of walking routes. Each route consists of various elements. Each element has its own characteristics and functions. The elements can be categorized into one of the two possible types, or they exhibit characteristics of both. The first one is characterised by a constant process rate or capacity only. The second type describes an element containing a finite distance in which the capacity or process rate may vary. Process times of various elements depend on the characteristics of the elements. The time required for passengers to complete an element is determined by the capacity and process rate of an element (Popper, 1973). Walking speed of passengers and the congestion level in the element, i.e. waiting times that might occur at queues, are other factors. The following are the basic elements of facilities in a station.

1. Entrance/exit - Station entrances/exits allow passengers going into and out of the stations. The number and locations of entrances must take into account during design. The capacity of an entrance/exit depends on its width and walking speed of passengers.
2. Corridors - They are walkways with finite distances. Capacity of a corridor is a function of its length, width, crowd condition and walking speeds of passengers. Walking speed of passengers varies with the dense conditions of the corridor.
3. Concourse - It is where passengers stop to consider their next actions. There are other elements in the concourse. Adequate space is needed for passenger activities during peak hours.
4. Platform - It is a place for passengers to alight/aboard a train. The capacity depends on its size. It must be able to deal with the expected crash-load of passengers.

5. Accumulation area - It enables passengers to orient themselves before entering critical areas. It reduces unnecessary passenger circulation and prevents “blocking back” effect while providing space for passengers to wait at lift, exits, and platforms.

6. Escalator - It enables large number of passengers to change levels with minimum effort. Escalator possesses characteristics of both types of elements discussed earlier. The number of people using the escalator is a function of escalator speed and if arrival rates are high a queue may form. It requires a fixed amount of time to process passengers, depending on its speed and distance to be covered.

7. Stair - The time required for a passenger to go through a section of staircases is considered to be a function of its length, width, passenger density and walking speed. The density and the speed of passengers are interrelated. As the density increases, passenger speed decreases. Generally, the density of passengers is determined as the quotient of the number of passengers on the stairs and stair area. The “Down” walking speed of passengers is assumed to be faster than “Up” walking speed (Popper, 1973).

8. Lift - It is capable of carrying passengers in both directions. The process time depends on its dwell times and travel times. Travel times are determined by the type of lift and distance it travels. Passengers have to wait when the lift is not available. Adequate circulation spaces should be provided in front of lifts to accommodate a large waiting crowd at peak hours. Such areas must be kept free of obstructions

9. Automatic fare collection (AFC) gate - AFC gates divide a station into ‘unpaid area’ and ‘paid area’. The time required for a passenger to process a gate depends on the process rate of the gates and total number of passengers using the gates.

Passenger Flow

The concept of passenger flow and the calculation of passenger capacities within a station are related to the station design and movement behaviour of passengers. Passenger flow is mainly a function of arrival volume and walking speed of passengers. It also depends on the status of elements and availability of space through a walking route.

Passengers may arrive at a station on foot or by other modes of transportation or line/train transfers. Arrival rates for travelling on foot, by vehicles are more random and continuous. Each batch of arrival brings on a certain number of passengers and the arrival rates of train/line transfers are driven by their scheduled arrival times. Each arrival brings in a higher volume of passengers.

Passenger walking speed and density are interrelated. The main influence on passenger movement in all types of circulation space within a station is the presence of other passengers. When the available space in front is reduced, a passenger will slow down. When passenger density exceeds a critical level, volume and speed become rapidly declining (Edwards, 1992). Free-flow walking speeds can vary substantially across the population. For example, one study identified walking speeds as low as 0.9 metres per second and as high as 1.6 metres per second.

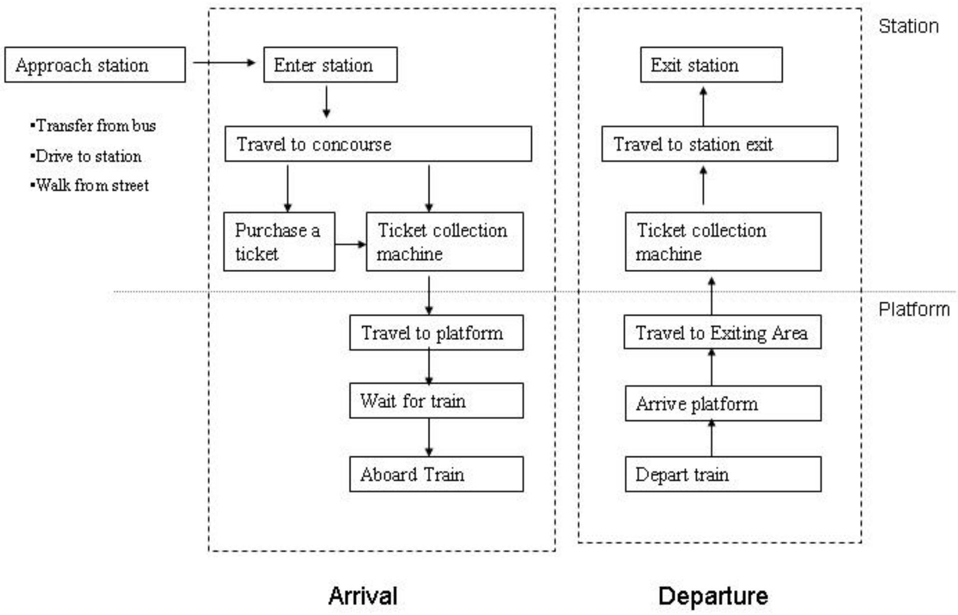

Fig. 1 Passenger flow chart

Every passenger must enter the station prior to boarding a train and must exit the station upon arrival at the final destination. While at the station, passengers often travel on escalators or stairs, then appear at the concourse, purchase a ticket, go through the ticket collection gates and arrive at the platform. When a train arrives at the platform, passengers will get off the train (some may go for a transfer to another line), only those who will stay on the train and passengers boarding from the platform will ride the train (Li, 2000). The flow chart of train station passenger flow is shown in Fig.1.

Passengers choose a route in a station with various approaches. One may choose a route based on his/her origin and destination while another may decide according to the station design. When there are more than one choices, a passenger usually chooses the shortest or quickest route by comparing the total estimated travel time of the possible routes. For example, when a passenger decides between staircase and escalator, he/she will observe the conditions of the two alternatives so as to select the fastest and easiest route. At platform, passengers diffuse along the platform edge and wait at the nearest platform edge. If the nearest platform edge is congested, passengers will choose the next less congested platform edge.

Passenger Flow Model

Train station passenger flow model is used in station layout upgrade in existing systems and design for projected demand in new systems. Modelling ensures that the passenger demands are met and simulation can be performed to evaluate possible station designs, crowd control and management and station safety and risk management by changing certain parameters.

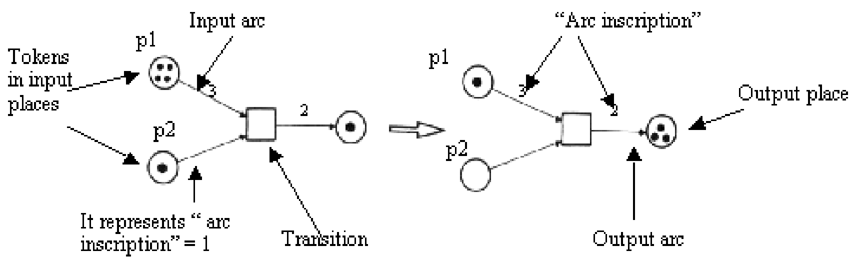

Fig 2 Firing of a Transition

Petri net (Brauer, 1985) is one of the useful concepts in modelling systems containing concurrent processes. It is suitable for procedures, organisations and devices where regulated flows, in particular information flow, take place. Petri net consists of places (P), transitions (T), tokens and arcs. There are input (from place to transition) and output arcs (from transition to place). A non-negative integer number (arc inscription) can be attached to the arc. A transition will be fired if each of its input places contains at least as many tokens as indicated by the “arc inscription” of the input arcs. Fig. 2 illustrates an example of Petri net. Three tokens are removed from the input place p1 and one token is removed form input place p2 based on the “arc inscription”. Two tokens are then added to the output places according to the “arc inscription” of the output arc.

Coloured Petri net (Jensen, 1992) (Takagi, 2002) is one of the advanced classes of Petri nets. The coloured net is defined by a finite set of colours and they are totally ordered. Every token is coloured. Transitions can be coloured and its enabling depends on the token colours. Every arc is labelled by the name of the functions. The functions on arcs define the marking variation associated to a given transition colour. The firing is processed if the required coloured tokens are available in every input place of transition. Tokens in the input places are then removed based on the functions labelled on the input arcs, and coloured tokens are added to the output place of the functions labelled on output arcs.

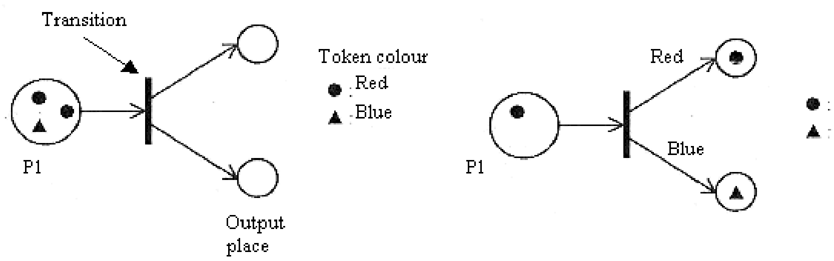

Fig. 3 CPN Firing of Transition

Fig. 3 shows a Coloured Petri Net based model. It consists of places, transitions and arcs, which are similar to Petri Net representation. However, the arc inscriptions will no longer be integer numbers but colour sets instead. Representation of Coloured Petri Net (CPN) enables system properties verifications in developing a passenger flow model. Within a station, facilities along a walking route can be considered as a network of places and transitions. The passengers are represented as “colour” tokens, which move around in the network. Each token carries complex information or data, such as the origin and destination of the passenger, the number of passengers it represents and the necessary time stamp. Fig. 4 shows an example of station layout using CPN representation. The station consists of an entrance, an exit, a concourse and platforms.

Transition firing and movement of tokens will be based on the inscription of arcs described earlier.

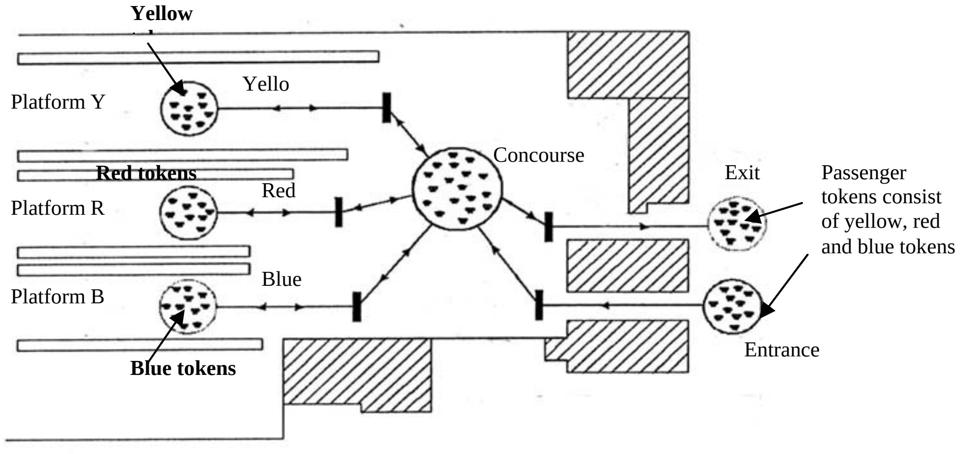

Fig. 4 CPN Passenger flow model

Examples

This section demonstrates certain functions of the model with a real metro station. Wan Chai station is along the double-tracked Island Line of the Hong Kong MTRCL line, it is at one of the busiest areas on the Hong Kong Island. The station consists of four layers (Street → Concourse → Chai Wan Platform (up-road) → Sheung Wan Platform (down-road)) with eight entrances. The platforms are served by trains with 8-cars. Fig. 5 illustrates the layout on the lowest level as an example.

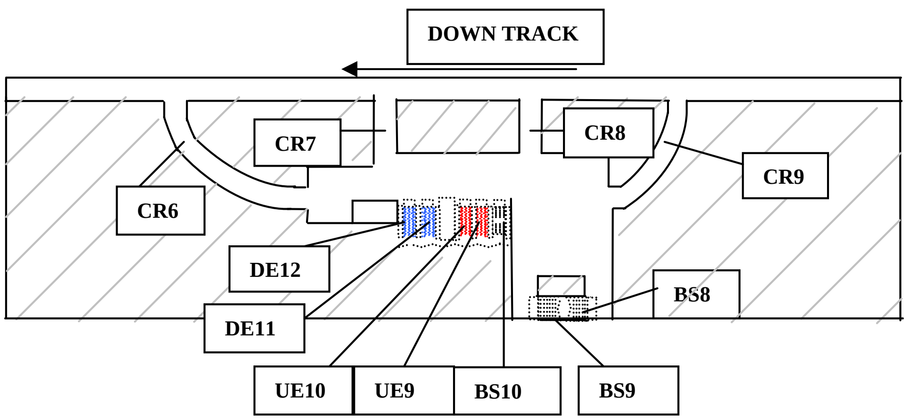

Fig. 5 Station layout on the down-track level

Simulations have been conducted on the Wan Chai station layout with the Petri-net model under different passenger arrival rate. The results are given in Table 2 in terms of average incoming/outgoing cycle time and average waiting time of all arrival passengers for a period of 2 hours.

Test	**Arrival Volume (Passengers/hr)**	**Average Time (Minutes)**			
		Incoming		**Outgoing**	
		Cycle Time	**Waiting Time**	**Cycle Time**	**Waiting Time**
1	10000 - 12000	5.2	1	5	0.57
2	12000 - 14000	5.3	1.1	5	0.58
3	14000 - 16000	6.4	2.1	5	0.57

Table 2 Simulation results from the unmodified layout

The result shows that incoming passengers suffer from more waiting time when the arrival volume is higher than 14,000 passengers/hour. It has been observed that it is due to a "bottleneck" in front of the escalator banks at the concourse. To tackle the problem, two measures have been taken, i) changing the moving direction of one of the escalators from up to down and ii) blocking the barrier at the staircases nearby. The congestion is then significantly relieved as shown in the Table 3.

Measures	**Incoming**		**Outgoing**	
	Average Time (minutes)			
	Cycle	**Waiting**	**Cycle**	**Waiting**
Original	6.4	2.1	5	0.57
(1)	5.3	1	5.2	0.7
(2)	5.5	1.2	5	0.56

Table 3 Simulation results from the modified layout

(Arrival volume: 14,000-16,000 passengers/hr)

Conclusions

A generic passenger flow model for metro system has been developed by the concept of Petri net. It is a useful computer-aided design tool for design and upgrade of a station layout from the viewpoint of maximising the capacity and reducing safety hazards in cases of incidents. Facilities within a station are considered as a network of places and transitions. The passengers are represented as tokens moving around in the network. An example has been given to illustrate the applicability of the model in real metro stations. The simulation results, in term of passenger waiting time, are helpful to fine-tune the layouts in response to the traffic demand.

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