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DEPLOYING AN MANUFACTURING TECHNIQUE IN URBAN BUSES FLEET OPERATIONS

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Abstract

For manufacturing industries, a mixed-model production line means the single line is capable of making diverse goods for a given interval. However, the mixed-model production concept could also be helpful to solve the gap between service supply and passengers demand of urban bus operations. Therefore, an approach with analytic mathematics model named "mixed-size fleet operations" for bus service with regular and mini buses is developed in this study. An innovative indicator for measuring the satisfaction of demand named 'service effectiveness' is also proposed. Moreover, a typical exclusive bus lane in Taipei city is taken for numerical demonstration under several operating scenarios. The results show that under the mixed-size operations approach, the service gap could be easily reduced without any increase in cost of service staff and facilities.

Keywords: Just-in-time, mixed-size fleet, effectiveness, mixed-model production

INTRODUCTION

For the urban bus passengers, high availability and frequency of buses are the main concern of service quality (Danaher, 2003); however, this concern is also the operator's dilemma to meet the passengers demand under appropriate fleet operating costs. Considering these issues, this study tries to deploy the famous mixed-model production concept in manufacturing industries on bus fleet operations. With the mixed-model production concept, urban bus services can be expected to well satisfy passengers demand without costing more for operators. In fact, the use of mixed-size fleet with mini buses is more and more important. A survey shows that on the average form 94 transit systems of 'American public transportation association' and 'Canadian urban transit association,' small buses make up approximately 18 percent of each operator's fleet (Hemily & King, 2002).

The mixed-model production concept is a key element of just-in-time (JIT) production methods. The single production line that is capable of making several different goods for a given period of time is called a mixed-model production line (Daniel et al., 2009; Prombanpong et al. 2010). It is often applied by companies to maintain diversified small-lot production to satisfy customers demand for a variety of products, without holding large inventories, and with less waste. The mixed-model production line uses various production planning techniques to achieve the goals conforming to customers' demand. These production planning techniques use different mathematical equations and formulas and even some complex algorithms to deliver the optimal solutions (Bukchin et al., 2002; Chuah & Yingling, 2005; Dhamala & Kubiak, 2005). Moreover, computer simulation is also becomes popular to perform the mixed-model production (Kuo et al., 1999; Watson & Wood, 1995). The evolution of production planning techniques emerges as optimization, heuristic, complexity and interactive scheduling periods, shows that Table 1. Because of the advantage of flexibility, interactive analytical technique plays important roles in these mixed-model production lines planning.

Table 1. Development of scheduling techniques.

Era	**Approach**	**Technique**
Optimization	Automatic	Optimization or heuristic
Heuristic	Automatic	Heuristic
Complexity: artificial intelligence	Automatic	Heuristic
Interactive schedulers	Interactive	Heuristic + operator

Source: Caridi and Sianesi, 2000.

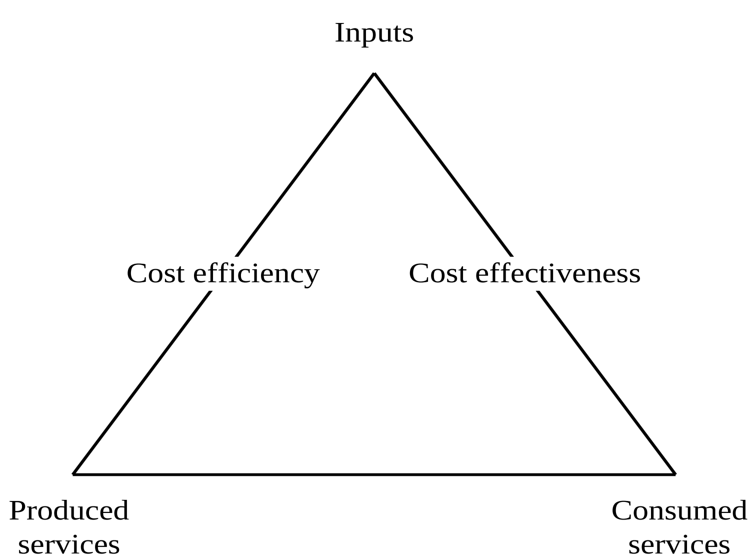
For the urban bus services, the mixed-model production concept may also be helpful to meet variable and unpredictable passengers demand. As for the wide applied optimization planning techniques, Lee et al. (1995) developed a model for optimizing vehicle sizes on multiple route operations of bus services. The optimized variables of vehicle sizes, optimal headway, and operating fleet size could be decided sequentially. Kim and Schonfeld (2012) then integrated into a new model for optimizing 'variable-type bus service (i.e., without fixed routes and schedules)' into the optimization models used for purely conventional or flexible service. Moreover, Kim and Schonfeld (2013) also tried to combine analytic optimization with a genetic algorithm (GA) for solving mix fleet bus services. In this study, the numerical analysis shows how the proposed 'mixed fleet variable type bus operation' can reduce total cost compared with alternative operations such as 'single fleet conventional bus,' 'single fleet flexible bus,' 'mixed fleet conventional bus' and 'mixed fleet flexible bus.'

However, these studies still have their limit for real world operations practice since the one-time determination characteristic of optimization planning techniques. Moreover, other study has tried to use fuzzy clustering techniques in response to variances in passengers demand attributes and traffic conditions (Sheu, 2005); however, it needs many on-roads and on-bus facilities to collect the real-time data, and might be difficult and expensive in practical operations.

With regard to the mixed-fleet transportation services, Fu and Ishkhanov (2004) fund that most para-transit agencies use a mix of different types of vehicles ranging from small sedans to large converted vans as a cost-effective way to meet the diverse travel needs and seating requirements of their clients. They developed a heuristic procedure that can be used to determine the optimal fleet mix for a given application; however, their model is only developed for low demand para-transit services, not the regular bus services. Furthermore, for the regular bus services in busy cities, Hsu (2006) developed a simple procedure to analyze the benefits of displacing some regular size buses with mini buses on existing bus lanes. However, simply the conceptual procedures are developed in this study.

Considering the productivity analysis for bus fleet operations, Hensher and Daniels (1995) investigated the relative performance of urban bus operators in Australia. An index of gross total factor productivity for each operator is developed and decomposed to identify the sources of variation across operators, such as the role of different institutional and regulatory constraints on relative performance. Their study proposed clear definitions on the cost efficiency and cost effectiveness of private and public urban bus operators in Australia. They defined the performance measurement dimensions for bus operations in efficiency and effectiveness aspects, shows that Figure 1.

Figure 1. Service performance measurement.



Source: Hensher and Daniels, 1995.

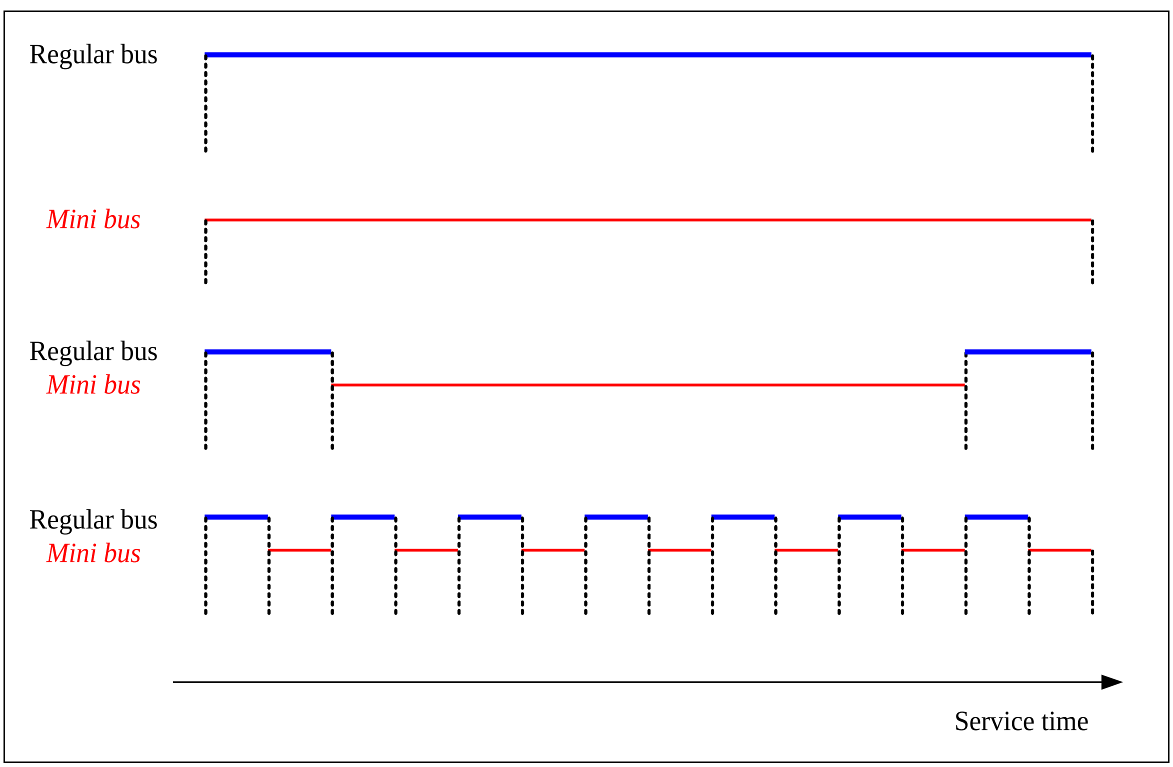
For another study made by De Borger and Kerstens (2008), Hensher and Daniels (1995) summarized some important results of the recent economic literature on the performance of bus transit operators, with the main emphasis on the determinants of productivity growth and efficiency in the industry. They found strong evidence that recent productivity growth is either negative or at best mildly positive.

With the reviewing for literature above, this study aims to develop an analytic mathematics model for the mixed-size fleet bus operations. Moreover, this study tries to propose an innovative indicator for service effectiveness for the bus fleet services. Thereafter, the numerical scenarios for urban bus services in Taipei city are analyzed.

METHODOLOGY

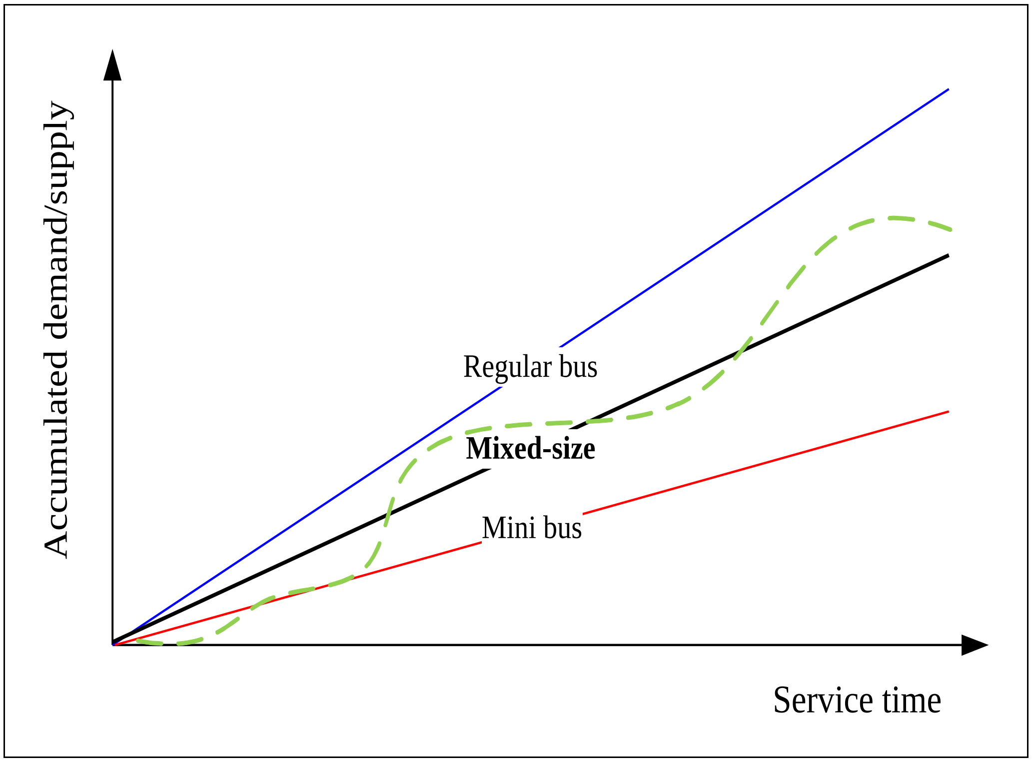
The mixed-size approach is expected to provide more flexible and suitable capacities for passengers demand in urban bus operations. Moreover, in manufacturing industries, if the mixed-model scheduling makes little variability gap between demand and supply, it is said to level or balance the schedule, also named the ‘leveled mixed-model production’ (Dhamala et al., 2012). Therefore, the theoretical concepts of mixed-size bus operations proposed in this study can be shown as Figure 2. In this figure, the first two service patterns present the simple scheduling with only regular buses or mini buses, the third service pattern shows an un-leveled mixed-size operation, and the fourth service pattern stands for a leveled mixed-size operation.

Figure 2. Diverse of simple and mixed-size operations



Moreover, Figure 3 shows the benefits of mixed-size operations, where the broken line represents the accumulated passengers demand. It shows that, for the current, bus size is always fixed (i.e., only regular or mini buses) in the same service line and this causes exceeding or insufficient supply capacities. However, supply capacities could be more flexibly and accurately responded to the passengers demand by mixing regular bus and mini bus services on the same line.

Figure 3. Accumulated demand and supply



Furthermore, to apply the mixed-size operations concept on urban bus services, an analytic mathematics model is developed in this study. In addition, not only measures the conventional supply side index (i.e., productivity or efficiency) as in literature (Fu, 2003; Odeck, 2008), this paper also formulates an innovative indicator of 'service effectiveness' for measuring the gap of delivered capacity and passengers demand. Definition of variables and parameters accompanied by some baseline values of the RenAi road exclusive bus lane in Taipei city are listed in Table 2. Note that variables or parameters that are left blank on the baseline value columns mean that they are dependent variables or there exists no single specific value for them.

Table 2. Definition of variables and parameters

Notation	Statement	Baseline Value
c_m	Capacity of a mini bus (passengers, including seated and standees)	27
c_r	Capacity of a regular size bus (passengers, including seated and standees)	58
$\overline{d}$	Original average hourly passenger number	3,602
d_b	Adjusted base value of average hourly passenger number	
d_i	Adjusted passenger number of i^{th} service hour	
e	Service effectiveness indicator (%)	
f_i	Deviation factor for passenger number of i^{th} service hour	
h	Headway of bus services (minutes)	
n	Daily service time (hours)	19
s_i	Supply capacity of i^{th} service hour (passengers)	
t	Hourly service time of mini buses (minutes)	
v	Hourly frequency of bus services (vehicles)	91

MODELING AND EMPIRICAL ANALYSIS

Since the proposed mixed-size fleet operations are based on the current service circumstance, three assumptions must be made as follows:

A1. Service headway is the same for regular and mini buses,

A2. Total number of service vehicles (i.e., regular buses plus mini buses) is fixed,

A3. Total staff and related service facilities are fixed.

Thereafter, 'The RenAi Road Exclusive Bus Lane' in Taipei city is taken for modeling and scenario analysis. This bus lane, with 3.1 km long, serving 19 hours a day from 5-24 o'clock, was launched in July 1996. According to Taipei city Department of Transportation, in 2012, there were 634,197 frequencies of regular size buses served on it (i.e., 1,738 buses per day, or 'v' is 91 buses per service hour), and the average hourly demand '$\overline{d}$' mounted to some 3,602 passengers.

To simulate the real hourly demand with peak factors, the peak hour adjustment factors 'f_i' of hourly passengers number are assumed as [1, 1.2, 1.5, 1.8, 1.2, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.2, 1.5, 1.8, 1.5, 1.2, 1.1, 1.1, 1] for each of the daily 19 service hours. Accordingly, the adjusted base value of hourly passengers demand 'd_b' for each single service hour can be calculated from Equation 1. Moreover, adjusted hourly passengers demand for each single service hour is then calculated from Equation 2.

$$d_b = \frac{\bar{d} \cdot n}{\sum_{i=1}^{n} f_i} \qquad (1)$$

$$d_i = d_b \cdot f_i \qquad i = 1 \sim n \qquad (2)$$

In addition, suppose that 's_i' stands for the supply capacity of *i* th service hour. The indicator 'e' is developed to analyze the service effectiveness of bus operations, shows that Equation 3.

$$e = \left| 1 - \left| \frac{\sum_{i=1}^{n} s_i - \sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} s_i} \right| \right| \cdot 100 \qquad (3)$$

And to compare the difference of service effectiveness among the current service pattern and mixed-size services, three scenarios of 'Simple operations with regular buses - The current service pattern,' 'Simple operations with mini buses,' and 'Mixed-size fleet operations' are proposed for analysis. Note that the 'Mixed-size fleet operations' here stands for the 'leveled' mixed-size operations (i.e., the fourth scenario in Figure 2), since the 'un-leveled' mixed-size operations (i.e., the third scenario in Figure 2) will let the mini buses idle at non-peak service hours, and this condition may not practically accepted by bus operators.

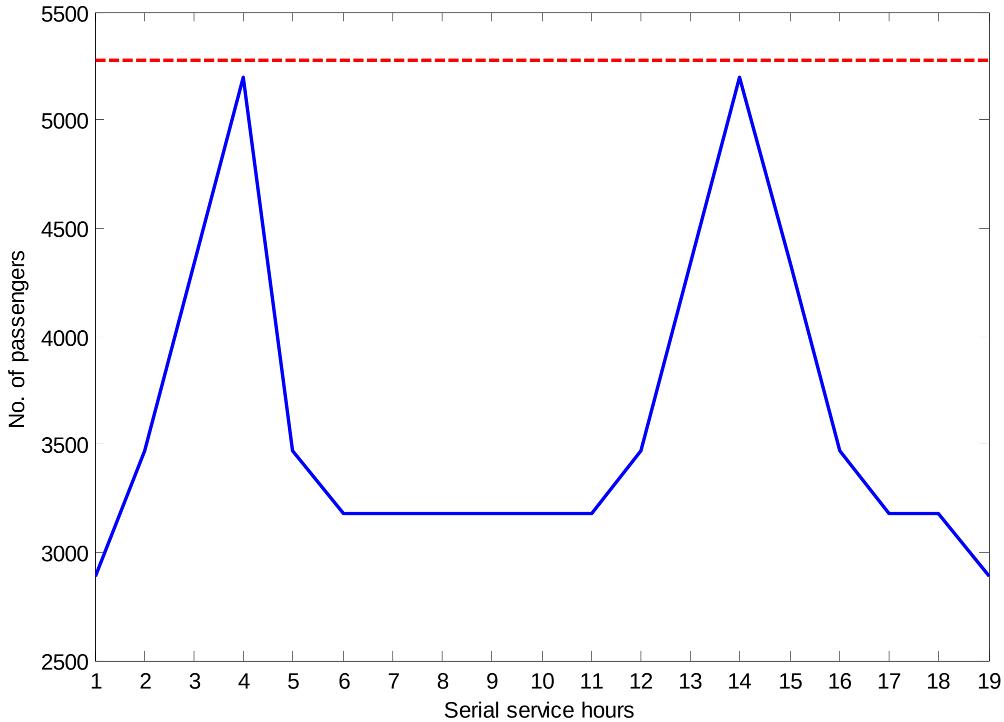
Simple Operations with Regular Buses

This is the current service pattern in RenAi road bus lane, Taipei city. In this scenario, hourly capacity supply is obtained by Equation 4.

$$s_i = v \cdot c_r \qquad i = 1 \sim n \qquad (4)$$

In accordance to the current service pattern, passenger demand and service supply are shown as Figure 4. The broken line stands for the supply capacity, and solid line stands for passengers demand. It is found that in most time, the supply capacity exceeds passengers demand, and cause the waste of supply capacity. Meanwhile, the service effectiveness is calculated as 68.3% in the current service pattern.

Figure 4. Demand vs. supply under current service pattern



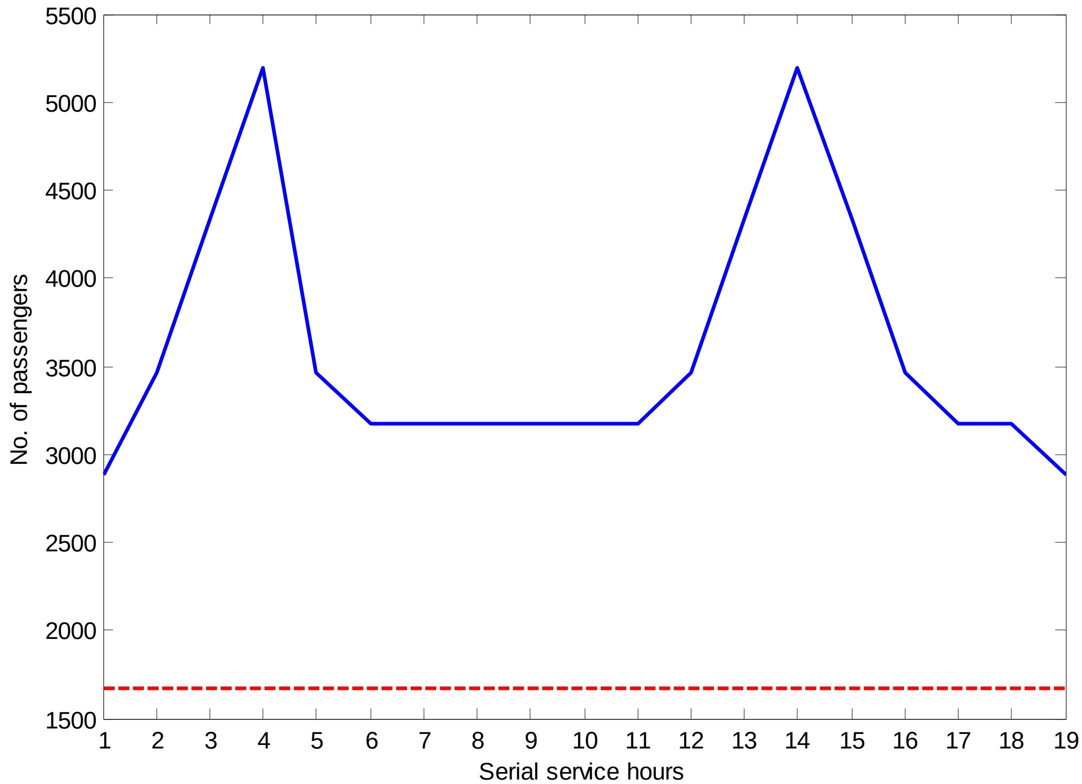
Simple Operations with Mini buses

In this contrasted scenario, the hourly passengers demand is similarly calculated from Equation 2, and the hourly supply capacity is obtained with Equation 5.

$$s_i = v \cdot c_m \qquad i = 1 \sim n \qquad (5)$$

With regard to the fully mini bus service pattern, passengers demand and service supply are shown as Figure 5. The broken line stands for the supply capacity, and solid line stands for passengers demand. It is found that, by the same fleet size and available drivers, the supply is always lower than passengers demand and leading the bad service for passengers. Meanwhile, the service effectiveness slumps to the poor 53.4% in this service pattern.

Figure 5. Demand vs. supply under fully mini bus service



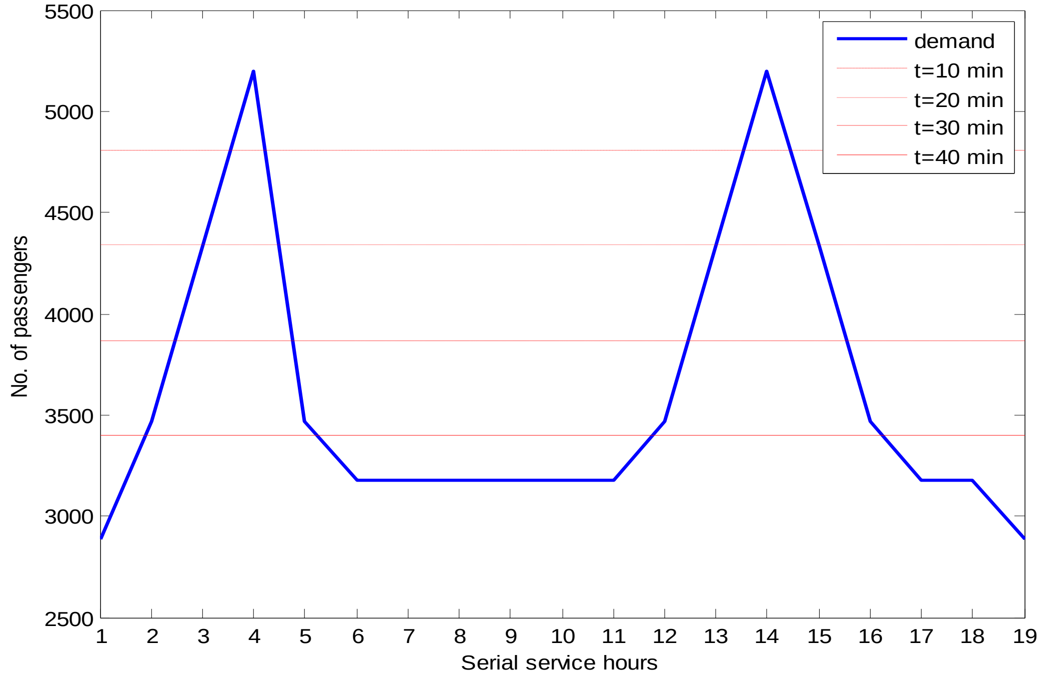
Mixed-Size Fleet Operations

Finally, in the mixed-size scenario, the hourly passengers demand is still calculated from Equation 2. However, the total hourly supply capacities of regular size buses and mini buses is calculated from Equation 6, where the hourly frequency of regular buses is '$(60-t)/h$,' and mini buses is 't/h.'

$$s_i = \frac{(60-t)\cdot c_r + t\cdot c_m}{h} \qquad i = 1 \sim n \qquad (6)$$

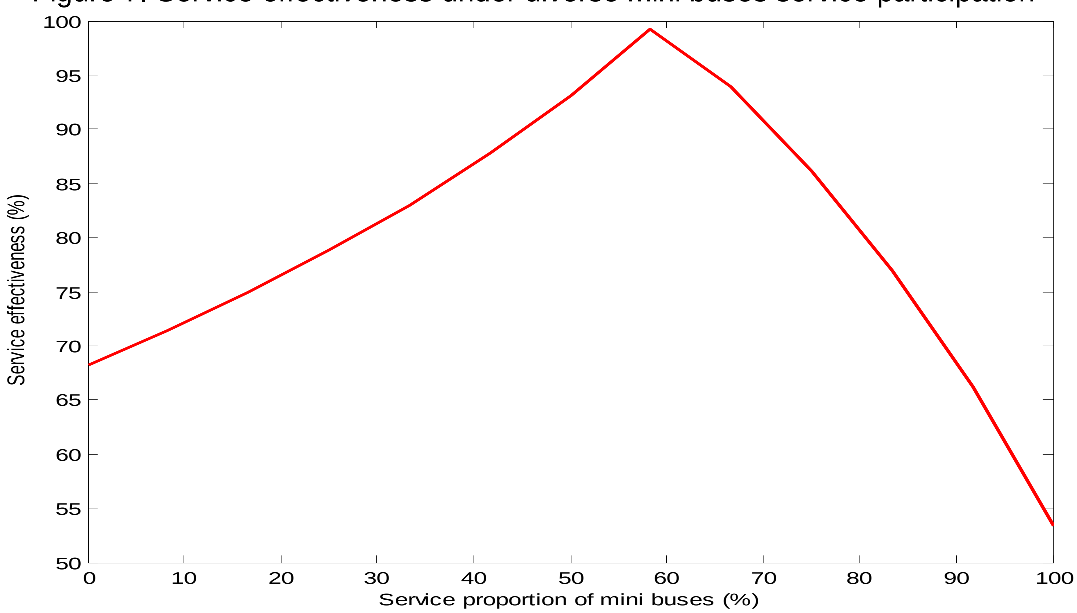
In the mixed-size service pattern with different mini buses service participation, passengers demand and service supply are shown as Figure 6.

Figure 6. Demand vs. supply under diverse mixed-size scenarios



Moreover, the service effectiveness of varied mini bus service participation is shown as Figure 7. It is found that, by the same fleet size and available drivers, the mixed-size service pattern keep the service effectiveness on mend if the participation of mini buses is lower than 35 minutes (i.e., a participation rate 58%, with the highest service effectiveness 99.2%), comparing with the service effectiveness 68.3% of the current regular buses along service pattern. In general, for the service effectiveness, the recommended participation rate of mini buses service goes 0%-91% gets the better service effectiveness than the current service condition.

Figure 7. Service effectiveness under diverse mini buses service participation



CONCLUSIONS

In this study, the manufacturing mixed-model production techniques are reviewed, and then inventively leveled mixed-size operations scenarios for urban bus services are developed. With the analyzed exclusive bus lane in Taipei city, it is found that for the urban bus services, the mixed-size operations concept could be helpful to solve the variable and unpredictable passengers demand.

According to the calculation of service effectiveness indicator, this study shows that for an appropriate participation rate of mini bus service, the mixed-size fleet operations strategy always performs better than the conventional single size fleet operations. Based on the numerical case of Taipei city, an improvement of service effectiveness from 68.3% to 99.2% is possible, if appropriate number of regular buses can be displaced by mini ones.

Moreover, to highlight the benefits of mixed-size fleet operations in this study, the available staff, vehicle numbers, regular buses and mini buses headway are held the same for both the single size and mixed-size fleet service scenarios. Under these assumptions, it is found that without any increase on human resources and operating costs, the mixed-size operating approach could effectively improve the current bus service.

The limitations of current study are mainly from the demand pattern, i.e., the demand is known every day; however, it may be dynamic. Therefore, a modified model with dynamic demand pattern is recommended in future research.

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