Hindawi
Journal of Advanced Transportation
Volume 2024, Article ID 7764326, 13 pages
https://doi.org/10.1155/2024/7764326

Research Article

Optimal Fleet Policy of Rental Vehicles with Relocation: A Simulation Study

John-Carlo Favier, Subhamoy Ganguly, and Timofey Shalpegin

Department of Information Systems and Operations Management, University of Auckland Business School, Auckland, New Zealand

Correspondence should be addressed to Subhamoy Ganguly; s.ganguly@auckland.ac.nz

Received 24 April 2023; Revised 3 November 2023; Accepted 12 December 2023; Published 23 January 2024

Academic Editor: Tomio Miwa

Popularity of one-way car rentals poses a challenge to rental car fleet management and brings to focus the importance of a strategic decision for rental car operators: whether to implement a single-fleet or a multifleet model. The single-fleet model allows movement of vehicles between regions, whereas the multifleet model does not. It is not obvious whether a single-fleet model is optimal due to its pooling effect, or a multifleet model due to shorter car relocation times. In practice, different rental car operators use different models. To answer this conundrum, we develop two simulation models and compare them in terms of fleet utilisation, branch service level, relocations, and operating profit. We have taken the New Zealand rental car industry as an example as the country consists of two well-defined regions: the North Island and the South Island. The results indicate that a multifleet model has a higher service level at key centres and higher utilisation. At the same time, the single-fleet model is relatively more profitable at the expense of a lower service level in key centres due to vehicles accumulating in the South Island due to a significant volume of one-way southbound travel. Overall, the implementation of either model should depend on the strategic goals of the rental car operator. Our work will be useful for practitioners considering whether or not to pool their fleet when allowing for one-way rentals with subsequent relocation.

1. Introduction

Rental cars are an important part of the travel industry. They allow for flexible travel plans and access to remote locations and are also economical compared to chauffeur-driven vehicles. Naturally, rental cars are popular among business and leisure travellers alike. Despite a temporary slowdown caused by COVID-19, the global car rental industry is expected to rebound and grow at an annual rate of 14%, reaching a projected global revenue of USD 205.68 billion by 2027 [1].

Rental car operators (RCOs) wishing to serve a wide geographical area generally set up bases in multiple locations where customers can pick up and drop off vehicles. Considering the uncertainty and seasonality of demand, network design and fleet management are important for RCOs with bases in multiple locations in a market. A fundamental challenge they must deal with is the trade-off between vehicle availability and fleet utilisation. The problem is further complicated by one-way rentals, where the drop-off location is different from the pick-up location. Such one-way rentals, often preferred by tourists, can alter the distribution of the fleet across locations, causing a shortage of vehicles at some locations and an accumulation of vehicles at others.

Under such circumstances, when the distribution of the fleet is significantly altered, the RCO must relocate vehicles across their network to restore the distribution to a desired state, often at a substantial cost. In addition to logistical costs, the process of relocation adversely impacts vehicle availability, as vehicles being relocated are temporarily unavailable for rent. To defray these costs, it is common for RCOs to charge an additional fee for one-way rentals.

It is easy to see that if one-way rentals comprise a small fraction of the business and there is no dominant direction for one-way rentals, the need for relocation will be low. In such a scenario, an RCO can effectively pool the entire fleet across its network, allowing for one-way rentals between any pair of locations. For example, large RCOs with a nationwide presence in the United States will allow a customer to rent a vehicle in Boston and drop it off five thousand kilometres away in San Francisco.

The impact of emerging apps on the hospitality and tourism industry is well documented [2]. Apps such as Transfercar and iMoova, which allow vehicles to be relocated at a low cost by matching vehicles with drivers who wish to travel in the same direction as the relocation, have made one-way rentals more affordable for RCOs. However, this does not eliminate the problem outlined below—rather, increasing the popularity of one-way rentals in turn can exacerbate the logistical problem of relocation. When one-way rentals represent a significant fraction of the business and demand in one direction far exceeds the demand in the opposite direction, then the cost of relocation becomes substantial for the RCOs. Such is the case in New Zealand, an island nation with two major islands, unambiguously named the North Island and the South Island.

International tourism is a major industry in New Zealand, accounting for 8% of GDP [3]. A large number of visitors arrive in Auckland [4], the country's largest city with its busiest international airport and located in the northern part of the North Island. A large fraction of these visitors rent vehicles to drive around the country and then drop off at another location. Therefore, when it comes to one-way rentals in New Zealand, Auckland is the foremost source, posing significant relocation challenges to the RCOs. The problem is further exacerbated by the fact that many of these tourists who set off from Auckland in the North Island finish their trip somewhere in the South Island [5].

Motorists travelling from one island to another need to cross Cook Strait between Wellington (North Island) and Picton (South Island) (Figure 1). Interislander™ ferries regularly ply the crossing between Wellington and Picton, and passengers are allowed to bring their motor vehicles onboard as well [6]. This option provides tourists with the ability to continue exploring the other island without having to change vehicles. Not surprisingly, this can also encourage one-way rentals that originate in the North Island (mostly in Auckland) and end in the South Island, creating a need for interisland vehicle relocation, as evidenced below.

Transfercar is a popular online platform for matching willing drivers with vehicles owned by RCOs that need to be relocated [7]. Using data obtained from Transfercar, we see that Auckland is the destination for about 52% of the relocations listed across New Zealand, and 74% of relocations headed to Auckland originate from somewhere in the South Island. As the largest New Zealand city and location of the country's busiest international airport, Auckland is indeed the most popular origin of one-way rentals, and hence, there is a need to relocate a large number of rental vehicles dropped off elsewhere back to Auckland. Moreover, a significant number of the one-way rentals that originate in Auckland end in the South Island, which explains the large fraction of Auckland-bound relocations coming from the South Island.

Figure 1: Map of New Zealand with key RCO locations.

This creates a dilemma for the RCOs operating in New Zealand—whether or not to allow the multi-island rentals that allow customers to pick up in one island and drop off in another. On the one hand, it is understandable that international tourists value multi-island rentals, and following basic principles of fleet utilisation, multi-island rentals allow an RCO to pool their fleet across both islands and employ a single-fleet model (SFM), possibly improving vehicle availability. On the other hand, multi-island rentals create the need for a significant number of interisland vehicle relocations, which can increase logistics costs of the RCO and reduce vehicle availability due to the long duration of relocation. It is interesting to note that among RCOs operating in New Zealand, some allow multi-island rentals, while others do not, as shown in Figure 2.

For RCOs that do not offer multi-island rentals and operate a double-fleet model (DFM), a tourist willing to start their trip in Auckland and finish somewhere in the South Island has to make two rental bookings. They will pick up the first car in Auckland and drop it off in Wellington (at the southern end of the North Island) before boarding the Interislander™ ferry. After crossing Cook Strait, the tourist will then pick up the second car from Picton (at the northern tip of the South Island) to continue their journey. Consequently, such bookings could create the need for two relocations: one from Wellington to Auckland and the other from the final destination in the South Island to Picton.

While the relative advantages of allowing (or not allowing) multi-island rentals are obvious (pooling of fleet versus relocation costs), it is not clear why some RCOs allow multi-island rentals and others do not, as shown in Figure 2. In this paper, our goal is to uncover why multi-island rentals seem appealing to some RCOs but not to others, i.e., what

Figure 2: NZ-based operators with and without multi-island policies.

are the strategic advantages of allowing (or not allowing) multi-island rentals. To that end, we use a simulation model to compare the effects on key operational parameters of allowing (versus not allowing) multi-island rentals. Our results show why allowing multi-island rentals might work better for locally owned budget RCOs targeting leisure travellers, while international brand RCOs tend to avoid multi-island rentals.

Our paper makes the following contributions: Using a simulation, we demonstrate the impact of allowing (or not allowing) multi-island rentals on key operational parameters such as vehicle utilisation, service levels, and relocations. Building on the work of Lohmann and Zahra [5], we explore the conditions of operational viability and profitability while allowing (or not allowing) multi-island rentals. Insights from our work may be useful in similar situations where a market is subdivided geographically, and relocation across geographies can be expensive because of topographical (e.g., ocean crossing) or political reasons (e.g., international borders). We believe our work will be useful for practitioners considering whether or not to pool their fleet across geographies where there are significant costs of border crossing.

The rest of our paper is organised as follows: First, we present a survey of the current literature and formalise the research questions. We then introduce the simulation model and the choice of parameters. Thereafter, we present the results and sensitivity analyses, followed by a discussion of the results in relation to the research question and limitations of the findings. Finally, we summarise the contributions of this study and identify potential future work.

2. Literature Review

Management and utilisation of assets are vital for transportation companies such as vehicle rentals, vehicle sharing, airlines, rail, and trucking. Fleet management (FM) refers to the practice of determining the optimal fleet size and composition available to rent or operate at any given location and time. Extant literature on FM addresses considerations such as network structure, fleet procurement, routing, and empty transfers [8–11].

Within the context of rental vehicles, Pachon et al. [9, 12] identify three broad yet sequential FM problems with respect to their planning horizons: (1) the strategic decision on rental network design, (2) the fleet composition and medium-term fleet deployment, and (3) operational decisions on short-term fleet deployment, fleet assignment, and vehicle relocations.

The overall design of a rental vehicle network involves a pivotal strategic decision on how to determine the optimal fleet size for any given RCO [12–14]. These decisions are long term and generally shape the strategic goals of an operator and ultimately the possible routes vehicles can travel [12, 13]. Oliveira et al. [13] note that the following two broad methods are used for determining the rental vehicle network decision—one by segmenting rental car branches (which we refer to as nodes) into pools and the other by treating all nodes as part of one inseparable pool.

Pachon et al. [12] and Yang et al. [15] suggest that nodes should be segmented or clustered into several smaller pools, and then, fleet composition is determined separately for each individual pool. Although there is no precise method used within the industry to segment locations into pools, geographic proximity and demand variability have been identified as essential factors to take into consideration [12, 14, 16]. Pachon et al. [12] suggest that the segmentation of pools is static, whereas Yang et al. [15] argue it should be dynamic. Irrespective of the approach taken, each pool operates a fleet that is shared among the intrapool nodes, without allowing for any interpool vehicle movements. It is claimed that efficiencies are gained due to the minimisation of time required to relocate vehicles between intrapool nodes, resulting in an increase in overall utilisation.

In contrast, the majority of the relevant rental vehicle literature, as identified by Oliveira et al. [13], suggests that the typical approach to rental vehicle network design is to treat all nodes in a market as one inseparable pool, resulting in a top-down approach to determining fleet composition. In terms of the interaction between nodes, it is common to divide nodes into administrative divisions, which then call upon one another to fulfil shortages in inventory, thus maximising the possible inventory each node can access [13]. Our work examines a special case where a market is spread across the two islands, with some RCOs considering the two islands as one unified pool and others treating them as two separate pools. We will refer to the unified fleet as the single-fleet model and the separate fleet as the multifleet model. While the multifleet model may imply multiple operators in the carsharing literature [17, 18], separate fleets are operated by the same RCO in our study.

Overall fleet composition is generally a tactical-level decision for a medium-term planning horizon. This decision primarily consists of determining the optimal fleet composition and where to deploy vehicles. Historically, these were longer-term decisions as operators purchased their own fleet; however, the flexibility and popularity of leasing vehicles have shortened the overall planning horizon to between three and eighteen months [13, 19].

Determining the optimal fleet composition for a given planning horizon is generally based on a combination of parameters for historical performance and predicted demand [13, 15]. Such parameters include historical sales data, the number of reservations turned down, estimated utilisation based on current and forecasted fleet size, operational expenses, and expected revenue per car [15, 19–22]. While performance-based measures are primarily taken into consideration, the lifecycle of the vehicle is also considered, particularly in firms with a higher proportion of leased fleet. The vehicle life cycle can be defined as the operational life of a vehicle from on-fleeting to off-fleeting [19]. On-fleeting is the process of onboarding a vehicle into the rental fleet, whereas off-fleeting is the removal of a vehicle from the rental fleet.

The final phase of the FM hierarchy is the operational-level strategy implemented at an intrapool or locational level [9]. Operational-level strategies in the context of the rental vehicle industry are formulated to address imbalances of fleet capacity across multiple nodes due to varying demand for one-way routes. While not allowing customers to take one-way reservations may eliminate the need for relocations, it restricts the total demand and revenue potential for operators [5]. Furthermore, as demand for rental vehicles is seasonal in both time and space, ensuring vehicles are relocated efficiently will improve revenue and utilisation [10, 19, 23].

Balancing a fleet involves two interdependent decisions—the number of vehicles to be deployed at each location and how many vehicles to move from one location to another in order to maximise capacity utilisation and thereby increase revenue. One of the earliest studies involving short-term planning for rental vehicles is by Edelstein and Melnyk [16]. Developed for Hertz, the proposed system consisted of a simple linear equation to assist managers in deciding relocations between stations.

Taking a different approach, Pachon et al. [9] develop a stochastic optimisation model to address the relocation problem within a pool. They determine the optimal fleet distribution strategy of the shared fleet available within each intrapool location to maximise revenue. Furthermore, daily demand at each location is used to determine how many vehicles to relocate overnight in anticipation of the next day's demand.

Haensel et al. [24] use simulation analysis to determine optimal locational capacity and booking control policies under stochastic demand. Conducted as a two-stage mixed-integer programme, the optimal booking control policy is considered before determining the optimal transfer policy under stochastic demand. As with Pachon et al. [9], the objective of the study is to maximise revenue and vehicle utilisation. Haensel et al. [24] define vehicle utilisation as the ratio between sold capacity and total available capacity.

Another example from short-term planning research is an analysis of relocations within the carsharing sector conducted by Ket et al. [10]. Building upon Barth and Todd [25], they investigate the use of two relocation mechanisms during periods of high demand: shortest time and inventory balancing. Roy et al. [26] analyze the impacts of various relocation strategies on customer wait time in a small metropolitan rental company. They develop a semiclosed queuing network that evaluates the effectiveness of three different relocation strategies: no relocations, customer relocations, and vehicle relocations. In a departure from the standard practice of assuming deterministic travel times between locations, Schmidt et al. [27] consider a time-dependent fleet size and multidepot vehicle routing problem for logistics distribution in an urban area, where traffic congestion varies by the time of day.

One final aspect of the short-term fleet logistics problem is determining the best method for allocating a particular fleet category to a reservation to satisfy both current and future reservations while minimising the number of empty transfers or relocations [13, 19, 24, 28–30].

The literature on one-way rentals has been growing fast in the recent years, e.g., Mounce and Nelson [31] or Ye et al. [32]. However, that research is applied on the local level to improve urban mobility in the context of carsharing. In contrast, our model incorporates both one-way and base-to-base rentals on a nationwide scale.

Within the New Zealand context, articles by Ernst et al. [28], Pearce and Sahli [33], and Lohmann and Zahra [5] provide insight into general rental vehicle operations and FM strategies. At the same time, they do not address the fleet pooling decision directly.

Overall, our survey of the current literature reveals two gaps: the impact of geography on rental vehicle FM strategies and the decision on whether to operate a single-pooled fleet for all of New Zealand or to use separate fleets for the two islands.

To our knowledge, the only studies that consider geography as a factor in FM are by Pachon et al. [12] and Yang et al. [14]. In both studies, the distance between nodes is considered when segmenting nodes into various pools. However, they do not incorporate one-way rentals and subsequent relocations in their models. The other studies surveyed do not take geographical factors into consideration. One commonality in the literature surveyed is that apart from the New Zealand studies, all the research is conducted within contiguous landmasses.

Within the context of NZ, geography plays a crucial factor in deciding FM models as the result of RCOs spanning the North and South Islands. It is not clear, however, whether the decision to operate a model based on a single-pooled fleet or separate fleets is the consequence of some operators segmenting nodes in a similar method to Pachon et al. [12] and Yang et al. [14], or simply due to geography. A further implication of operating across two islands is the additional cost of transporting vehicles across Cook Strait on ferries, as well as the complexities of coordinating transport on both ends of the journey.

Beyond geography, there is a gap in the literature as well as practice with regard to how to determine whether to operate separate fleets or a pooled fleet. The RCO decision to operate separate fleets in the NZ context is identified by Lohmann and Zahra [5] as a way of preventing vehicles from accumulating in the South Island. As a result of the qualitative nature of their study, any performance gains of separate fleets as compared to a pooled fleet have not been quantified. Nor does their research indicate the conditions under which an operator should consider the respective models. Using a simulation model, our current work investigates the conditions of viability and profitability of operating while allowing (or not allowing) multi-island rentals, which we refer to as a single-fleet model (SFM) and dual-fleet model (DFM), respectively.

3. Model

The purpose of this study will compare both DFM and SFM to develop insights regarding their operational performance. This will be conducted through a discrete-event simulation as performed by several studies identified in the survey of the current literature. The problem of fleet management with relocation is inherently complex, involving multiple variables and factors that interact in dynamic ways. Discrete-event simulation is well suited to handle such complexity and capture the intricate relationships between various components of the system. Furthermore, discrete-event simulation provides a high level of flexibility, which allows us to model the system without overly restrictive assumptions, thus overcoming an important drawback of optimisation approaches [17]. This adaptability ensures that the simulation reflects the intricacies of the rental car industry accurately.

The simulation models for both SFM and DFM include key components of customer demand and vehicle supply. Customer demand is modelled as an open network; i.e., demand enters the network and, whether fulfilled or not, eventually leaves the network. In contrast, vehicle supply is modelled as a closed network; i.e., vehicles never leave the network, and they can be paired with demand to form a reservation entity and move from node to node within the network. Figure 3 highlights the differences between the single- and double-fleet models and their components. Following Guillen et al. [34], we use SIMIO as the simulation software for our models.

In Figure 3, the directed solid lines illustrate all possible relocation routes for each model. Instances in which the origin and destination nodes coincide represent cases where the customer returns the car to the original location, thus requiring no relocation. In the model, it was captured by having a relocation at zero cost and requiring zero time. Note that in the double-fleet model, no cars can travel between nodes 1–3 located on the North Island to nodes 4–6 located on the South Island, which is captured by the absence of directed solid lines on the DFM representation.

3.1. Demand.

3.1. Demand. Demand entities enter the model following a predetermined Poisson arrival rate λ. While average arrival rates differ between peak and nonpeak seasons, for purposes of this study, we have kept λ constant as we simulate 120 days corresponding to NZ summer with relatively stable demand. While the demand rate may be different between weekdays and weekends, keeping the rate constant helps us focus on our study's objective, which is to understand the difference between the operational performances of SFM and DFM.

As illustrated in Figure 4, once the demand entity enters the system (represented by the black circle in Figure 4), it is allocated to the node i with a probability μ_i. Next, it is checked (as represented by the small grey circle) that the vehicle is available, i.e., $V_i > 0$. If no vehicle is available, the demand request is rejected (represented by the white circle). If a vehicle is available, the demand request is accepted and converted into a reservation entity. Accepted and unfulfilled demand is tracked in order to determine the service level (SL) at both node and system levels.

Following a first-in-first-out protocol, a reservation entity is batched to a vehicle entity which then travels to another node along one of the possible routes of the original node. The routes are denoted as N_{ij}, where i is the origin node and j is the destination node. Note that probabilities of a demand entity being assigned to an origin-destination route have been obtained from historical demand data, which we do not report for the sake of brevity. Once the batched entity reaches its destination j, the vehicle entity and reservation entity are separated, at which point the reservation entity is terminated in most instances. The only exception is for reservations in the DFM system that reach either Wellington or Picton—these reservations have a probability of being transferred to the corresponding node across Cook Strait to continue travel in the network.

To simplify the network, the simulation considers a total of six nodes—three in each of the two major islands. The cities included are as follows: Auckland and Wellington, the two busiest nodes in the North Island, and Christchurch and Queenstown, the two busiest in the South Island. While it is common for all four nodes to have both an airport location and a city location, they have been modelled as one large node as the airport and city locations commonly share a fleet. Rotorua has been selected as the third North Island node as it is known to be popular among tourists [5]. Picton has been selected in the South Island due to its strategic importance for rental companies with a double-fleet system. It is assumed that each node costs an average of $500K per annum to operate.

Each pair of nodes is connected by a time path. Considering all possible pick-up-drop-off location pairs (including returning to the same location), the SFM includes a total of 36 possible routes. In contrast, the DFM includes 48

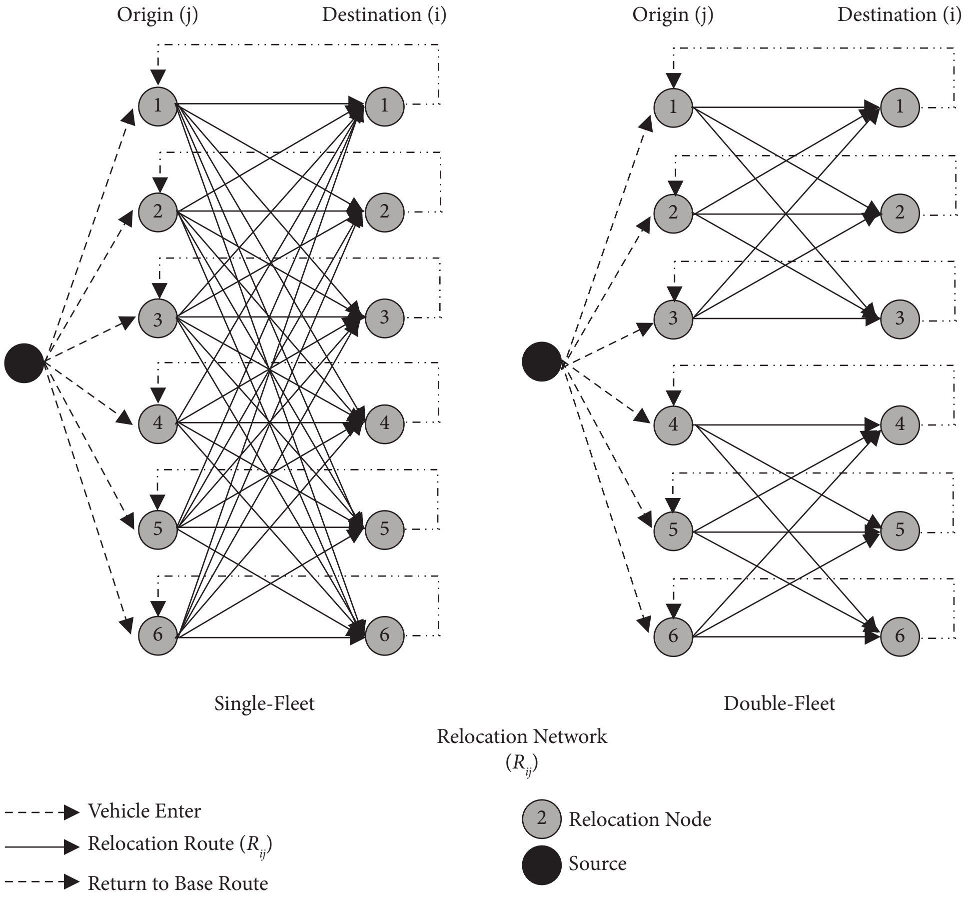


FIGURE 3: Relocation network for the single-fleet and double-fleet models.

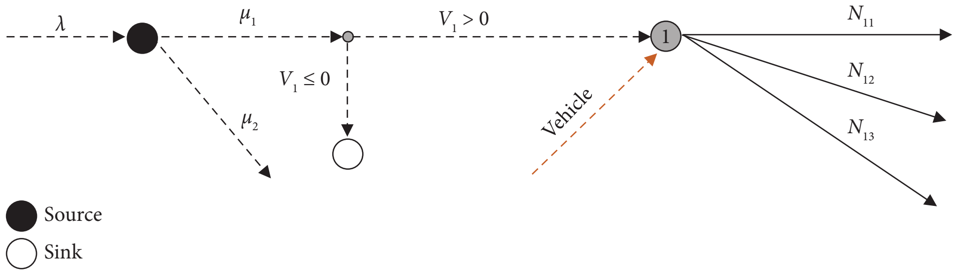


FIGURE 4: Reservation acceptance and vehicle assignment module.

routes for the following reason. As mentioned previously, the DFM requires interisland reservation entities to drop off their vehicle at either Picton or Wellington and pick up a new vehicle at the other node across Cook Strait. To incorporate this into the model, we create two additional virtual nodes, Wellington Ferry Terminal and Picton Ferry Terminal, resulting in a higher number of routes compared to the SFM. The route selection weight from the additional nodes has been recalculated to ensure the same probabilities apply as per the SFM route selection weights and make the demand pattern equivalent for both models.

Each path, or route N_{ij}, is characterised by a selection weight and a travel time. Selection weight is the probability that a vehicle leaving a node travels to another node or returns to the base. Travel time is the assigned number of days to complete travel from node A to B and is triangularly distributed, which allows for vehicles travelling along the same path to take different travel times. In line with George and Xia [35], it is assumed that each time path has unlimited capacity and entities can pass one another.

An important parameter is the total rate per day (TRPD—the sum of rental and insurance revenue, which represents the total estimated revenue per vehicle per day). This metric is routinely used in the rental vehicle industry. For purposes of comparison in this study, we assume a base TRPD of $150 per day. This is based on a five-day rate from a first-tier operator for travel between 30 December 2019 and 3 January 2020 for a compact vehicle.

3.2. Supply—Initial Deployment, Customer Drop-Off, and Relocation. The total fleet size is set at the start of the simulation and distributed in proportion to historical demand across the six nodes. These values represent the ideal opening inventory at each node, assuming that the simulation starts with no reservations. We refer to the fleet distribution of the vehicles at the start of the simulation as the initial fleet deployment. Since we are not investigating problems involving multiple vehicle categories and upgrades, for simplicity, we assume a homogenous fleet. This assumption has been used in multiple studies surveyed in the literature review [10, 24, 25]. It is further assumed that all vehicles are leased at the cost of \$400 per month and have a daily running cost of \$30, which accounts for the depreciation of tyres, oil, brake pads, and other associated costs.

As with Edelstein and Melnyk [16] and Kek et al. [10], the model utilises the concept of virtual vehicles or net availability at node i, V_i, to dictate both the demand and relocation modules. This allows the net availability of vehicles at each node to be identified for the current simulation time. For simplification, it is assumed that vehicles never break down, i.e., $V_i = O_i + D_i - P_i$, where O_i is the number of vehicles on-site at the node i at any given moment, D_i is the number of vehicles in the process of being dropped off, and P_i is the number of vehicles in the process of being picked up. It should be noted that D_i is the sum of customer-driven drop-offs and relocations. In the DFM, P_i includes pick-ups that have been transferred from either Wellington or Picton.

The simulation allows vehicles to be relocated to another node at the cost of the RCO—\$300 for an intraisland relocation and \$550 for an interisland relocation. From a modelling perspective, this allows a mechanism for nodes to have vehicles in stock to satisfy incoming demand for the length of the simulation. The costs are based on the average relocation costs per vehicle charged by third-party vehicle transport providers. The simulation assumes that all cars are relocated by trucks managed by third parties.

The algorithm of relocation, based on Todd and Barth [25] and Kek et al. [10], is triggered when vehicle inventory at a node falls below a prespecified minimum threshold. The threshold for each node is determined as a function of the initial number of vehicles allocated. The decision to relocate vehicles begins once a vehicle entity arrives at its intended destination and is separated from the reservation entity. The threshold values for each node, as well as the demand distribution and the initial fleet allocation, are presented in Table 1.

In this instance, the decision to keep the vehicle at the node or to relocate it is made based on V_i relative to a node's minimum threshold number. If V_i is below the specified threshold for the node i, no relocations will be made. Otherwise, if it is above the minimum threshold, then vehicles will be relocated to the node j with a probability of Z_{ij} provided the destination node is below the specified minimum threshold for the node j. A selection weight value Z_{ij} is assigned by the RCO to each relocation route, denoted as R_{ij}, for a relocation from node i to j. The purpose of Z_{ij} is to select the relocation destination if multiple nodes are requesting vehicles.

During relocation, the time taken to traverse the route R_{ij} is deterministic and typically shorter than a rented vehicle's travel time N_{ij}, due to the urgency of relocation. Furthermore, it is assumed that all relocations are conducted via trucks as opposed to relocation aggregators to minimise the loss of potential bookings as well as to maximise the operational life of the vehicles, assuming all fleet is leased. These relocations come at an average cost of \$300 for intraisland transfers and \$550 for interisland transfers.

3.3. Reinstating Initial Fleet Deployment. According to Fink and Reiners [18], it is common practice to ensure that the same number of vehicles, but not necessarily the exact set of vehicles, is returned to the node where they were onfleeted for future resale by the leasing company or manufacturer. This postsimulation relocation is conducted to model the off-fleeting process and also the way an RCO prepares for the next peak season. The insights developed from this exercise are intended to provide indications for overall fleet distribution and gauge the comparative effectiveness of the models for minimising preseason or off-fleeting relocation costs.

This analysis is conducted as a mixed-integer linear programme in Microsoft Solver that takes the ending season-ending inventory levels at each node as input and restores the inventory levels at each node to that at the beginning of the season at the minimum possible cost.

3.4. Key Parameters. We use the following measures to compare the performances of the two models.

3.4.1. Service Level. Several studies have identified service level (SL) as a performance indicator of effectiveness [10, 19, 35]. SL is commonly defined as the fraction of demand satisfied. As previously discussed, the demand entity is rejected if $V_i = 0$. SL is monitored at both the node and system level to measure and compare the effectiveness of the fleet-operating models at the given interarrival rate of demand:

$$\begin{aligned}\text{service level}_i &= \frac{\text{total demand}_i - \text{rejected demand}_i}{\text{total demand}_i} \\ &= \frac{\text{satisfied}_i}{\text{total demand}_i}.\end{aligned} \tag{1}$$

Hence, we define the service level at the node i as the ratio of the satisfied demand at this node to the total demand received in this node.

3.4.2. Utilisation. According to the industry experts involved in the study, overall fleet utilisation for most rental car companies over peak summer demand is 80%. For the purpose of this study, we look at three types of utilisation: overall, revenue-generating (RG), and non-revenue-generating (NRG). As defined below, RG utilisation captures the vehicles hired and hence generates revenue, NRG

Table 1: Node demand and threshold percentages.

Node (i)	Demand distribution (μ_i) (%)	Initial opening inventory (% of total fleet size, C_i)	Node minimum threshold (F_i) (%)
(1) Auckland	43	38	10
(2) Rotorua	6	3	20
(3) Wellington	7	5	20
(4) Picton	2	4	10
(5) Christchurch	25	30	15
(6) Queenstown	15	20	15

utilisation represents vehicles being relocated and hence does not earn revenue, and overall utilisation is the sum of those two:

$$\text{utilisation (overall)} = \frac{\text{hire days} + \text{relocated days}}{\text{max possible days}},$$
$$\text{utilisation (RG)} = \frac{\text{hire days}}{\text{max possible days}}, \qquad (2)$$
$$\text{utilisation (NRG)} = \frac{\text{relocated days}}{\text{max possible days}}.$$

3.4.3. Relocation Costs. We look at costs of relocation that occur during each run of the simulation, as well as the cost of reinstating the vehicle inventory at each node to the initial deployment level at the end of the simulation. As specified previously, the cost for interisland transfers is \$550, while an intraisland transfer is \$300:

$$550 \sum_{i \in N} \sum_{j \in S} \left(X_{ij} + X_{ji} \right) + 300 \left(\sum_{i \in N} \sum_{j \in N, j \neq i.} X_{ij} + \sum_{i \in S} \sum_{j \in S, j \neq i} X_{ij} \right), \qquad (3)$$

where X_{ij} = vehicles relocated from node i to node j.

3.5. Run Parameters. We consider a total of four scenarios. Each scenario consists of 500 replications and runs for a total of 148 days. From these replications, a 95% confidence interval is created for each metric analyzed. Each replication has a 14-day warm-up period and a 14-day cool-down period. Results reported in this study are from the 120 days between the warm-up and cool-down periods. This duration is equivalent to the peak summer demand in NZ—from the start of December to the end of March. To ensure all accepted demand over the 120-day period is accounted for, no new demand entities are created beyond the 134th day, thereby resulting in an accurate result for ending inventory at the node i, denoted as E_i.

4. Numerical Experiment and Results

To compare the performances of the SFM and DFM, we consider four different scenarios, as described below.

4.1. Scenarios

(S1) Small RCO, low demand (base model): This scenario is designed to replicate a small RCO with a fleet size of 2000 vehicles at the indicated 80% total utilisation over peak summer demand. The interarrival rate of demand is Poisson distributed at 4 minutes.

(S2) Large RCO, low demand: This scenario increases the total fleet size to 4000 vehicles while keeping demand constant. The purpose of this scenario is to test the impact of an increase in fleet size on relocations and SL.

(S3) Large RCO, high demand: This scenario is designed to replicate a medium-large RCO over the peak summer period with a fleet size of 4000 vehicles and a commensurate high demand, Poisson distributed at 2 minutes. The purpose of S3 is to test the impact of higher demand on overall operating profit.

(S4) Small RCO, low demand, network optimised for SFM: This scenario is an extension of the SFM in scenario one, in which the node at Picton is removed, while its demand and fleet are assigned to Christchurch. The purpose of this scenario is to compare the performance of this network with SFM in the base model (S1). Naturally, DFM has been excluded from this scenario.

4.2. Fleet Utilisation. Table 2 shows the overall utilisation of the fleet for all four scenarios. In S1 (base case) and S3 (large RCO, commensurate demand), the DFM has higher overall utilisation than the SFM. Even though the higher overall utilisation of DFM is primarily driven by NRG utilisation, there is also a small increase in RG utilisation, resulting in increased revenue. In comparison, the removal of the node in Picton, as run in S4, marginally increases RG utilisation by 1 p.p. and NRG by 0.4 p.p. compared to the SFM in S1. Comparing S1 with S2 (Table 2) shows that doubling the fleet size and keeping demand constant have almost halved the overall utilisation, with a larger reduction in NRG utilisation (as there is a lower need for relocation).

As suggested by numerous studies, a higher utilisation rate will lead to higher revenue [5, 19, 26]. What is not apparent in any of these studies, however, is the composition of utilisation. Assuming these studies define utilisation synonymously with the definition of RG utilisation used in the current study, this may lead to a false promise of further

Table 2: Comparison of overall, RG, and NRG utilisation for S1–4.

Scenario	S1		S2		S3		S4
Model	SFM (%)	DFM (%)	SFM (%)	DFM (%)	SFM (%)	DFM (%)	SFM (%)
RG utilisation	70.9	71.7	43.1	38.6	71.5	71.7	71.9
NRG utilisation	7.2	10.9	3.3	3.6	7.2	10.9	7.6
Overall utilisation	78.1	82.6	46.4	42.2	78.7	82.6	79.4

potential growth in sales. For example, given the aforementioned assumption, utilisation for the DFM in S1 would be 71.7% overall. This could indicate a further potential to increase overall sales by 28.3%. However, as can be inferred from these results, the 71.7% RG utilisation was made possible by an NRG utilisation of 10.9%, bringing the overall utilisation to 82.6%. Therefore, it is suggested that in future research and in practice, utilisation should be considered in terms of both RG and NRG.

4.3. Service Level. It is notable that the SFM in all scenarios shows a higher SL than the DFM (Table 3). Despite the higher overall SL with SFM, it is apparent that Auckland, the city with the highest demand, managed to get close to a 100% SL only in S2 as a result of the increase in fleet size. In comparison, DFM managed a 100% SL for Auckland and Christchurch in all DFM scenarios but struggled to service demand in other nodes. It is interesting to note that Queenstown achieved a high SL compared to the SFM in S1 and S2. Furthermore, both Wellington and Christchurch only achieved a 50% SL in the DFM, regardless of the scenario.

In comparison, the DFM resulted in a higher SL in both Auckland and Christchurch, which collectively commanded a total of 68% of all incoming demand (see Figure 5). It is noticeable that under DFM, in the first three scenarios, Wellington and Picton experienced low SL for demand originating at either of these nodes. This is primarily due to vehicles being reserved for interisland travel, and SL does not improve with an increase in the fleet size.

An implication of these results is the appropriateness of either model in terms of an operator's target market. As discussed previously, first-tier operators in NZ target business customers, inbound airline passengers, and tourists. Given the gateway status of both Auckland and Christchurch, it is evident the DFM will be most appropriate for first-tier operators, as evidenced by the high SL. On the other hand, second-tier operators target leisure customers. In reference to Figure 2, many second-tier NZ operators have implemented the SFM, and these results suggest they are missing out on additional revenue from Auckland. Given that summer is a crucial period for both tiers of operators, it is critical to ensure correct fleet planning in the lead-up to summer. As indicated by the results of S2, an increase in the fleet size can help increase SL for SFM operators.

From an operational perspective, another method for improving SL is by establishing effective relocation policies to ensure each node has adequate inventory. As identified by both Todd and Barth [25] and Kek et al. [10], policies such as inventory thresholds can ensure a high SL.

Table 3: Service level at node and system level for S1–S4 by model.

Model	SF				DF		
Scenario	S1 (%)	S2 (%)	S3 (%)	S4 (%)	S1 (%)	S2 (%)	S3 (%)
Auckland	79.0	99.6	79.9	80.6	100.0	100.0	100.0
Rotorua	90.6	99.8	93.9	90.9	40.0	86.5	47.9
Wellington	99.9	100.0	100.0	99.9	50.0	50.0	50.1
Picton	100.0	100.0	100.0	0.0	50.1	49.3	50.0
Christchurch	99.7	100.0	100.0	100.0	100.0	100.0	100.0
Queenstown	100.0	100.0	100.0	91.3	65.8	100.0	64.0
Overall	90.5	99.8	91.1	91.3	86.9	96.0	86.9

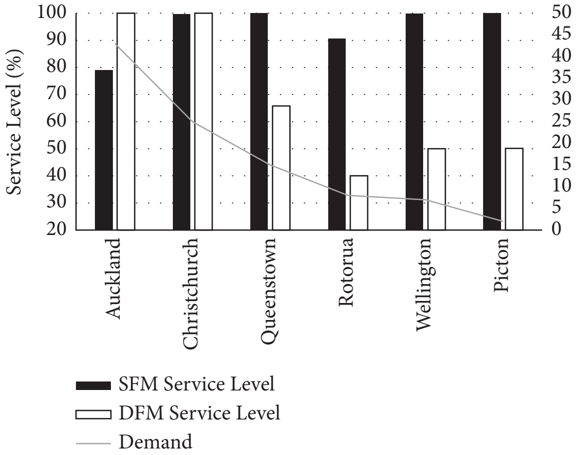


Figure 5: Service level achieved in scenario 1.

4.4. Relocations. Considering the inventory balancing relocation module, Table 4 reflects the relocation costs and volume for both models. It is interesting to note that the DFM has a significantly higher within-simulation relocation cost than the SFM. In the case of S1, this results in a \$2.2 mn increase in within-simulation relocation cost. S3 reflects a similar proportional difference in costs. As indicated in Table 4, most relocations conducted in the SFM were between-island relocations as a result of vehicles accumulating in the South Island. By design, all the relocations in the DFM were within island. This can primarily be explained by the volume of reservations travelling between islands requiring vehicles to be ready at both ends of Cook Strait. Furthermore, due to the lower overall threshold for Wellington and the high demand in Auckland, constant relocations are required. It is evident in S2 that the increase in fleet size reduces relocations. Another notable result is the average relocation time, 3.2 days vs. 1.5 days for SFM and DFM, respectively.

Table 4: Relocation cost and volume for S1–S4.

Scenario	S1		S2		S3		S4
Model	SFM	DFM	SFM	DFM	SFM	DFM	SFM
Between island	3665	0	3486	0	7383	0	3723
Within island	1858	15992	1470	11192	3809	31828	2095
Total relocation costs	$2,568,214	$4,780,126	$2,355,820	$3,357,700	$5,192,964	$9,548,481	$2,701,977

The overall ending inventory pattern by node was similar in all four scenarios. It was found that SFM accumulated vehicles in the South Island, most notably in Queenstown. Auckland, on the other hand, was short of vehicles the majority of the time. Based on the mixed-integer linear optimisation conducted to restore the final inventory levels of S1, the SFM costs $174,600 compared to $48,655 in the DFM.

The implications of these findings highlight the trade-off in SL and costs in terms of relocation, as well as in fleet procurement cost in the case of S2. As this study assumes all relocations are conducted via trucks, it is evident cost can be further reduced. The application of directional fees or incentives can be used to balance demand in both directions for heavily imbalanced routes [5, 24, 36], thus reducing the number of empty transfers.

Alternative relocation methods can also be applied, such as hired drivers and relocation aggregators, to reduce costs further. The latter provides a likelihood of additional auxiliary revenue. However, these methods may reduce the operational life of vehicles as they increase the likelihood of vehicles reaching mileage maximums as per leasing agreements [18]. An industry expert indicated that relocation by driving vehicles increases the likelihood of vehicles breaking down, impacting overall available capacity. Therefore, evaluating the opportunity costs is vital. Other industry practices can also be applied to decrease the number of relocations. A standard method used by rental vehicle companies is the application of either volume restrictions or an overall restriction for travel on specific routes.

4.5. Operating Profit. Based on the revenue and cost parameters established in previous sections, Table 5 reflects both revenue and costs, provided the TRPD remains constant at $150. In both S1 and S3, the DFM experienced a marginal increase in total revenue of an average of $250K compared to the SFM. However, this is reversed when comparing S1 to S2, where the increase in fleet resulted in a $3.2 mn increase in total revenue, but at the additional cost of leasing additional vehicles. It is evident in the first three scenarios that SFM has an overall higher operating profit than DFM. As previously discussed, this is primarily due to the higher within-simulation relocation costs.

To understand the impact of TRPD on operating profit, a sensitivity analysis was conducted on S1 (the base case) with several values of average TRPD (Figure 6). We see that the operating profit is higher in the SFM across all the TRPD tested. The overall trend shows that ceteris paribus, the lower the TRPD, the less profitable both models.

We note that for an average TRPD of $100 or less, the DFM becomes unprofitable, primarily because of within-relocation costs. This could potentially explain why only first-tier operators (who enjoy a higher TRPD) implement a DFM, while second-tier operators with significantly lower rates operate with the SFM.

While the results of this sensitivity suggest the SFM is more profitable overall than the DFM, additional efficiencies can be obtained using the DFM, such as higher service level at the major demand centres, as discussed in the previous sections. As indicated by Fink and Reiners [18], ensuring a high SL results in an increase in both customer satisfaction and loyalty. Pearce and Sahli [33] have also indicated that the inbound airline customer market is a crucial market segment for first-tier operators, providing a constant flow of customers. Therefore, ensuring a high SL and customer satisfaction in both Auckland and Christchurch is vital to securing lucrative contracts with various airlines.

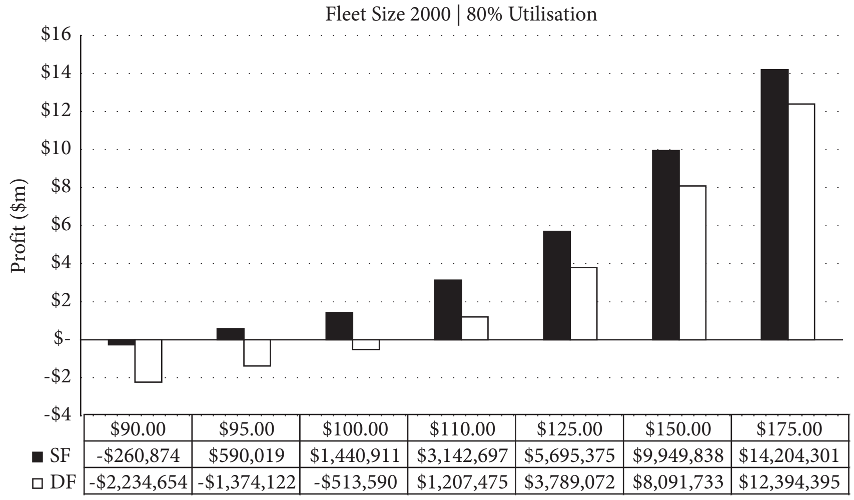
An important aspect that distinguishes between the two tiers of operators is the number of nodes operated. As suggested by Pearce and Sahli [33], first-tier operators have a higher number of nodes than second-tier operators, therefore indicating a generally larger fleet size than that of second-tier operators, given the number of nodes served [35]. As argued by Lohmann and Zahra [4], the viability of the DFM hinges on the ability to operate a node in Picton. The results from S4 indicate that the removal of this node in the SFM could help to improve operating profit by reducing node costs. Assuming that node leasing and operational cost remain constant regardless of TRPD, the closing of this node could further optimise operating profit. This finding may also extend to other nodes, but further analysis by industry practitioners should be conducted. The reduction in cost would be significant for second-tier operators, given their lower average TRPD than that of first-tier operators.

4.6. Managerial Insights. Our study shows that the single fleet, or pooling strategy, provides a higher level of operating profit for a single high season. At the same time, a multifleet model (i.e., not pooling) has two significant advantages over the single-fleet model. First, it provides a higher service level in the major demand centres. Second, it has substantially lower costs of relocating vehicles at the end of the season to restore the original inventory level in each location. Figure 7 represents the optimal pooling decision graphically.

The importance of providing a high service level in major demand centres depends on the general strategy of the RCO. A service level has a profound effect on customer loyalty [37]. For this reason, RCOs seeking to establish long-term relationships with customers will more likely prioritise the

Table 5: Breakdown of revenue and costs for S1–S4 at TRPD of $150.

Scenario	S1		S2		S3		S4
Model	SFM	DFM	SFM	DFM	SFM	DFM	SFM
Total revenue	$25,526,779	$25,815,968	$31,050,034	$27,789,605	$51,561,674	$51,615,863	$25,878,794
Reservation costs	$1,608,727	$1,544,110	$1,926,085	$1,716,311	$3,240,065	$3,086,453	$1,623,767
Relocation costs	$2,568,214	$4,780,126	$2,355,820	$3,357,700	$5,192,964	$9,548,481	$2,701,977
Daily cost/vehicle	$7,200,000	$7,200,000	$14,400,000	$14,400,000	$14,400,000	$14,400,000	$7,200,000
Vehicle leasing cost	$3,200,000	$3,200,000	$6,400,000	$6,400,000	$6,400,000	$6,400,000	$3,200,000
Branch leasing cost	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$833,333
Operating profit	$9,949,838	$8,091,733	$4,968,129	$915,593	$21,328,645	$17,180,929	$10,319,717



	$90.00	$95.00	$100.00	$110.00	$125.00	$150.00	$175.00
■ SF	-$260,874	$590,019	$1,440,911	$3,142,697	$5,695,375	$9,949,838	$14,204,301
☐ DF	-$2,234,654	-$1,374,122	-$513,590	$1,207,475	$3,789,072	$8,091,733	$12,394,395

Figure 6: Impact of TRDP on operating profit for S1.

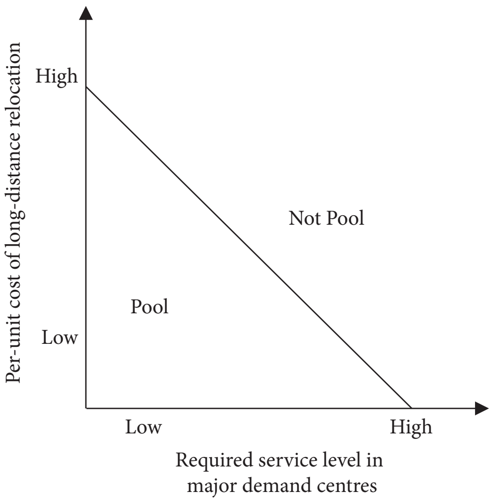


Figure 7: Optimal pooling strategy.

service level. This factor may be more relevant to large international RCOs or those targeting business customers. At the same time, RCOs serving budget or nonreturning customers, such as tourists, may not require an exceptionally high service level in major demand centres. This logic explains why first-tier RCOs tend to use the dual-fleet strategy in New Zealand, while many second-tier RCOs operate a single fleet of vehicles.

The cost of reinstating the original vehicle inventory level depends on a number of factors specific to particular markets. For example, long-distance relocations in New Zealand require ferry services to cross Cook Strait between the North and South Islands. In other markets, large distances, road quality, or international border crossings could create additional costs. Overall, if the long-distance relocation costs are high, it can be more profitable for an RCO not to pool vehicles in a single fleet. This could be the reason why the dual-fleet strategy is common in New Zealand with its relatively high cost of long-distance relocation, while it is less common in countries with fewer geographical or infrastructural barriers, such as Australia or the USA.

5. Conclusion

This study looks at the relative merits and demerits of single-fleet models and multifleet models in the presence of a significant volume of one-way rentals in one direction. To that end, we compared two rental vehicle fleet management models implemented by rental car operators (RCOs) in New Zealand. For this purpose, two novel simulation models were developed to compare and investigate the respective impacts of DFM and SFM on vehicle utilisation, node and system service level (SL), relocations, and operating profit. Both models were tested under four scenarios, which varied primarily in terms of fleet size and overall demand.

The results of this study showed an overall higher utilisation for the DFM. However, this was primarily driven by a higher number of within-simulation relocations than the SFM. In terms of SL, this study highlights that while the SFM showed an overall higher SL, the DFM emphasised SL at large nodes. Beyond within-simulation relocations, it was identified that the overall cost to reinstate the original node inventory level was significantly lower for the DFM than for the SFM.

Lastly, a comparison was made in terms of operating profit. It was identified that the SFM had a higher operating profit overall than the DFM at all levels of the total rate per day (TRPD) tested. Furthermore, this study provides an indicator in terms of TRPD with regard to which model should be considered. However, it is recommended that other soft variables not covered by this study, such as reputation and loyalty, should also be considered. It can therefore be concluded that while both models have their own merits, the implementation of either will largely depend on the strategic goals of the operator.

Summarizing our findings, the single-fleet model provides lower overall costs due to lower relocation costs. At the same time, a multifleet model leads to a higher service level in major centres. Thus, we answer our key question, to pool or not to pool, as follows: pooling may be optimal for operators focused on the overall cost of their operations potentially at the expense of the service level. In the context of the car rental industry, these are likely to be operators mainly working with tourists and other nonrepeat customer groups. However, operators prioritising the service level will benefit from unpooling their fleet and operating a double-fleet model. These are likely to be operators working with business customers or maintaining a well-established loyalty programme for repeat customers.

The primary practical and theoretical contribution of this study is the comparisons made between DFM and SFM. Furthermore, this study also contributes to the body of knowledge by discussing, albeit briefly, the importance of observing overall utilisation as a function of both revenue-generating and nonrevenue-generating utilisations in the context of rental vehicles. It is therefore suggested that future work on rental vehicles in both academia and in practice should take this into consideration.

Our work could be extended in several ways. Future work in this area could consider the applicability of different variants of the DFM and SFM on larger geographical scales with similar imbalances in demand. Furthermore, the current model does not differentiate the demand on weekdays and weekends. Providing more granularity in this regard may generate additional insights. As this study is strictly confined to the rental car industry, other future work in this field could consider the overall applicability of the models to other passenger rental vehicle types, such as recreational vehicles. Future research could also consider looking beyond the application of these models from a business perspective to consider the customer perspective.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

Open access publishing was facilitated by the University of Auckland, as part of Wiley–The University of Auckland agreement via the Council of Australian University Librarians.

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