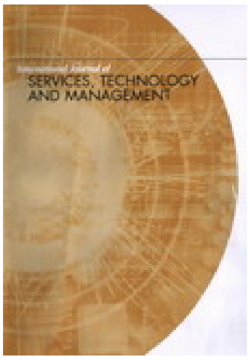

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Simulation modelling for retail self-checkouts: performance analysis and optimisation

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Simulation modelling for retail self-checkouts: performance analysis and optimisation

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Abstract: Many retail stores have installed self-checkout lanes in addition to their regular cashier counters. However, there has been no quantitative research regarding whether self-checkouts actually decrease average wait times during checkout. This study conducted a simulation to estimate customer wait times at checkouts of both types – cashiers and self-checkout. The simulation parameters were modified based on real-world data from an existing study. We present the patterns of the wait times, number of waiting customers over arrival rates, and the number of checkout counters. We also demonstrate use of the goal programming optimisation method to show how retail stores could manage self-checkout lanes along with conventional cashier lanes.

Keywords: self-checkout; simulation optimisation; retail stores; service operations.

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1 Introduction

Most retail stores, including large hypermarkets such as Walmart and grocery supermarket chains such as Safeway, have installed self-checkout lanes to supplement staffed checkout counters with the aim of enhancing checkout service and cultivating customer satisfaction and loyalty. Checkout service is an essential retail operation. Research indicates many customers are dissatisfied with an insufficient number of checkout counters and that long lines at checkout affect customers' intentions to shop at a particular retailer in the future (Chain Store Age, 2008). According to a survey conducted by Forrester Consulting, 65% of grocery shoppers choose self-checkout lanes to avoid a slow checkout (eMarketer, 2018). The second most popular action is shopping at off-peak hours (53%), which only applies to customers whose time is flexible. All other actions to avoid long wait times are far less popular among grocery buyers. As self-checkouts become more popular, the number of cashiers employed in the retail industry is rapidly decreasing (McWilliams et al., 2016; Thibodeau, 2013). There is increasing interest in self-service technologies for checkout, and many researchers have studied the factors that affect successful implementation of these technologies (Chiu et al., 2023; Duarte et al., 2022; Khalufi and Shah, 2022; Nusrat and Huang, 2024; Schweitzer and Simon, 2021).

Although self-checkout options have been largely well-received by customers, whether self-checkout lanes reduce customer wait times has not yet been verified. The discrepancy between customers' actual wait time and perceived wait time was explained by Maister (1984) as the psychology of waiting lines. He identified eight propositions that managers could exploit to improve customers' waiting line experience without reducing actual wait time; self-checkout lanes conform to several of these. For example, they occupy customers' attention and time ('occupied time feels shorter than unoccupied time') and help customers start the checkout process sooner ('people want to get started'; that is, pre-process waits feel longer than in-process waits). Furthermore, some customers prefer self-checkout because they are doing something or are in more control of the checkout process (Anitsal and Paige, 2006), although it may take more time than going through a normal checkout.

Existing literature on self-checkouts predominantly examines the pros and cons of self-checkouts (Wang et al., 2012), but there is a lack of quantitative evidence and little research on the impact of self-checkout options on wait time. It is worth investigating actual checkout wait times. Prolonged wait times result in negative overall service evaluations (Caruelle et al., 2023), negative attitudes toward the service provider (Hui and Tse, 1996), and decreased consumer loyalty (Bielen and Demoulin, 2007). Even in online retail, waiting time is a crucial factor affecting customer behaviour (Gallino et al., 2023). Because consumers' perceived wait time is affected by actual checkout waiting time (Anić et al., 2011), actual wait time can be an appropriate measure for analysing self-checkout performance; it also enables quantitative analysis using simulation data. The research questions we address in this study are as follows:

1 Do self-checkouts reduce customer wait times?

2 Under what circumstances can the self-checkout lanes be useful?

3 How can we determine the optimal ratio of self-checkout counters to cashiers?

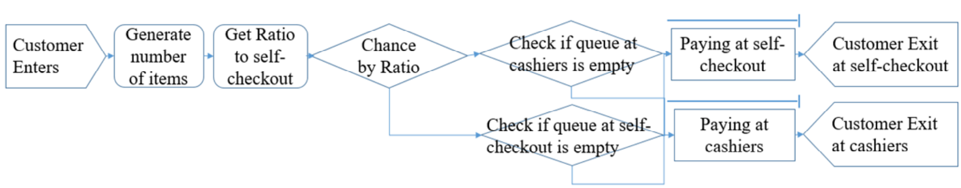
We explore these research questions by developing queueing models and analysing customer wait times at both cashier and self-checkout lanes via simulation. Section 2 introduces the model used for the analysis. In Section 3, we present the results of an extensive simulation study to investigate the factors influencing the performance of checkout services. Section 4 discusses determination of the optimal number of self-checkout counters using goal programming with multiple decision criteria, and Section 5 concludes the paper with limitations and future research directions.

2 Simulation modelling

2.1 Model

The simulation model developed using the ARENA software is shown in Figure 1. We assume that the customers arriving for checkout services join either the queue for cashiers or the queue for self-checkouts. The ratio of customers who decide to use the self-checkout counters is denoted by p_n where the index n indicates the number of items a customer buys. While each cashier checkout counter has a separate waiting line, our model assumes one queue for *M* number of cashiers. We also assume that there is one queue for *N* number of self-checkouts, which most retailers are currently adopting. Schimmel and Bekker (2013) found that there is no significant difference in wait times between one combined queue and separate queues for all counters. When the store is not very crowded, the waiting situations in the two systems would be almost identical.

Figure 1 Simulation model of this study (see online version for colours)



In our simulation model, a customer arrives with an exponentially-distributed inter-arrival time and arrival rate λ. The customer buys *n* items and chooses either self-checkout with probability p_n or cashiers with probability $1 - p_n$ for checkout service. If the queue of the customer's choice is crowded, but the other queue is empty, the customer switches checkout lanes. The checkout service time is a linear function of the number of items a customer buys.

2.2 *Simulation data settings*

We used transaction data from a Polish retail store (Antczak and Weron, 2019) to pre-analyse the transaction times at cashiers and self-checkouts and determine our simulation parameter datasets. The transaction data was obtained at a single retail store in Poland and contains information about the type of server (cashier/self-checkout), the number of items sold, the amount paid, the type of payment (cash/card), transaction time (time from scanning the first item to processing payment), and break time (time after payment until the next transaction) for each transaction.

Since the data did not provide exact checkout service times, we estimated it by selecting the data of only peak times, which the existing study identified as Thursdays from 10 AM to 1 PM and Fridays and Saturdays from 11 AM to 2 PM, given that idle time is rare during peak hours (Antczak and Weron, 2019). Estimated service time was calculated as the sum of transaction time and break time for these time slots; a summary of the related statistics is given in Table 2. On average, service times were longer at self-checkouts even though customers using the self-checkout counters bought fewer items. This finding suggests cashiers are more skilled than customers and process checkouts faster.

Table 1 Summary statistics of estimated service time and number of items sold during peak times (from the selected data)

		Cashiers	*Self-checkouts*
Number of transactions	18,437	4,111	
Estimated service time (sec)	Mean	86.0596	175.4892
	Standard deviation	62.7478	117.9422
	Median	72	145
	Minimum	7	20
	Maximum	1334	1147
Number of items sold	Mean	18.3778	9.8115
	Standard deviation	17.8737	9.9225
	Median	13	7
	Minimum	1	1
	Maximum	310	76

On average, customers who used self-checkout lanes bought 9.81 items and spent 175.49 seconds on checkout, while customers served by cashiers bought an average of 18.38 items and spent 86.06 seconds on checkout. The data indicates that customers who buy fewer items tend to use self-checkout lanes. However, the mean service time is longer at self-checkout counters. These observations imply that self-checkout lanes may not effectively improve checkout service, contrary to their intended purposes. Using regression analysis (which turned out statistically valid with significantly low p-values), we found the linear relationship between the service time and the number of items for purchase:

- Service time at a cashier when a customer buys n items: $\mu_C(n) = 2.19 * n + 45.78$ (sec)

- Service time at a self-checkout counter when a customer buys *n* items: $\mu_S(n) = 8.05*n + 104.44$ (sec).

The regression results provide good estimates of average scanning time of one item (the coefficients of regression equations) and average bagging and payment time per purchase (the constant terms of regression equations). We used these equations in our ARENA simulation, determining the arrival rate of this simulation study to be $\lambda = \{200, 250, 300\}$, and identified which combination of cashiers and self-checkouts generated the best results for each case.

The number of purchase items per customer was randomly assigned from the exponential distribution of 16.4, based on the data from Antczak and Weron (2019). The ratio of customers choosing self-checkout was determined by the number of items, also based on Antczak and Weron's (2019) data. These simulation parameter settings produced enough simulation results to investigate the factors influencing customer wait times for both checkout types.

3 Simulation results

We set up the simulation to investigate the effects of factors such as arrival rate and number of cashiers or self-checkouts on waiting. To observe the relationship between those factors and wait times, we plotted average waiting time and average number of customers in line with respect to the changes in arrival rate, number of cashiers, or number of self-checkouts (LC: average number of waiting customers at cashiers, LS: average number of waiting customers at self-checkouts, WC: average wait time at cashiers, WS: average wait time at self-checkouts):

- Arrival rate = {200, 250, 300}
- Number of cashiers = {5, 6, 7}
- Number of self-checkout counters = {3, 4, 5, 6}.

Figure 2 Effect of arrival rate on waiting (see online version for colours)

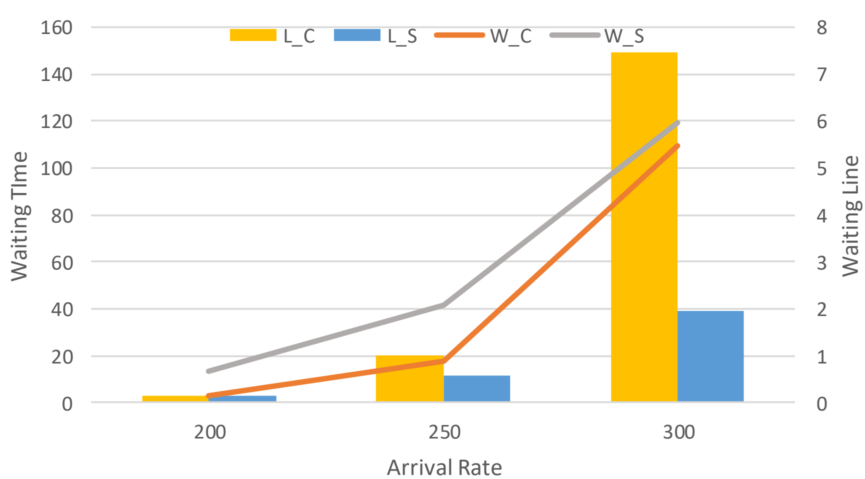


Figure 3 Effect of cashier numbers on waiting (see online version for colours)

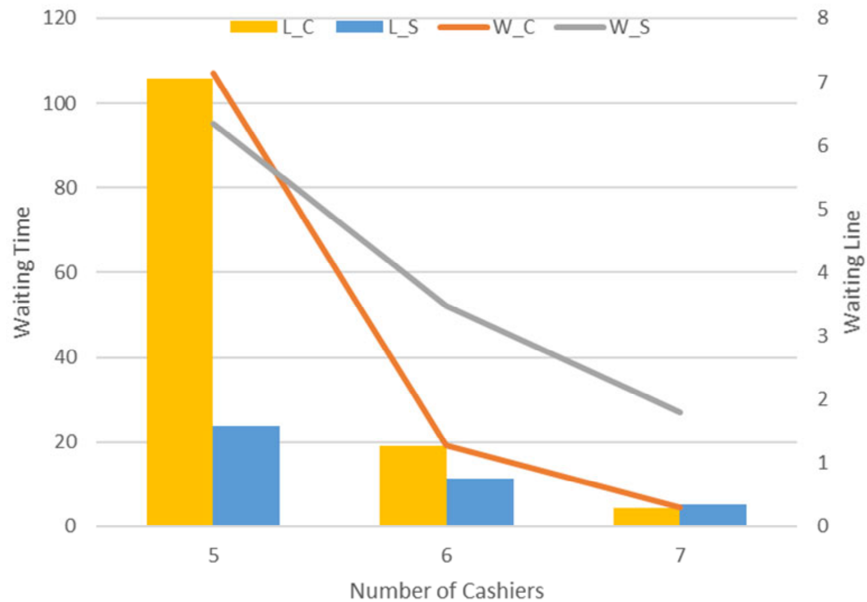


Figure 4 Effect of self-checkout numbers on waiting (see online version for colours)

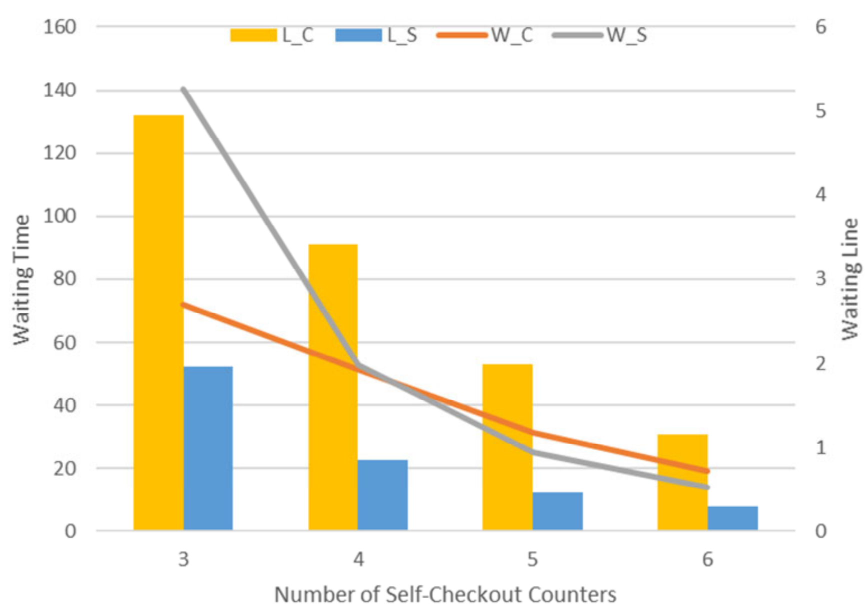


Figure 2 shows that average wait time and average number of waiting customers increase with arrival rate. Retail stores may need more checkout lanes for peak times than for non-peak times in order to prevent lengthy wait times.

Figure 3 shows that average wait time and average number of waiting customers decrease as number of cashiers increases. When there are six cashiers, average wait time is significantly shorter than when there are five cashiers. On the other hand, when there are seven cashiers, wait time savings are relatively minimal. This result implies that, once stores have a certain number of cashiers, adding more cashiers may not significantly reduce customer wait times.

Figure 4 illustrates that average wait times and average number of waiting customers decrease with the number of self-checkout counters. While the marginal value of adding a cashier rapidly decreases, the marginal value of adding a self-checkout lane seems relatively constant under the experimental setup.

4 Checkout staffing decisions using goal programming

It is not clear what mix of cashiers and self-checkout lanes is optimal; decisions will differ based on the decision makers' relative prioritisation of customer service and cost efficiency. For example, if a retailer aims to reduce customers' waiting time at checkout, increasing the number of cashiers and/or self-checkout machines will achieve the desired result. However, we cannot ignore the utilisation rate of those resources. The two conflicting goals make the staffing decision difficult. This study adopts one of many research approaches to the problem of more than two objectives: the goal programming method. This method has been widely used in optimisation decisions for problems with more than two goals, even in different units. The objective of the goal-programming optimisation model is to minimise the gaps between target value and achieved outcome. The decision-maker may give top priority to a certain goal by assigning a larger weight to the goal.

This study used the two kinds of performance measures from the simulation study – average customer wait time and utilisation of both types of checkout – to find a solution to the goal programming model. Let us first consider the case where an average of 200 customers per hour arrive at the store. Simulation of the combinations varying cashiers (from 3 to 7) and self-checkout machines (from 1 to 8) and exclusion of too long an average wait time (longer than 5 minutes) and too low a utilisation (lower than 70%) yield the three outcomes shown in Table 2.

Table 2 Average wait time and utilisation of some candidates for goal programming

(Cashier, self-checkout) combination	*Average wait time (sec)*		*Average utilisation (%)*	
	Cashier	*Self*	*Cashier*	*Self*
(3, 5)	166.38	41.04	93.7	89.78
(3, 6)	88.43	24.27	90.44	82.57
(4, 3)	64.96	93.50	87.41	90.05

Which is an optimal choice? It is not easy to draw an intuitive conclusion. As cashiers' labour is costly, three cashiers and five self-checkouts may be optimal for some retailers as it offers higher utilisation of cashiers. On the other hand, for shorter customer wait times, a retailer may choose four cashiers and three self-checkouts despite the high cost of cashier labour, or three cashiers, six self-checkouts, despite the high maintenance cost of self-checkout machines.

In cases where there are multiple goals, we consider the two ultimate or best achievable goals for goal programming optimisation: one goal toward 0 minutes of customer wait time and the other goal toward 100% of checkout utilisation. We add a constraint that the average customer wait time at both types of checkouts should be less than 5 minutes. Although this constraint may be subject to change based on the retailer's desired goal, the 5-minute threshold has been cited as a survey result in existing literature, suggesting customers tend to be dissatisfied with waits longer than 5 minutes.

The goal programming model is as follows:

$$\text{Minimise } w_1 t_C + w_2 t_S + w_3 (100 - u_C) + w_4 (100 - u_S)$$

$$s.t.\ t_C < 5 \text{ (min)}$$

$$t_S < 5 \text{ (min)}$$

where

t_C average wait time at cashiers (min)

t_S average wait time at self-checkouts (min)

u_C average utilisation at cashiers (%)

u_S average utilisation at self-checkouts (%)

w_n weight (n = 1, …, 4), $\sum_{n=1}^{4} w_n = 1$.

Table 3 summarises the optimal solutions based on the assigned weights.

Table 3 Optimal solutions of goal programming for different weights

Scenario	*Weights (w_1, w_2, w_3, w_4)*	*optimal solution (cashier, self-checkout)*		
		Arrival 200	*Arrival 250*	*Arrival 300*
1	(0.25, 0.25, 0.25, 0.25)	(3, 5)	(4, 5)	(5, 5)
2	(0.4, 0.4, 0.1, 0.1)	(3, 5)	(4, 5)	(5, 6)
3	(0.1, 0.1, 0.4, 0.4)	(3, 5)	(4, 5)	(5, 5)
4	(0.1, 0.1, 0.7, 0.1)	(3, 5)	(3, 8)	(4, 8)

Scenario 1 gives the same weights on all four performance measures (customer wait times at cashiers and self-checkouts, utilisations of cashiers and self-checkouts). The optimal combinations of servers are three cashiers and five self-checkouts for 200 customers arriving per hour, four cashiers and five self-checkout for 250 customers arriving per hour, and five cashiers and five self-checkouts for 300 customers arriving per hour. Interestingly, the optimal number of self-checkout machines would be the same for the three cases. If we adopt this solution, we may consider installing five self-checkout machines and varying the number of cashiers by time; for example, having additional part-time cashiers for peak times.

Scenario 2 assigns a higher weight to customer wait times, and scenario 3 assigns a higher weight to utilisation. In both scenarios, the optimal solutions do not differ significantly from that of scenario 1. This result indicates that the optimal solutions for checkout staffing decisions are robust even when different objectives are prioritised in the goal programming model.

If one factor is weighted much more heavily than the others, the result may change. For example, scenario 4 gives seven times higher weight to the utilisation of cashiers than on other measures, assuming the decision maker's top priority is to reduce labour costs. In this case, the optimal solution is to have one fewer cashier than was optimal in the previous scenarios and three more self-checkout machines; three self-checkout counters are equivalent to one cashier in this goal programming model.

5 Conclusions

This study explored key considerations for self-checkout management in retail stores. Self-checkout counters have been installed to improve customer service in many retail stores. Although self-checkout lanes may lower customers' perceived wait time or give them a feeling of control, it is questionable whether self-checkout average wait times are actually lower. Fully trained cashiers are generally much faster in checkout transactions than customers. Based on point-of-sales data from Antczak and Weron (2019), we verified that self-checkout counters have longer transaction times despite scanning a smaller number of items than cashiers.

Many previous studies focused on the psychological effects of self-checkouts; there has been no quantitative analysis of customer wait times at retail stores with both cashiers and self-checkout lanes. We conducted a simulation study to investigate customer wait times during checkout in such retailers. The simulation parameters, modified based on the data from Antczak and Weron (2019), included arrival rates during peak times, distribution of number of items for purchase, distribution of the percentage ratio of customers who use self-checkout counters depending on the number of items they buy, and the transaction time as a function of purchase amount at each type of checkout counter. Our analysis yielded quantitative information such as customer wait times, number of customers waiting in line, and utilisations of cashiers and self-checkout lanes as performance measures. We observed that customer wait times are shorter when the customer arrival rate is lower, when there are more cashiers, and when there are more self-checkout machines. In addition, we present a guideline to determine the optimal combination of cashiers and self-checkout lanes through goal programming.

The results of this study provide meaningful managerial insights into managing self-checkout counters in practice. Furthermore, we may consider incorporating the relevant cost information such as cashier's labour cost and the purchase/maintenance costs of self-checkout machines in the optimisation model as future research.

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