The revolution of the checkout area

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Preface

This document is what we call a BMI-thesis. The BMI-thesis is part of the curriculum of the master's program Business Mathematics and Informatics, or BMI. The BMI program is a multidisciplinary program, aimed at improving business processes by applying a combination of methods based upon mathematics, computer science and business management. I participated in the BMI program at the Vrije Universiteit in Amsterdam. This is the only university that offers Business Mathematics and Informatics.

The BMI-thesis has several goals. Based upon a problem statement the student performs a research. The student reports on the research in a written report. The main goal is to describe the problem clearly and make it understandable for a reasonably educated reader. The aim of the project is to focus on the business aspect of the problem as well as on the mathematical and computer science aspects.

The main subject of this thesis is the queue at the checkout counter of a supermarket. At the moment, this is a very hot topic, because of the recent introduction of a revolutionary checkout system: the self checkout machine. Many supermarkets are experimenting with the new system. The goal of this thesis is to perform a mainly quantitative analysis of the self checkout system. The thesis will particularly focus on the system that has been introduced in several establishments of the C1000 supermarket. The reader of this document will gain insight in the pros and cons of the new system relative to the traditional system with cashiers.

I would like to express special thanks to Wemke van der Weij, PhD at the Vrije Universiteit, for supporting me throughout the process of creating this document.

Contents

Chapter 1

The rise of self service

Nowadays nobody finds it strange to walk into a supermarket with a shopping cart, gather all your required goods and bring them to the cash desk. However, this form of self service has not existed for very long yet. It took years and years for the foodstuffs branch to realize that consumers were prepared to do many things themselves.

Throughout the years the foodstuffs branch has evolved from the traditional grocery store to high tech supermarkets with self checkout machines. During this process, the queues at the checkout desks have also experienced some radical changes. This chapter describes the history of the supermarket and the consequences on the checkout queue. The history has been derived from [3], [5], [12], [15], and [25].

1.1 The grocery store

Up until around 1950 the Netherlands were only familiar with what we now consider as old-fashioned grocery stores. These grocery stores were so-called service shops. The grocer received his goods from the wholesaler in large volume packages. Sugar was delivered in large packs of 50 kilo grammes; peas, beans, rice, etcetera were delivered in huge gunny sacks; candy and cookies came in boxes, canisters or pots; salt, syrup and sauerkraut arrived in large barrels. Wholesalers rarely delivered prepackaged products in consumer sized packages. This situation gave the shop attendant the responsibility to repack the goods in the desired package sizes. The consumer did not gather the goods himself, but had to ask for each separate article and define the desired amount at the counter. The grocery stores of the previous century were arranged comparable to the present-day pattisserie, greengrocer or butchery. Characteristic for the service store were the large counters containing cash registers and balances. Behind the counters were large shelves with open bins filled with goods. Figure 1.1 gives an impression of a traditional grocery shop.

The queue in the traditional grocery shop has some typical characteristics. The number of cashiers, representing the servers in the queuing model, is limited. Only one, two, or maybe three shop attendants act as server at the counter, which is referred to as a single queue. The service time of the server in the grocery store includes several actions. Besides handling the payment the server also has to gather, weigh and pack all the goods the customer desires. The queue in the traditional grocery store can be described as multiple (yet limited) single server, First In First Out (FIFO) queue, with relatively long service times.

1.2 The self-serving store

The first step toward self service was taken by Clarence Saunders, a grocer from Virginia, USA. Saunders launched the self-service revolution in America by opening the first self-service Piggly Wiggly store, at 79 Jefferson Street in Memphis, Tennessee. In this revolutionary store the customers selected their own goods from the shelves. The store incorporated shopping baskets,

Figure 1.1: A traditional grocery store.

self-service branded products, and checkouts at the front. Removing unnecessary clerks, creating elaborate aisle displays, and rearranging the store to force customers to view all the merchandise were just some of the characteristics of the early Piggly Wiggly stores. The concept of the 'Self-Serving Store' was patented by Saunders in 1917.

The concept of self service was introduced in the Netherlands several years later. In 1948 the Van Woerkom brothers introduced the concept in Nijmegen. The low counters with cash registers and balances, characteristics of the traditional grocery store, disappeared from the shop. All articles were pre-packed and labeled with a price tag. Arriving customers could now take a shopping basket and start collecting all their goods from the shelves. The grocery stores were ready for the step toward the supermarket. The wholesalers, however, did not adapt to the new concept yet. Deliveries were still made in large volume packages and the grocer still needed to repack the goods in consumer sized packs. The only difference for the grocer was the fact that the balance had been moved from the store to the storage room. Not much of an improvement one could say. However, both the customers and the shopkeepers appeared to be very attracted to the new self-service system. The customers appreciated the privilege to be allowed to gather their goods themselves and the grocer was able to allocate his time more efficient. In idle times there was room for the shopkeeper to weigh and pack the goods in consumer sized packages.

The step from the grocery store to the self-serving store also means a change in the queuing system. With the introduction of checkouts at the front of the store the single queue belongs to the past. Moreover, the service times of the servers decrease radically as the shop attendant has no longer the obligation to weigh and pack all goods for the customers. The queuing system in the self-serving store can be described as an FIFO multi-server, multi-queue with short service times relative to those of the grocery store.

With the introduction of self serving stores most grocers realized that the foodstuffs industry was about to change radically.

1.3 The supermarket

Shortly after the introduction of self-serving the first supermarkets started to emerge. According to the Smithsonian Institution, the first true supermarket in the United States was opened by Michael J. Cullen, on August 4, 1937, in a 560 square meter former garage in Jamaica, Queens, New York. The store, King Kullen, operated under the slogan "Pile it high. Sell it low." As with the self-serving stores, the Netherlands followed America several years later. The first Dutch supermarket was the N.V. Suco, opened in Amsterdam in 1953. This first real supermarket did not bring the expected success. Shortly after the opening it was taken over by Dirk van den Broek.

The main characteristics of a supermarket that distinguish it from the self-serving stores and the traditional grocery stores are the size and the selection. The supermarket is bigger in size and has a wider selection of products.

The queuing system of the supermarket is not much different from that of the self-serving store. The supermarket mainly distinguishes itself from the self-serving store with its size and selection of products. The same holds for the queuing model. The description as multiple FIFO multi-server queues still holds. However, the number of servers and arrivals is large compared to those at the self-serving store. The queuing model of a supermarket will play a major role throughout this thesis. It will be compared to the self checkout machine, the next step in the history of self service. The queuing model of the supermarket will be described in detail in Chapter 2.

Figure 1.2: Wide selection of coffee.

1.4 The next step

Nowadays all consumers are familiar with self-service at the supermarket. Gathering your own products is ‘business as usual’. However, the revolution of self service is not over yet. Due to heavy competition in the supermarket branch many companies are searching for new concepts. Some retailers have already made the next step in the self-service revolution. They introduced self checkout machines. With this new system the customers not only gather their own products, they also checkout on their own. The customer is permitted to scan the bar codes of their own items and perform the payments without intervention of a cashier. This revolutionary system has several benefits. The benefit to the retailer is in the reduction of staffing requirements. The companies that introduce self checkout systems also claim a huge benefit for the customer. The user of the self checkout machine would experience a shorter sojourn time because of expected decreased queuing times. This thesis will provide some insight in the consequences of self checkout machines. In order to illustrate the effect of this step in the self-service revolution we will take a closer look at a pioneer in the Netherlands in the self checkout field, the C1000, a supermarket chain under authority of Schuitema N.V. The C1000 has thoroughly tested the new system. In this thesis we provide a model of the C1000 setup and compare it with the traditional set of cashier-staffed checkout desks.

Figure 1.3: Self checkout at C1000.

1.5 Self checkout at C1000

As mentioned in the annual report 2002 of Schuitema N.V. [19], Schuitema realized that the customer really desired fast checkout at supermarkets. One way to fulfill this demand is placing so-called self checkout machines. In November 2002, C1000 initiated this as a test in Bodegraven. A press release [16] noted that, with the installation of three fully operational unmanned self checkout counters, C1000 Bodegraven was the first of its kind in the Netherlands. The system consists of a scanner and a conveyor belt at which the customer scans his products. In this first pilot the customer still has to visit a cashier to perform the payments. The pilot appeared to be an immediate success. According to the 2002 annual report [19] 25% of the customers were willing to use the new system. This success leaded to an expansion of the test. Four more C1000 supermarkets in Surhuisterveen, Eibergen, Landgraaf and Bodegraven were equipped with the new self checkout system. A press release of November 2, 2003 [17] makes notion of this next step in the test program. At two of the four test sites the customers not only scanned their own articles, but were also able to perform electronic payment of the goods with PIN[1] or chipknip[2]. For cash payments the client still had to attend a cashier. Again the pilot was considered a succes. As stated in the Schuitema N.V. annual report of 2004 [21] the tests of self checkout systems covered 10 establishments of C1000 in 2004. At present day, the self checkout systems are in use in many C1000 stores.

Due to the introduction of self checkout machines the queuing model of the supermarket has to be changed dramatically. The rather straight-forward model of the traditional supermarket has to be replaced by a more complicated model. This new model is the core of this thesis. In the following chapters both the traditional situation and the new self checkout system will be modeled and compared quantitatively. In the new situation the customer perception also plays an important role. This perception will be addressed in Chapter 4.

[1] PIN is an online electronic point-of-sale payment system which transfers payments in real-time.

[2] Chipknip is an electronic cash system used in the Netherlands. All ATM cards issued by Dutch banks have smart cards that can be loaded with value via Chipknip loading stations next to ATMs. Chipknip can be used for payments at parking machines, shops etc.

Chapter 2

Modeling the traditional supermarket

In order to compare the traditional supermarket with cashiers and the new self checkout system of C1000, checkouts are modeled as a queue length model. This model has several components on which assumptions have to be made. In this chapter all components will be addressed separately. Finally the components will be merged into a model that can be analyzed and compared to the self checkout system.

2.1 The arrival process

The process of customers arriving at a supermarket can be modeled as a Poisson process (see [10], [26] and [23] for more information on the Poisson process). The Poisson process is a viable model when the arrivals originate from a large population of independent potential customers (see Virtamo [26]). This immediately justifies the choice for the Poisson arrival process. A supermarket has a large population of potential customers and each customer acts independently of other customers. The choice for a Poisson arrival process has several advantages. One of these advantages is the useful consequence of randomly splitting a Poisson process. This aspect of the Poisson process is used in Section 2.2 on counter selection. Another useful characteristic of the Poisson process is the PASTA property (see [10], [26] and [23] for more information on the PASTA property). This property holds that arriving customers find on average the same situation in the queuing system as an outside observer does, looking at an arbitrary point in time. This makes it possible to draw conclusions about interesting measures such as expected sojourn time and average queue length.

2.2 Counter selection

In the previous section the arrival process at the supermarket has been defined. However, what really matters is the arrival process at the checkout counters. Assume that the supermarket checkout region consists of N counters and that an arbitrary customer chooses counter i with probability p_i. The arrival process at each individual checkout counter can then be described as what Virtamo [26] calls a randomly split Poisson process, which we recall in Theorem 2.1.

Theorem 2.1 *If a Poisson process with intensity λ is randomly split into subprocesses with probabilities $p_1, p_2, \ldots, p_N$, where $p_1 + p_2 + \ldots + p_N = 1$, then the resulting processes are independent Poisson processes with intensities $p_1\lambda, p_2\lambda, \ldots, p_N\lambda$.*

As a result of Theorem 2.1 the model of the traditional supermarket consists of N independent Poisson arrival processes. Hence, customers arrive at the First In First Out (FIFO) queue on

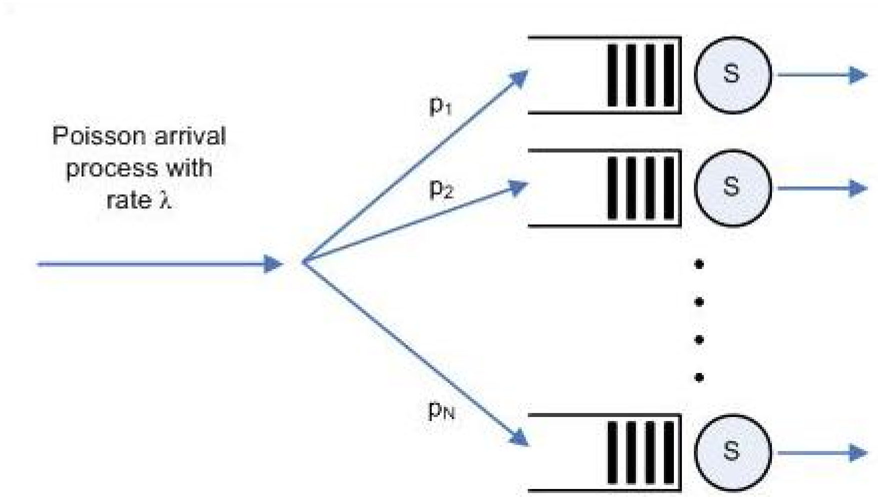

Figure 2.1: Model of the traditional supermarket.

server i according to a Poisson process with rate $p_i\lambda$. Figure 2.1 schematically illustrates the model of the traditional queues at the supermarket.

All servers are assumed to have identically distributed service times. We also assume that there are no special counters for shopping baskets. Consequence of this assumption is that $p_1 = p_2 = \ldots = p_N = 1/N$ since no counter will be preferred over another. The expected service time $\mathbb{E}S$ of a checkout counter will be discussed in detail in the next section.

2.3 Service times

The service time at a checkout counter highly depends on the method of payment. Two payment methods are considered in this model. A customer can either pay cash or pay electronically with PIN. For computational reasons the two different service times are both assumed to have an exponential distribution. Denote with β_{pin} the expected service time for a customer paying electronically and let β_{cash} denote the expected service time of a customer paying cash. Now suppose that an arbitrary customer wants to pay electronically with probability p_{pin} and cash with probability p_{cash}. Hence, the service times S in the model of the traditional supermarket are assumed to be hyper exponentially distributed and hence, have the following characteristics:

$$\mathbb{E}S = \sum_{i=1}^{2} \frac{p_i}{\mu_i} = \frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{cash}} \tag{2.1}$$

$$\mathbb{E}S^2 = \sum_{i=1}^{2} \frac{2}{\mu_i^2} p_i = \frac{2}{\mu_{pin}^2} p_{pin} + \frac{2}{\mu_{cash}^2} p_{cash}, \tag{2.2}$$

where $\mu_{pin} = 1/\beta_{pin}$ and $\mu_{cash} = 1/\beta_{cash}$ are the service rates for the different payment methods. And note that $\mathbb{E}S$ denotes the expected service time and $\mathbb{E}S^2$ the second moment of the service time.

2.4 Interpreting the traditional model

As a result of Theorem 2.1 the model of Figure 2.1 can be interpreted as N independent $M|G|1$ queues. Performance measures for these queues come in two types. The first type of performance measures result from mean value analysis. The mean value analysis measures things such as average queue length and average sojourn time. The second type of performance measures concern tail probabilities, like the probability that more than k customers are waiting in the queue. These tail probabilities can only be computed if the stationary distribution of the number of customers in the system is known.

2.4.1 Mean Value Analysis

The mean value analysis for the $M|G|1$ queues of the model of the traditional supermarket can be performed using the *Pollaczek-Khintchine* formula (See for example [23]) for the expected number of customers in the queue $\mathbb{E}L$. Using Equations 2.1 and 2.2 this leads to:

$$\mathbb{E}L = \lambda\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{cash}}\right) + \frac{\lambda^2\left(\frac{2p_{pin}}{\mu_{pin}^2} + \frac{2p_{cash}}{\mu_{cash}^2}\right)}{2\left(1-\lambda\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{cash}}\right)\right)}. \quad (2.3)$$

where L denotes the average length of the queue including the customer in service, λ is the arrival rate, and S is the service time. As discussed in Section 2.3 the service times in the model of the traditional supermarket are assumed to be hyper exponentially distributed. Using *Little's law*, as described in [10], [23] and others, it is possible to obtain the average sojourn time $\mathbb{E}W$.

Law 2.1 (Little) *The expected number of customers in the system $\mathbb{E}L$ can be expressed in terms of the expected sojourn time $\mathbb{E}W$ as follows:*

$$\mathbb{E}L = \lambda\mathbb{E}W.$$

2.4.2 The distribution of the queue length

The distribution of the number of customers in the queue can be determined based on the lecture notes of J. Virtamo [27]. We start the derivation with the observation that there exists an embedded Markov chain, by means of which the distribution can be solved. This embedded markov chain has state transition epochs at the moment a customer leaves the system. The state of the chain is defined as the number of customers in the queue at the moment a departure takes place. From now on the following notation will be used:

- L_- = the queue length observed by an arriving customer;
- L_+ = the queue length observed by a departing customer;
- L = the queue length at an arbitrary moment.

By the PASTA property of a Poisson arrival process it holds that $L_- \sim L$. In addition to that, it also holds that $L_- \sim L_+$. Proof of the latter can be derived from Figure 2.2 below. The figure shows that the events $\{L_- = i\}$ and $\{L_+ = i\}$ occur pairwise for all i. Hence, $\mathbb{P}(L_- = i) = \mathbb{P}(L_+ = i)$, and thus $L_- \sim L_+$. Some simple logic tells that $\{L_- \sim L_+\} \cap \{L_- \sim L\} \Rightarrow L_+ \sim L$, so to find the distribution of L it is sufficient to find the distribution of the number of customers in the queue immediately after departures. From now on we focus on the discrete-event process formed by L_+. Since $L_+ \sim L$ we can forget about the plus and let L_k simply denote the state of the process (queue length) at the moment customer k departs. Furthermore, we introduce V_k, the number of customers arrived during the service time of customer k. The discrete-event process L_k constitutes a Markov chain. This can be proved by showing that L_{k+1} can be expressed in terms of L_k and a random variable V_{k+1} that is independent of L_k and its history:

$$L_{k+1} = L_k - 1 + V_{k+1}$$

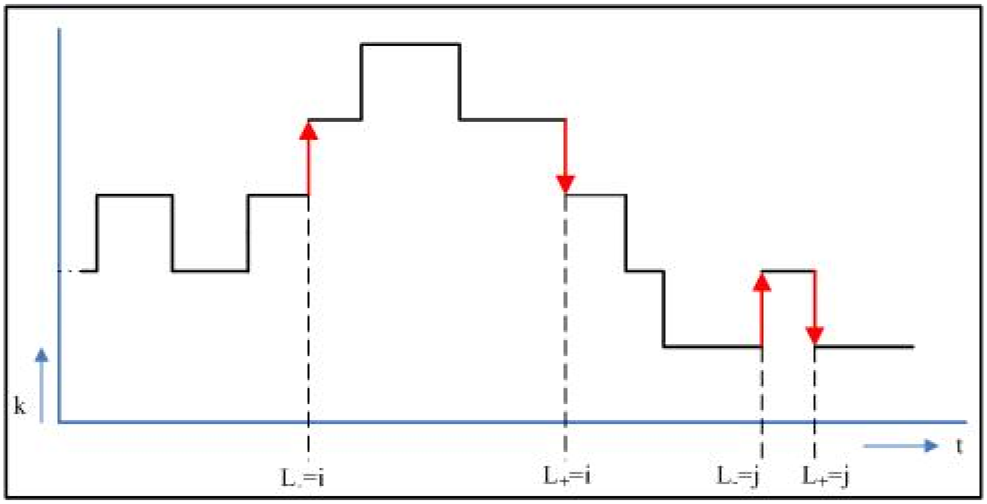

Figure 2.2: The arrival process in a graph

Virtamo [27] gives the following proof:

- If $L_k \geq 1$, then, upon the departure of customer k, customer $k+1$ is in the queue and enters the server immediately. The next state is viewed at the departure moment of customer $k+1$. At that moment there will be one customer less in the queue than at the previous departure (Customer $k+1$ left). However, during service of customer $k+1$ there have been V_{k+1} arrivals.
- If $L_k = 0$, the remaining queue at the departure moment of customer k is empty. Upon the arrival of customer $k+1$ the queue length will be incremented by one. However, this increment will be undone at the next transition epoch. Upon departure of customer $k+1$ the queue will only contain the customers arrived during the service time of customer $k+1$, which equals V_{k+1}.
- As the service times are independent and the arrivals are Poissonian, the V_k are independent of each other. Moreover, V_{k+1} is independent of the queue length process before the departure of customer k, i.e. L_k, and its previous values.

Hence, L_{k+1} depends on L_k but not on the earlier history. The Markov property holds and the process L_k constitutes a Markov chain.

□

The queue length distribution can now be determined algorithmically. In order to do so, consider the embedded Markov chain L_k. Now introduce $n_i = \mathbb{P}(V_{k+1} = i)$ and let $f_S(x)$ denote the probability density function of the service time S. By the law of total probability (see Koole [10], paragraph 1.4) it holds that

$$\begin{aligned} n_i &= \mathbb{P}(V_{k+1} = i) = \int_0^\infty \mathbb{P}(V_{k+1} = i | S = x) f_S(x) dx \\ &= \int_0^\infty \frac{(\lambda x)^i}{i!} e^{-\lambda x} f_S(x) dx, \qquad i = 0, 1, \ldots \end{aligned} \tag{2.4}$$

The values of n_i are needed for the transition probabilities of the Markov chain and can be calculated. For some simple distributions (like exponential) it can even be computed analytically. For the somewhat more complicated hyper exponential service times we have to rely on numerical methods. The transition probabilities are given by

$$p(i,j) = \mathbb{P}(L_{k+1} = j | L_k = i) = \begin{cases} \mathbb{P}(V_{k+1} = j - i + 1) & = & n_{j-i+1} & \text{if } i \geq 1 \\ \mathbb{P}(V_{k+1} = j - i) & = & n_{j-i} & \text{if } i = 0 \end{cases}.$$

The transition diagram in Figure 2.3 helps us find the following transition matrix:

$$\mathbf{P} = \begin{pmatrix} n_0 & n_1 & n_2 & n_3 & \cdots \\ n_0 & n_1 & n_2 & n_3 & \cdots \\ 0 & n_0 & n_1 & n_2 & \cdots \\ 0 & 0 & n_0 & n_1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}.$$

With these transition probabilities we can find the stationary probabilities π_i by solving the following set of recursion equations:

$$\begin{aligned} n_0\pi_1 &= (n_1 + n_2 + \ldots)\pi_0 \\ n_0\pi_2 &= (n_2 + n_3 + \ldots)\pi_0 + (n_2 + n_3 + \ldots)\pi_1 \\ n_0\pi_3 &= (n_3 + n_4 + \ldots)\pi_0 + (n_3 + n_4 + \ldots)\pi_1 + (n_2 + n_3 + \ldots)\pi_2 \\ &\vdots \\ n_0\pi_i &= (n_i + n_{i+1} + \ldots)\pi_0 + (n_i + n_{i+1} + \ldots)\pi_1 + \ldots + (n_2 + n_3 + \ldots)\pi_{i-1}. \end{aligned} \tag{2.5}$$

The recursion can be started with π_0, the fraction of time the system is empty. This is known to be $1 - \rho$, with ρ the fraction of time the server is busy, also called the load. With the value of π_i known for all i we can determine all desired tail probabilities. An interesting measure is the probability of more than n customers in the queue:

$$\mathbb{P}(L > n) = \sum_{i=n}^{\infty} \pi_i = 1 - \sum_{i=0}^{n-1} \pi_i.$$

With the stationary probabilities π_i known, we have acquired all necessary information about

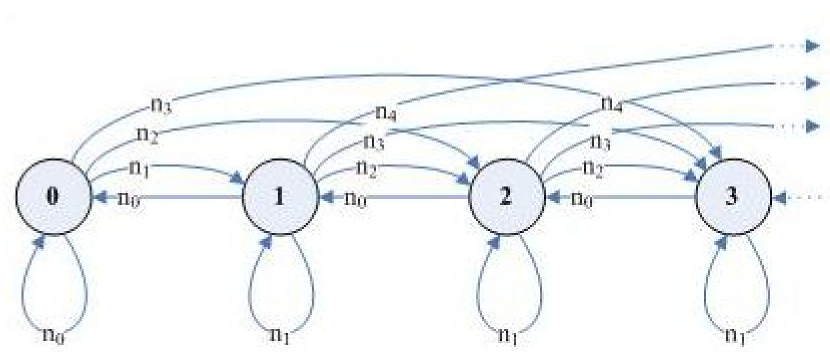

Figure 2.3: Transition diagram of the Markov chain.

the distribution of the queue length at the checkout counters. In order to be able to compare the traditional supermarket to the self checkout area of the C1000 supermarket, we use our findings on the distribution of the queue length to assign a performance measure to the traditional queuing model. This measure will be the expected sojourn time $\mathbb{E}W$ in the system. The expected sojourn time will be calculated given a certain amount of servers. The number of servers will be determined by means of the crowdiness of the supermarket. This can be done using the tail probabilities as defined before. We consider the supermarket as too crowded if the probability of more than 3

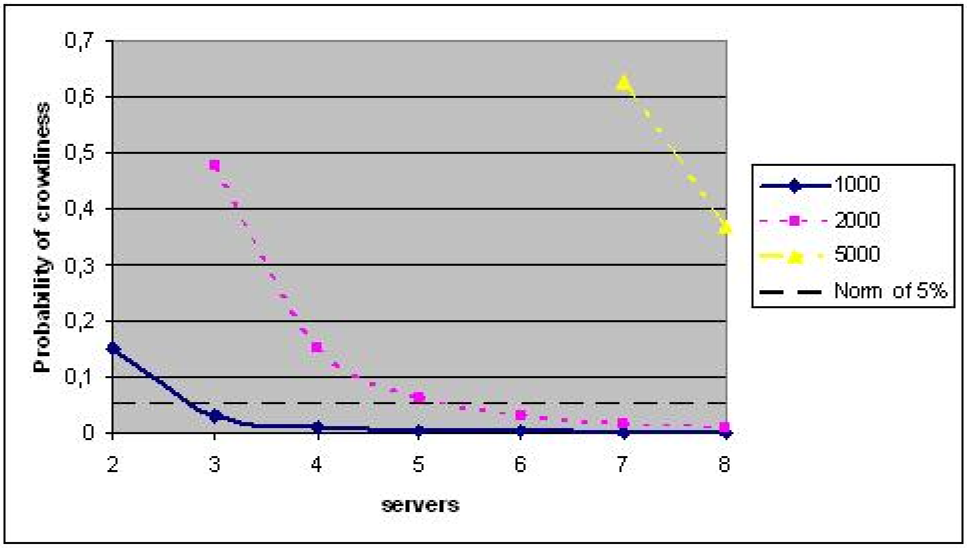

Figure 2.4: The probability of crowdiness

customers in the queue is larger than 0.05. Figure 2.4 shows the probability of the supermarket being too crowded, at arrival rates of respectively 1000, 2000 and 5000 customers per day. It is obvious that an arrival rate of 5000 customers per day requires a very large number of servers. The black dashed line in the figure is the crowdiness norm of 0.05. In the next section we measure the performance of the traditional supermarket with six available servers, since at that number of cashiers the probability of crowdiness at a moderate day (2000 customers) is less than 0.05. This number of servers will also be used to model the situation at C1000 in Chapter 3.

2.5 Computational example

In this section we describe a computational example. We use the statistical properties of the queue length, as described in the previous sections, to assign a performance measure to the queuing system of the traditional supermarket. For this purpose we first gather numerical data regarding the checkouts observed in practice.

De Nederlandsche Bank (DNB) has investigated methods of payment preferred by consumers in several counter based facilities. The results have been published in a quarterly report [6]. Interesting for our computational example is the ratio of cash paying customers relative to customers preferring to pay electronically. Figure 2.5 shows the results of our interest. From the figure we can learn that approximately 31% of the transactions in the supermarket is performed through cash payment. The rest of the transactions is performed electronically. In the model of the traditional supermarket we use the following probabilities for the payments, $p_{cash} = 0.31$ and $p_{pin} = 0.69$. The report from DNB also mentions average transaction times. Paying cash takes on average 19 seconds and paying electronically requires on average 26 seconds. The difference in service times of 7 seconds will be maintained in this computational example. Assuming that scanning the articles takes on average 30 seconds, we get the following expected service times. $\beta_{cash} = 30 + 19 = 49$ seconds and $\beta_{pin} = 30 + 26 = 56$ seconds.

We consider a supermarket with six checkout counters. As mentioned in the previous section, this number suffices to prevent crowdiness in the supermarket. The mean value analysis described in Section 2.4.1 can now be applied to measure the performance of the traditional supermarket in this computational example. We are interested in the expected sojourn time and the expected queue length. These measures can be obtained using the Pollaczek-Khintchine formulas from Section 2.4.1. The expected queue length of the traditional supermarket is displayed as a function

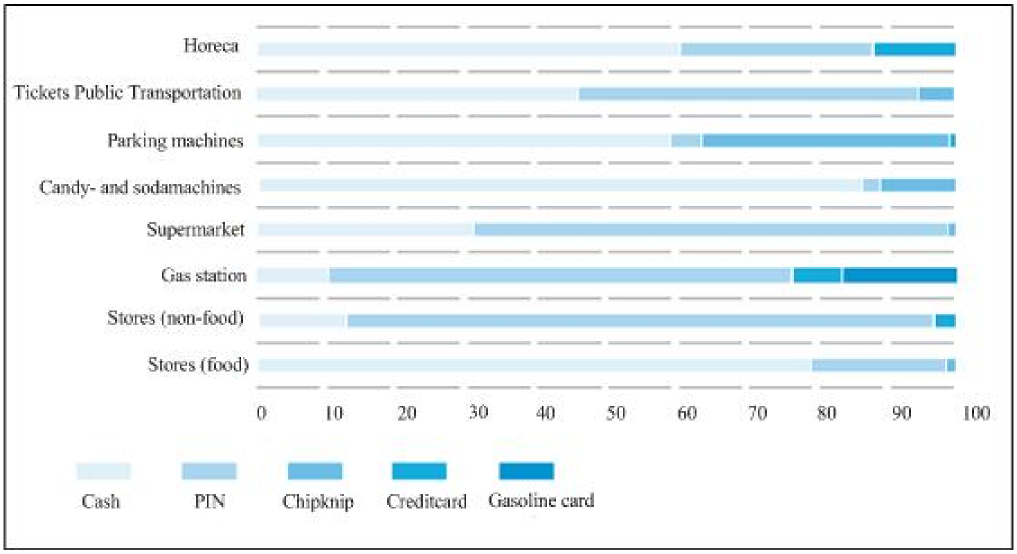

Figure 2.5: Distribution of payment methods at several counter based facilities. Source: DNB [6]

of the number of servers in Figure 2.6. The queue length expectation is again shown for 1000, 2000 and 5000 customers per day. The expected queue length at six servers is marked with a cirkel. Given the expected queue length it is possible to use Little's formula to obtain the expected

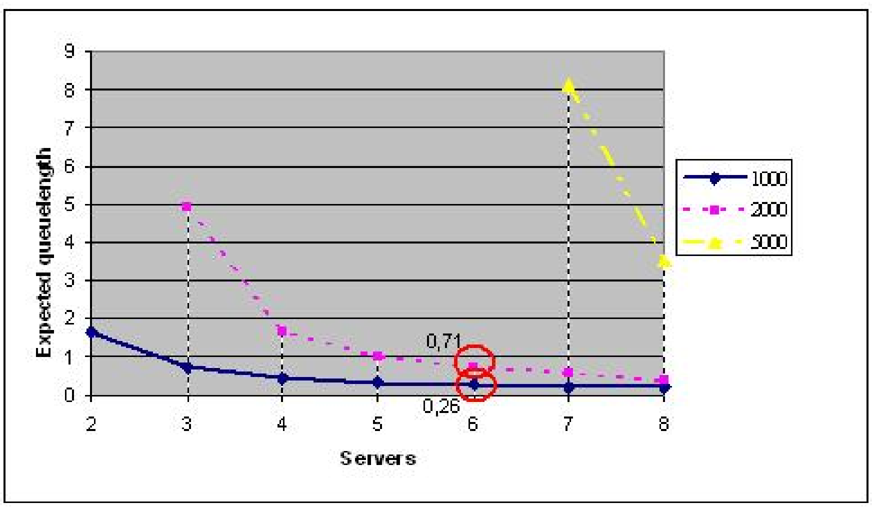

Figure 2.6: Expected queue length at different numbers of servers.

sojourn time $\mathbb{E}W$ in the traditional supermarket with six servers at a moderate day with 2000 visitors. Assuming the supermarket is opened for twelve hours a day, this leads to an arrival rate of ($\lambda = 2000/(12 \times 60 \times 60 \times 6) = 0.0077$) at each of the six servers. From Figure 2.6 we learn that $\mathbb{E}L = 0.71$ Hence,

$$\mathbb{E}W = \frac{\mathbb{E}L}{\lambda} = \frac{0.71}{0.0077} \approx 92.2.$$

Hence, a customer visiting this traditional supermarket can expect to be spending approximately 92.2 seconds at the checkout region.

Chapter 3

Self checkout at C1000

Since the traditional supermarket is completely modeled and evaluated in Chapter 2, it is now time to introduce the self checkout counters. All N traditional checkout counters will be replaced by N self checkout machines. The replacement of the counters has some consequences for the model. The arrival process remains the same. Customers still arrive according to a Poisson process and select checkout machine i with probability $p_i = 1/N$. The rest of the new model will be different from the traditional model. The new model can still be described as an open network of queues. However, in addition to the traditional model, the network now includes a second set of queues. Figure 3.1 gives an illustration of the network. It shows N parallel self checkout counters followed

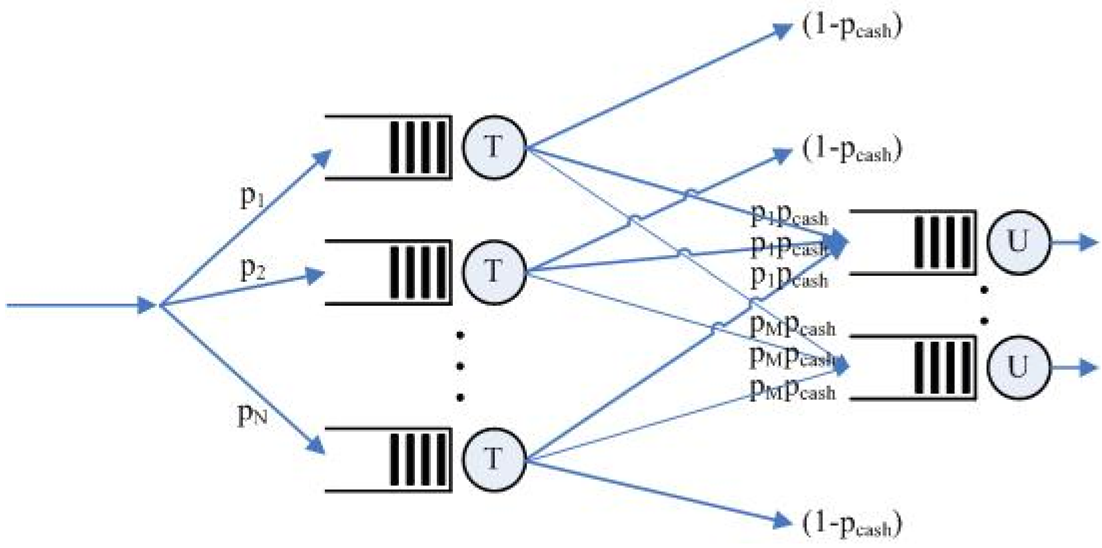

Figure 3.1: The C1000 modeled as an open queuing network.

by a second set of queues. This second system contains the counters at which the cash payments will be performed. Apart from the arrival process all components have changed relative to the traditional model. The self checkout machines have different service times T and the departure processes at the self checkout machines start to play a role. As the departures are not Poissonian, the second set of qeueus consists of $G|G|1$ queues instead of the $M|G|1$ queues evaluated before. As mentioned in remark 5.3.5 of Koole [10] there is no exact expression for the $G|G|1$ queue. However, the famous Pollaczek-Khintchine formula can be used as the basis for an approximation of the expected sojourn time of the $G|G|1$ queue:

$$\mathbb{E}W \quad \approx \quad \mathbb{E}S + \frac{\rho \mathbb{E}S \left(c^2(A) + c^2(S) \right)}{2(1-\rho)}, \tag{3.1}$$

where S is the service time, ρ is the load on the $G|G|1$ queues, A is the expected inter arrival time, and $c^2(x)$ is the squared coefficient of variation of x. In order to perform a mean value analysis we need information about the departure process of the self checkout machines and the service times at the cash payment counters. All the desired information will be provided in the next sections.

3.1 Service times at the self checkout machines

Two different routines can be performed at a self checkout machine. With probability p_{cash} the customer is paying cash. In that case the only action performed at the self checkout machine is scanning the products. Because of the computational advantages we again assume an exponentially distributed scanning time with expectation β_{scan}. The second routine will take place with probability $p_{pin} = 1 - p_{cash}$. In this case the customer is paying electronically. This method of payment is available at the self checkout machines. The service time at the machines in this scenario consists of scanning the products and paying electronically. We assume that a customer is able to scan and pay the products just as fast as the cashier in the traditional system. The resulting overall service time at the self checkout machines is assumed to be exponentially distributed with expectation β_{scan}, with probability p_{cash}, whereas the expectation is β_{pin}, with probability $p_{pin} = 1 - p_{cash}$. Hence, the service times T at the self checkout machines are again hyper exponentially distributed.

3.2 Departure process at the self checkout machines

As discussed in the previous section, the service times of the self checkout machines are not just exponentially distributed. The choice for the more realistic hyper exponential distribution has consequences for the departure processes of each of the servers. In case of exponential distributions the departure processes would simply be new Poisson processes. The departure processes in the C1000 model are somewhat more complicated. The output of the parallel $M|G|1$ queues is the input for the cash counters. As mentioned before we need some characteristics of the departure process to perform a mean value analysis. First we need the expected inter departure times $\mathbb{E}(D)$ or the departure rate λ_i of self checkout machine i. In equilibrium the outflow of a server equals the inflow and hence, $\lambda_i = \lambda/N$. Furthermore we need the squared coefficient of variation $c^2(D)$ of the departure process. In chapter 5 of Graves, Rinnooy Kan, and Zipkin [9] we find the following approximation:

$$c^2(D) \quad = \quad (1-\rho^2)c^2(A) + \rho^2 c^2(S), \tag{3.2}$$

where ρ is the load on the server, A is the stochastic variable denoting the inter arrival time, and S denotes the hyper exponentially distributed service time. The coefficient of variation of a probability distribution is defined as the ratio of the standard deviation to the mean: $c_s = \sigma_S/\mathbb{E}S$. The inter arrival times A at the self checkout machines are exponentially distributed and thus $c^2(A) = 1$ (see chapter 7 of Thijms and Kalvelagen [24]). The first and second moment of the expectation of the hyper exponential distribution are known (see (2.1) and (2.2)). Hence, by using the relation $\sigma_S^2 = \mathbb{E}S^2 - (\mathbb{E}S)^2$ (see chapter 4 of Ross [13]) in combination with (2.1) and (2.2) we derive $c^2(S)$:

$$\begin{aligned} c^2(S) = \frac{\sigma_S^2}{\mathbb{E}^2 S} \quad &= \quad \frac{\frac{2}{\mu_{pin}^2} p_{pin} + \frac{2}{\mu_{scan}^2} p_{cash} - \left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}}\right)^2}{\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}}\right)^2} \\ &= \quad \frac{\frac{2}{\mu_{pin}^2} p_{pin} + \frac{2}{\mu_{scan}^2} p_{cash}}{\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}}\right)^2} - 1. \end{aligned} \tag{3.3}$$

Using Equation (3.3) in Equation (3.2), and using that the squared coefficient of variation of a Poisson arrival process equals 1, the following expression for $c^2(D)$ yields:

$$c^2(D) \quad = \quad (1-\rho^2) + \rho^2 \left(\frac{\frac{2}{\mu_{pin}^2} p_{pin} + \frac{2}{\mu_{scan}^2} p_{cash}}{\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}} \right)^2} - 1 \right). \tag{3.4}$$

Using that the load ρ on the self checkout machine equals

$$\rho \quad = \quad \lambda \mathbb{E} S = \lambda \left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}} \right), \tag{3.5}$$

we can write Equation (3.4) as

$$c^2(D) \quad = \quad 1 - 2\left(\lambda \left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}} \right) \right)^2 + \lambda^2 \frac{\frac{2}{\mu_{pin}^2} p_{pin} + \frac{2}{\mu_{scan}^2} p_{cash}}{\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}} \right)^2} \tag{3.6}$$

3.3 Arrival processes at the cash payment counters

In the previous section we derived an expression for the squared coefficient of variation of the departure process at a self checkout machine. The next step is to determine the desired characteristics of the arrival processes at the cash counters. The model of the C1000 supermarket is a network of $G|G|1$ queues. The departure process at each of the self checkout counters is split into $M+1$ flows: one flow to each of the M cash payment counters and one flow leaving the system. The overall arrival process at cash counter j consists of the combination of all flows departing from the N self checkout machines that arrive at counter j. Denote by C_{ij}^2 the squared coefficient of variation of the flow leading from self checkout machine i to cash payment counter j. Zijm [30] gives the following expression for the squared coefficient of variation of the flow from i to j.

$$C_{ij}^2 \quad = \quad p_{ij} c^2(D_i) + 1 - p_{ij}, \tag{3.7}$$

where $c^2(D_i)$ denotes the squared coefficient of variation of the departure process at self-checkout machine i. This coefficient equals the result of equation (3.6) for all i, since all self-checkout machines are identical. Furthermore, a customer moves from self-checkout machine i to cash counter j with probability p_{ij}, where $p_{i0} = p_{pin}$ is the probability that the customer leaves the system. The cash counters are assumed to be identical and hence, the probability that a customer chooses cash counter j equals p_{cash}/M for all $j = 1, \ldots, M$. Hence,

$$C_{ij}^2 \quad = \quad \frac{p_{cash}}{M} c^2(D_i) + 1 - \frac{p_{cash}}{M}. \tag{3.8}$$

The final step toward the squared coefficient of variation of the arrival processes is combining the flows arriving at the cash counter. Many research has been performed on approximations for combined flows. Here we will use the approximation of Whitt [28]:

$$c^2(A_j) \quad = \quad w_j \sum_{i=0}^{N} Q_{ij} C_{ij}^2 + 1 - w_j, \qquad j = 1, \ldots, M, \tag{3.9}$$

where

$$w_j = \frac{1}{1 + 4(1-\rho_j)^2 (v_j - 1)}, \qquad j = 1, \ldots, M, \tag{3.10}$$

and

$$v_j = \left(\sum_{i=0}^{N} Q_{ij}^2 \right)^{-1}, \qquad j = 1, \ldots, M. \tag{3.11}$$

Hence, required input for the calculation of the squared coefficients of variation are the values of Q_{ij}, denoting the fraction of the arrival flow at cash counter j that originates from self checkout machine i. Because of the assumption of similar cash counters this value equals $1/N$ for each counter. Hence,

$$v_j = \left(\sum_{i=0}^{N} \left(\frac{1}{N} \right)^2 \right)^{-1} = \left(\frac{N}{N^2} \right)^{-1} = \frac{N^2}{N} = N, \tag{3.12}$$

and

$$w_j = \frac{1}{1 + 4(1-\rho_j)^2(N-1)}, \qquad j = 1, \ldots, M. \tag{3.13}$$

Hence,(3.9) can be written as

$$c^2(A_j) = \frac{1}{1 + 4(1-\rho_j)^2(N-1)} \sum_{i=0}^{N} \frac{C_{ij}^2}{N} + 1 - \frac{1}{1 + 4(1-\rho_j)^2(N-1)}, \quad j = 1, \ldots, M; \tag{3.14}$$

With Equation (3.14) the squared coefficients of variation $c^2(A)$ of the arrival processes at the cash counters have been fully defined. Now, before we can apply Equation (3.1) to calculate the expected sojourn time, we need one more ingredient: the load on the cash payment counters.

In order to calculate the load on the cash checkout counters, we use a characteristic of a queuing system in equilibrium: The inflow of a server equals the outflow. Hence, the outflow λ_i at self checkout counter i equals λ/N. Each outflow is split up into two parts. With probability p_{pin} a customer leaves the system. Let λ_{i0} denote the flow leading from self checkout counter i out of the system. Then $\lambda_{i0} = p_{pin} \frac{\lambda}{N}$. The remainder of the flow from self checkout counter i continues toward the cash checkout region. Since each cash checkout is assumed to be identical the flow λ_{ij} from self checkout i to cash counter j equals $p_{cash} \frac{\lambda}{N} \frac{1}{M}$ for all i, j.

The final ingredient for the calculation of the load on the cash counters is the expected service time. This is relatively easy to define. Service at the cash counters only consists of one possible action: handling the payment. The service times U at the cash counters are assumed to be exponentially distributed with mean β_{pay}. The load ρ on server j can be defined as $\lambda_j \mathbb{E} S_j = N \cdot \lambda_{ij} \mathbb{E} S_j$. Hence,

$$\rho_j = \frac{\lambda p_{cash}}{M} \beta_{pay}, \qquad \text{for all} \quad j. \tag{3.15}$$

Now, using all ingredients gathered in this chapter, we can summarize the expression for the expected sojourn time $\mathbb{E}W_{cash}$ at the cash checkout area as follows:

$$\mathbb{E}W_{cash} \approx \mathbb{E}S + \frac{\rho \mathbb{E}S \left(c^2(A) + c^2(S) \right)}{2(1-\rho)}, \tag{3.16}$$

$$\mathbb{E}S = \beta_{pay}, \tag{3.17}$$

$$\rho = \frac{\lambda p_{cash}}{M} \beta_{pay}, \tag{3.18}$$

$$c^2(A_j) = \frac{1}{1 + 4(1-\rho)^2(N-1)} \sum_{i=0}^{N} \frac{C_{ij}^2}{N} + 1 - \frac{1}{1 + 4(1-\rho)^2(N-1)}, \tag{3.19}$$

$$C_{ij}^2 = \frac{p_{cash}}{M} c^2(D_i) + 1 - \frac{p_{cash}}{M}, \qquad \text{for all} \quad j, \tag{3.20}$$

$$c^2(D_i) = 1 - 2 \left(\lambda \left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}} \right) \right)^2 + \lambda^2 \frac{\frac{2}{\mu_{pin}^2} p_{pin} + \frac{2}{\mu_{scan}^2} p_{cash}}{\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}} \right)^2} \qquad \text{for all} \quad i, \tag{3.21}$$

$$c^2(S) = 1 \qquad \text{(exponential distribution)} \tag{3.22}$$

3.4 Interpreting the C1000 model

As mentioned before the model of the C1000 configuration can be analyzed like an open queuing network. The first part of the network consists of N parallel $M|G|1$ queues with a Poisson arrival process and hyper exponential service times. The second part consists of M parallel $G|M|1$ queues with exponential service times and an arrival process defined by the departure processes of the $M|G|1$ queues. Based on these observations we will compare the performance of the new model with the traditional model through mean value analysis. The expected sojourn time in the new supermarket can be computed as follows.

Let W_s denote the sojourn time at the self checkout machines and let W_c be the sojourn time at the cash counters. With probability p_{pin} the customer only uses the self checkout machines. With probability $p_{cash} = 1 - p_{pin}$ the customer has to visit a cash counter. The expected sojourn time $\mathbb{E}W$ of the new supermarket can be expressed as follows:

$$\mathbb{E}W = p_{pin} \times \mathbb{E}W_s + p_{cash} \times (\mathbb{E}W_c + \mathbb{E}W_s) \tag{3.23}$$

3.5 Computational example

In the previous sections we have gathered all necessary ingredients for the mean value analysis of the new system. In this section each component will be computed separately before they will be combined into an overall expected sojourn time. The first component that will be dealt with is the expected sojourn time at the self checkout desks $\mathbb{E}W_s$. This expectation can be computed rather straightforward from the Pollaczek-Khintchine formula.

$$\mathbb{E}L_s = \lambda\mathbb{E}S + \frac{\lambda^2\mathbb{E}S^2}{2(1-\lambda\mathbb{E}S)} \tag{3.24}$$

$$= \lambda\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}}\right) + \frac{(\lambda/N)^2\left(\frac{p_{pin}}{\mu_{pin}^2} + \frac{p_{cash}}{\mu_{scan}^2}\right)}{2\left(1-(\lambda/N)\left(\frac{p_{pin}}{\mu_{pin}} + \frac{p_{cash}}{\mu_{scan}}\right)\right)}, \tag{3.25}$$

where $\mu_{scan} = 1/\beta_{scan}$. For computational efforts we assume that β_{scan} equals 30 seconds, which is just the original β_{cash} minus the cash transaction time of 19 seconds as described in the report from DNB [6]. The number of self checkout machines N is assumed to be 6, being the optimal number of servers found in Section 2.5. The arrival rate is again chosen to represent a moderate day with a total of 2000 customers arriving. With all these parameters set we find as average queue length $\mathbb{E}L_s = 0.60$. Hence, using Little's law again, we find that

$$\mathbb{E}W_s = \frac{\mathbb{E}L_s}{\lambda} = \frac{0.60}{0.0077} = 77.9. \tag{3.26}$$

From this result we can already draw the first conclusion. If a customer prefers to pay electronically, he or she benefits from the self checkout region. The checkout procedure takes place at the self checkout counters only. Hence, the expected sojourn time in the checkout area equals $\mathbb{E}W_s$. Compared to the traditional supermarket, the sojourn time decreases by $92.2 - 77.9 = 14.3$ seconds.

Now, using Equation 3.16, we learn that

$$\mathbb{E}W_c \approx \mathbb{E}S + \frac{\rho\mathbb{E}S\left(c^2(A) + c^2(S)\right)}{2(1-\rho)} = 19.3 \quad \text{seconds},$$

and thus

$$\mathbb{E}W = p_{pin} \cdot 77.9 + p_{cash} \cdot (77.9 + 19.3) = 83.4 \quad \text{seconds},$$

almost 9 seconds shorter than in the traditional supermarket.

From this computational example we can conclude that the sojourn time in the checkout area decreases due to the introduction of the self checkout counters. Especially when a customer pays electronically, the new checkout methodology results in a strong reduction of the sojourn time.

Chapter 4

Pro's and cons of self scanning

In the previous chapters we discussed the theoretical consequences of self checkout systems. The analysis of the different queuing models pointed out that self checkout counters can decrease sojourn times and shorten the queue lengths. Theoretically the new approach seems to be an outcome for all the annoyance a customer runs into when visiting a supermarket.

After years of pilots and test phases, several supermarkets have now started to enroll the self checkout concept. Time to test whether the theoretical conclusions also hold in practice. In this chapter we discuss several practical consequences of the self checkout system. We address the consequences for three different groups of stakeholders: the customers, the supermarket management, and the employees or cashiers.

4.1 Customer perception

An important measure for the self checkout systems is the way customers experience the new shopping methodology. Many proponents of the system propagated with the advantages the self checkout counters have for the customers. Queues would decrease to a minimum, sojourn times would be shortened and the increased amount of responsibility would give the customer an extra feeling of freedom.

Interviews with customers and responses on internet forums indeed proved several advantages of the new system. Besides the advantages mentioned before, several other issues appeared to play a role. An important observation was that many customers appreciated the fact that the self checkout counters are always open. Customers are no longer dependent of the number of cashiers available.

The lack of a cashier results in both positive and negative reactions. An interesting observation is the fact that customers appeared to appreciate the responsibility over their own products. Several customers stated that they often denounced the way a cashier treated the products in the old situation. Hasty operations often caused food to be crushed and eggs to be broken. Now that the customer is responsible for its own goods, no angry looks have to be exchanged because of some dispute about the way products are treated.

The overall customer perception is positive. People using the machines even seem to enjoy it. Some minor disadvantages can be mentioned. There are some arguments against the lack of cashiers. First there is the fact that the machines do not work flawlessly. If the scanner declines a product, or refuses service in some other way, a cashier or service employee remains indispensable. The way employees respond to problems is not always experienced as good and fast.

Besides the sometimes questionable response to problems, there is the social aspect of the presence of a cashier. Several customers mentioned the fact that shopping should be a social event. The cashier is often referred to as a nice opportunity for some social interaction. Critics pretend that the self checkout machines cause people to drift further apart. The comparison with shopping on line is often made. People no longer meet other people while obtaining their daily needing.

Another minor shortcoming of the new methodology is the fact that there is no possibility (yet) to withdraw additional money at the automatic counters. For this purpose the person either has to line up at the traditional counter or has to pay a visit to the cash dispenser around the corner.

Some customers have their doubts about the system being theft-proof. Several people mentioned their concern about the relative ease at which products can be 'forgotten'. Supermarket chain Albert-Heijn responded to this concern with the announcement that anomalies in the advantage of the customer probably evened out against the mistakes of the customer in the company's advantage. Besides, the regular random checks discourage the customer to restrain any products. These checks are not experienced as annoying. It only happens once in a while and the disturbance does not even out against the everlasting queues at the traditional checkout counters.

4.2 Added value for the supermarket

Implementing a self checkout area is an expensive operation. It requires an investment of somewhere between 75,000 and 100,000 euro's. An article on Distrifood [8], an independent news site for supermarkets, mentions that self scanning is three times as expensive as the traditional method per checkout. Besides, several tests pointed out that the large investment needed for a self checkout zone is only effective with at least 6 checkouts, and if more than 40 percent of all transactions is actually being performed by means of the new checkout method.

The checkout systems initially leave the supermarket with a huge amount of costs. However, they are not just a source of expenses. The supermarkets also benefit from the machines by means of increasing efficiency when it comes to staffing requirements. The new system makes cashiers redundant which causes the staffing costs to decrease. Spokesmen of the major supermarkets dismiss this argument by stating that the cashiers will not be replaced, but rather attain a new role as service provider. However, once the customer is getting used to the new system, service will be required less frequent, and many cashiers will become redundant after all. Staffing requirements decrease and the supermarket saves costs.

An interesting observation is the fact that the cost arguments mentioned above do not seem to be the main discussion when it comes to the decision whether to implement the self checkout service or not. Large players in the field, like Albert Heijn and C1000, dismiss this kind of arguments by stating that the costs do not compensate for the many advantages the new system provides. The supermarkets view the self checkout area as an extra quality of service for the customer. The customer perception described in the previous section appears to be a strong argument for C1000 and its competitors to take the costs for granted and to use the system as a means to be competitive in the area of quality of service rather than in the area of costs.

4.3 Cashiers: the victims

As mentioned in the previous section, cashiers seem to become redundant if the self checkout revolution continues. Despite of the promises of employers that cashiers will only attain a new role, we believe that on the long run the cashiers may be considered as the victims of this innovation. Although staffed checkouts will probably exist adjacent to the new system for a while, the staffing requirements will decrease. Especially as the customers get more and more used to the new situation, and cashiers will no longer be needed as service providers.

Chapter 5

Alternatives

5.1 The hand scanner of Albert Heijn

Albert Heijn is a competitor of C1000. Afraid to lose the battle for the shortest queue Albert Heijn introduced its own self checkout system. When entering the Albert Heijn supermarket the customer faces a wall of so-called hand scanners. A machine next to the wall asks the customer for his membership card (AH bonuskaart). As soon as the card is read one of the hand scanners lights up. The customer takes the scanner from the wall and enters the supermarket. On his way through the supermarket the customer scans the bar codes of all his collected products. When the customer has gathered all the required goods he proceeds to the checkout corner, an unmanned machine designed to perform electronic payments. The checkout post once again asks for the membership card and determines the price of the gathered goods. The customer now chooses a method of (electronic) payment, pays, returns the handscanner to the wall and proceeds homeward.

5.1.1 Advantages and disadvantages of the handscanner

The main advantage of the handscanner is saving time. The customer no longer has to wait in a line to scan the gathered goods. The only possible queue might occur at the checkout corner with relatively short service times. Another advantage is the fact that the customer can see the total costs of the goods in his basket at any given time. Customers no longer get shocked hearing the price of the goods at the checkout counter.

The handscanner also offers a huge advantage to the retailer. The staffing requirements decrease significantly as soon as the system is fully integrated in the supermarket. During the roll out phase one might need extra personnel to help the customers getting familiar with the new device. However, as soon as the customers get used to the system, many cashiers will be redundant. Especially when the store also decides to introduce the cash payment machines. The only personnel needed in that scenario will be some service personnel and someone performing the random checks.

The hand scanners have two major disadvantages. The first one is the lack of an option to pay cash. The checkout corners only accept electronical payment. This makes the system less effective for 'basket customers' that require only a small amount of products. About half of these customers prefers to pay cash. The lack of this option, however is a disadvantage that can be resolved by introducing extra checkout corners that can handle cash payments. An example of such a machine is the CashPoint, designed by the Dutch company Scangineers BV. More about this CashPoint can be found in Section 5.3. A more difficult disadvantage is the increased sensitivity for fraud. Customers could easily 'forget' to scan one or more articles. Albert Heijn tries to prevent theft by performing random checks on customers leaving the supermarket. A third disadvantage is mentioned as an advantage before. The retailer will benefit from the reduction of staffing requirements. The employees, however, will have to fear for their jobs.

Figure 5.1: The hand scanners of Albert Heijn

5.2 Radio Frequency Identification

A new and upcoming technique that could further resolve the queuing problem in the supermarket is Radio Frequency Identification, or RFID. Dekker [7] explains RFID as a small chip that can transmit a radio signal containing an identification code. A commonly used standard for these identification codes is the Electronic Product Code (EPC). The number transmitted by the RFID tag can be looked up in a central EPC database. This database contains the meaning of the transmitted number and links the number to products, producers, serial numbers etcetera. There are two types of RFID tags. Active tags have their own power source to generate their outgoing signal. These active tags have a large range and are very reliable. Unfortunately active tags are not very well suited for the foodstuffs branch. At present the smallest active RFID tags have about the size of a cold capsule and cost a few dollars. It is simply too expensive to fit all products with an RFID tag. More interesting for the supermarket is the passive RFID tag. The passive version has no power source of its own. The power needed to transmit the identification code is provided by the RFID receiver. The incoming radio frequency signal provides just enough power for the tag to transmit a response. The lack of an on board power supply means that the device can be very small. In February 2007 Hitachi created an RFID device measuring 0.05x0.05mm, and thin enough to be embedded in a sheet of paper. A pioneering supermarket in the area of RFID is WalMart. They were the first to introduce the technique in 7 stores throughout Texas. WalMart uses RFID tags that cost about $0,05 a piece and have the size of a postage stamp.

5.2.1 Advantages and disadvantages of RFID

The challenge for the RFID tag in the supermarket branch is to compete with the traditional bar code. The RFID tag has some interesting characteristics that the bar code lacks. The RFID tags work at a distance. The consequence is that the scanner or receiver does not have to be aimed at the code or tag. RFID technology enables tag reading from a greater distance, even in harsh environments. The greatest ambition of the supermarket branch is to be able to identify all products in a shopping cart in a small time instance. This would yield a significant decrease in waiting times at the checkout counters since the products no longer have to be scanned one by one. Another advantage is the storage capacity of the RFID tag. The identification code transmitted by the RFID tag can be much longer than the bar code. This creates a larger number of available codes and makes it possible to track each product individually. The bar code only identifies the type of product.

The RFID tag could be a very interesting technology for all sorts of applications. However, the technology is still rather immature. The signals transmitted by the tags are sensitive to attenuation. The product's packaging reduces the amplitude and intensity of the signal. Suppliers of WalMart in the United States have tried to successfully introduce the RFID tags in their production lines for several years now. However, the technology did not work as good as expected.

In practice, the successful read rates currently run only 80%[1]. The suppliers faced another difficulty with the introduction of RFID. The new technology is relatively expensive and especially small suppliers find it hard to create return on investment (ROI). Only very large companies such as Procter&Gamble are able to benefit from the RFID technology. Paul Fox, a spokesman for P&G Global Operations said at computerworld.com [4]: *"We have seen significant benefits within our own four walls. It's helping streamline processes and making them more efficient. We know what we're about to ship, and there are no errors and no picking the wrong case and no miscounting"*. Large suppliers like Procter&Gamble are able to create ROI through large volume transactions. Small suppliers do not have that luxury and face the relatively high costs of the new technology.

5.2.2 C1000 and RFID

As mentioned in the 2004 annual report of schuitema NV [21], C1000 is very interested in RFID technology. The supermarket likes the possibility of driving a shopping cart along an RFID receiver to scan all products at once. Although the technology is still rather immature, Schuitema NV sees great opportunities in RFID and is in several ways involved with the development of the technology. Schuitema's chairman of the executive board Jan Brouwer is also chairman of the Task force RFID, an initiative of Centraal Bureau Levensmiddelenhandel (CBL, the Dutch authority of Food retail) and the Dutch Federation of Foodstuffs Industry (FNLI). Moreover, Schuitema NV cooperated with Accenture, Hewlett Packard, KPN, Philips, Rabobank en SAP to set up the RFID Foundation in the Netherlands. Goal of this foundation is to join forces and knowledge in the area of RFID to perform research and stimulate its applications. At present C1000 has made a first step toward implementation of RFID by starting a test in the distribution center in Woerden. Containers are equipped with passive tags in order to identify and track them.

5.3 Automatic cash payments

Automatic cash payment is not really an alternative for the self checkout machines. It is actually an extension to the system. Scangineers BV, a Dutch company producing self checkout machines, mentions in its brochure [14] the possibility to integrate a so-called CashPoint in the self checkout region. The CashPoint enables the customer to perform cash payments as well as electronic payments. The main advantage of this extension is further reduction of staffing requirements.

[1]The test phase of RFID at WalMart turned out that on average 20% of the tags do not function properly

Chapter 6

Conclusions

Throughout the years the foodstuffs branch has evolved from the traditional grocery store to high tech supermarkets with self checkout machines. During this process, the queues at the checkout desks have also experienced some radical changes. In this thesis we discussed both theoretical and practical consequences of the introduction of self checkout counters.

In order to perform theoretical analysis on the impact of self checkout systems we modeled both the traditional supermarket and the new supermarket with a self checkout region. The traditional supermarket can be modeled as a set of N independent $M|G|1$ queues. The arrival process at each of these queues can be described by means of Poisson processes. Service times are assumed to be exponentially distributed.

The $M|G|1$ queue provides us with several opportunities to measure the performance of the traditional supermarket. Using Little's law and the Pollaczek-Khintchine formula we were able to perform a mean value analysis. Moreover, we were able to approximate the distribution of the queue length. The mean value analysis and the approximation of the queue length distribution gave us the opportunity to calculate several measures for an artificial traditional supermarket. Interesting statistics can be derived such as the probability that more than k customers are in the queue, and the expected sojourn time in the system.

The model of the traditional supermarket can be used as a reference when evaluating the new system with self checkout counters. In order to do so, we also modeled the new situation. This model is slightly more complicated. The new model can be described as an open network of queues, with two sets of queues. The first set consists of the self checkout counters, whereas the second set consists of the cash payment counters for customers who do not use the possibility of paying electronically. Due to this new situation we can no longer use the interesting properties of the $M|G|1$ queues. The arrival process at the second set of queues (the cash payment counters) depends on the departure process at the self checkout counters, which is not Poissonian. A consequence of this fact is that the second set of queues consists of $G|G|1$ queues instead of $M|G|1$ queues.

There is no exact expression for the sojourn time of the $G|G|1$ queue. However, using the Pollaczek-Khintchine formula, we managed to derive an approximation for the expected sojourn time in the queue. Furthermore, we used ideas of Graves, Rinnooy Kan, and Zipkin [9], Thijms and Kalvelagen [24], and Zijm [30] to derive several statistical properties of the new queuing system.

The models of the traditional supermarket and the new self checkout supermarket provided us with tools to make a theoretical comparison between both queuing mechanisms. The main conclusion of this comparison is the fact that the average sojourn time in the queuing system decreases because of the introduction of self checkout counters. The average sojourn time is decreased from 92 seconds to 83 seconds by means of the self checkout area. This is a reduction of approximately 10%. For an electronically paying customer the reduction in sojourn time is even larger (15%).

The theoretical results obtained by means of the models are based on several assumptions. Judging the new queuing system merely on the results of the model, is therefore rather naive. After years of pilots and test phases, several supermarkets have now started to enroll the self checkout concept. Hence, experience from practice can support the theoretical comparison. Findings of three different groups of stakeholders gave us a good impression of the true impact of the self checkout regions.

An important group of stakeholders is formed by the customers of the supermarket. The customers point of view revealed the following advantages:

- sojourn times decrease;
- self checkouts give the customers more responsibility leading to a feeling of freedom;
- self checkout counters are always open;
- customers are responsible for their own goods: no dispute about how to treat the products.

and the following disadvantages:

- self checkouts eliminate the social interaction with a cashier;
- machines do not work flawlessly;
- there is no possibility to withdraw cash at the self checkout counters;
- there are doubts about the system being theft proof.

A second group of stakeholders is formed by the supermarkets and their managers. Implementing a self checkout area is an expensive operation. Although costs can be saved through decreasing staffing requirements, self checkout areas still seem to be more expensive than the traditional system. However, the cost arguments do not seem to be the main discussion when it comes to the decision whether to implement the self checkout service or not. Large players in the field, such as Albert Heijn and C1000, dismiss this kind of arguments by stating that the costs do not compensate for the many advantages the new system provides. The supermarkets view the self checkout area as an extra quality of service for the customer. Supermarkets use the system as a means to be competitive in the area of quality of service rather than in the area of costs.

The last group of stakeholders is the group we refer to as the victims of the self checkout system. The employees (cashiers) become redundant because of the unmanned checkout machines. Although the staffed checkout counters will probably exist adjacent to the new system for a while, the staffing requirements will decrease. Especially as customers get more and more used to the new situation, and cashiers will no longer be needed as service providers.

Besides the self checkout machines of C1000, there exist several alternative methodologies of self checkout systems. Albert Heijn seems to be outrunning the competitors with its handscanner. This system has been successfully tested in several Albert Heijn stores throughout the country. Besides the handscanner of Albert Heijn there exists a revolutionary system called Radio Frequency Identification (RFID). However, this technique is still in a rather premature stadium of development. High costs and frequent errors still form obstacles for comprehensive implementation of this new system.

Overall we conclude that self checkout areas offer great advantages to most stakeholders. Customer perception is the most important driver for implementing the new system. C1000 is not the only player in the field of self checkout systems, and several alternatives are competing for victory in the revolution of the checkout area.

Bibliography

[1] Albrecht: *Supermarket Cards: The Tip of the Retail Surveillance Iceberg*,
Denver University Law Review, Volume 79, Issue 4, pp. 534-539 and 558-565
(2002)

[2] Bose: *An introduction to queuing systems*,
Springer: ISBN 0306467348
(2002)

[3] Clerx: *Middenstandsbeleid, realiteit of leuze*,
Politieke Opstellen 8, Centrum voor Parlementaire Geschiedenis, Radboud Universiteit Nijmegen
(1988)

[4] Computerworld: *Procter&Gamble: Wal-Mart RFID Effort Effective*,
Computerworld, edition February 26, 2007
http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=284160
(2007)

[5] De Jager: *Albert Heijn. Memoires van een optimist*,
De Prom, Amsterdam: ISBN 9057132737
(1997)

[6] De Nederlandse Bank: *Hoe consumenten betaalmiddelen beleven: een publieksmeting*,
DNB Kwartaalbericht 2005
(2005)

[7] Dekker: *FAQ: Radio frequency identification*,
Emerce, edition 38, May 21
(2004)

[8] Distrifood.nl: *AH en C1000: zelfscan is service*,
http://www.distrifood.nl/bedrijfsvoering/id540-49756/ah_en_c1000_zelfscan_is_service.html
(2007)

[9] Graves, Rinnooy Kan, and Zipkin: *Logistics of Production and Inventory*,
Handbooks in Operations Research and Management Science, Vol. 4: Logistics of Production and Inventory.
(1993)

[10] Koole: *Optimization of Business Processes: An Introduction to Applied Stochastic Modeling*,
version of April 4, 2007
(2007)

[11] Latouche and Ramaswami: *Introduction to Matrix Analytic Methods in Stochastic Modelling*,
1st edition. Chapter 2: PH Distributions
(1999)

[12] Rijkens: *Handel en Wandel, nagelaten gedenkschriften 1888-1965*,
Ad Donker, Rotterdam
(1965)

[13] Ross: *A first course in probability*,
6th edition, Prentice Hall: ISBN 0130338516
(2001)

[14] Scangineers BV: *ScanPoint modulair zelfscan concept v0.1*,
Brochure Scangineers September 2005
(2005)

[15] Schrover: *De Fiva als een bijzondere variant van collectieve verticale prijsbinding, 1928-1975*,
NEHA jaarboek 1996, pp 292-329
(1996)

[16] Schuitema nieuwsarchief: *Consumenten rekenen zelf boodschappen af*,
http://www.schuitema.nl/files/financieel/2002/magaz-fjv-2002_04-09.pdf
(2002)

[17] Schuitema nieuwsarchief: *Proef met zelfscankassa's wordt uitgebreid*,
http://www.schuitema.com/default.asp?action=KlapUitMenu&MenuItemid=104&SubMenuItemid
=110&archief=true&nieuwsid=105
(2003)

[18] Schuitema nieuwsarchief: *Schuitema in platform RFID Nederland*,
http://www.schuitema.nl/default.asp?action=KlapUitMenu&MenuItemid=104&SubMenuItemid
=110&archief=true&nieuwsid=142
(2004)

[19] Schuitema NV: *Inspelen op veranderend consumentengedrag*,
Jaarverslag 2002
(2002)

[20] Schuitema NV: *Werken aan de winkel*,
Jaarverslag 2003
(2003)

[21] Schuitema NV: *Kosten verlagen, efficiency verbeteren*,
Jaarverslag 2004
(2004)

[22] Schuitema.nl: *C1000/innovaties: zelfscankassa's*,
http://www.schuitema.nl/default.asp?action=ShowMenuHorizontaal&MenuItemID=65&SubMenuItemid
=166&ContentID=167

[23] Thijms: *Operationele Analyse, een inleiding in modellen en methoden*,
Epsilon Uitgaven Utrecht, ISBN 9050410755
(2002)

[24] Thijms and Kalvelagen: *Modelbouw in de operations research*,
Academic Service Schoonhoven, ISBN 9052611157
(1994)

[25] Van der Velden: *Ondernemen in Detailhandel 2002, sectorscoop*,
EIM Zoetermeer
(2002)

[26] Virtamo: *Queueing Theory / Poisson process*,
Lecture notes October 2005
http://www.netlab.hut.fi/opetus/s383143/kalvot/E_poisson.pdf
(2005)

[27] Virtamo: *Queueing Theory / The M/G/1 queue*,
Lecture notes October 2005
http://www.netlab.hut.fi/opetus/s383143/kalvot/E_mg1jono.pdf
(2005)

[28] Whitt:*Approximating a point process by a renewal process. two basic methods*,
Operations Research, volume 30, number 1
(1982)

[29] Yan and Veeraraghavan: *Networks of queues*,
lecture notes April 19, 2004
http://www.ece.virginia.edu/∼mv/edu/715/lectures/QNet.pdf
(2004)

[30] Zijm: *Manufacturing and logistic systems analysis, planning and control*,
Dictation
(2003)