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Supporting time-based competition with the help of production and operation management

Theoretical verification of the application of line structuring rules in service systems

Theses of doctoral dissertation

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CONTENTS

1. SCIENTIFIC BACKGROUND AND OBJECTIVES OF THE RESEARCHES

Company competitiveness is determined by the strength and steadiness of the possessed competitive advantages (Porter, 1993). In the last two decades, companies, which are successful in cost- and quality-based competitions, are looking for other factors that can help them to gain further competitive advantage. Time has turned into a strategic resource and, as a consequence, its importance has become equivalent to the significance of money, productivity and innovation (Stalk, 1988). Consequently, time-based competition nowadays spreads among leading companies; time has turned into a strategic resource.

In service systems, the most important time parameters are related to customer waiting. Waiting is an important determinant of service level and customer satisfaction (Taylor, 1994). As a part of the service-profit chain, customer waiting strongly influences profitability as well (Heskett et al., 1994). Consequently, reducing dissatisfaction related to waiting is highly important in service systems, and managers try to decrease customer waiting (Kostecki, 1996). So the search for configurations of waiting lines and service facilities which can reduce waiting time has become a major concern of service managers (Hill et al., 2002).

To reduce customer waiting, primarily waiting times should be analyzed. With the help of *queuing theory*, different waiting measures can be determined (Hillier–Lieberman, 1995). Based on these measures, *production and operations management* tries to optimize operation, attempts to minimize customer waiting (Koltai, 2003). However, the waiting experience cannot be described only with objective waiting measures. *Perception management* researches the subjective social and psychological factors which influence the perception of waiting duration (Larson, 1987). Companies which are successful in time-based competition try to improve both objective and subjective waiting measures (Nie, 2000).

To study queuing systems analytical and empirical models can be used. Analytical models are based on the formulae of queuing theory (Kleirock, 1975). These formulae are valid only for simple queuing models. Complex queuing systems and queuing networks can be analyzed with empirical models, with simulation. Queuing theory helps rapid modelling; simulation supports sophisticated studies (Suri, 2009).

In time-based competition, companies have to become competitive in the area of time parameters but they also have to hold on in cost- and quality-based competitions (Li–Lee, 1994). A queuing system configuration which corresponds to all of these objectives is the application of line structuring rules. A special implementation of line structuring rules is the introduction of express checkouts. When express checkouts are applied two customer groups are created. The number of items that controls line-type (checkout) selection is called limit value. As the limit value has great impact on waiting times, the effects of introducing express checkouts on customer waiting should be known in advance. Accordingly, the objectives of my researches can be summarized as follows:

- Review of the different measures which can be used to express customer waiting. Surveying the opportunities for optimizing the operation of queuing systems using different waiting measures and objective functions.
- Analyzing the effects of line structuring rules on customer waiting. Studying the impact of the control parameter of line structuring rules on their waiting reduction effects.
- Deriving formulae and constructing tools to analyze the effects of line structuring rules on customer waiting without the actual application of express checkouts.
- Proving that line structuring rules can improve customer satisfaction, that is, in time-based competition, competitive advantage can be gained by the application of express checkouts.

2. METHODS OF RESEARCH

I have studied the operation of line structuring rules and their effects on customer waiting. Line structuring rules are widely used in production and service systems for reducing waiting times. I have illustrated my results with the data of the real queuing system of a do-it-yourself superstore.

I have begun my researches with *literature review*. I have studied the formation of time-based competition and its tools which can be used to reduce waiting times in service systems. I have also reviewed the results of waiting time analyses. These researches have included the review of different analytical tools and the survey of objective and subjective waiting measures which can be used to analyze customer waiting.

Based on the results of literature review, I have developed a numerical model using the formulae of queuing theory. After the *model development*, I have analyzed the effects of express checkouts on waiting times. With the real data of a do-it-yourself superstore, I have demonstrated that the input data of the model can be gained with simple *data collection* and without the actual introduction of express checkouts. Using the results of *statistical analyses* of the input data, I have also built a simulation model to verify my analytical results.

My researches have proved the hypothesis that the control parameter of line structuring rules, the limit parameter of express lines has great impact on waiting times. However, the results have not confirmed that the application of express checkouts can significantly reduce customer waiting. Therefore, I have refined the objective function of waiting minimization. For this, I have used the results of psychophysics, perception management and utility theory. The operation optimization with the different objective functions based on objective and subjective waiting measures have formed a comprehensive *analytical method* of customer waiting. With this method, I have proved that deliberately planned line structuring rules are an important tool of operation managers to support time-based competition.

3. NEW SCIENTIFIC RESULTS

Companies, which are successful in cost- and quality-based competitions, are looking for other factors that can help them to gain further competitive advantage. Consequently, time-based competition spreads among leading companies; time has turned into a strategic resource. While companies have to hold on in cost- and quality-based competitions, they also should become competitive in the area of time parameters.

Time parameters can appear in several forms. In service systems, the most important time parameters are related to customer waiting. Consequently, the search for configurations of waiting lines and service facilities which can reduce waiting time has become a major concern of service managers.

3.1. Thesis 1

A queuing system configuration frequently used to reduce customer waiting is the application of express checkouts. When express checkouts are applied two customer groups are created. The number of items that controls line-type (checkout) selection is called limit value. Customers buying more items than the limit value have to use the regular checkouts. When the number of items bought is less than or equal to the limit value, customers can join the express lines. As the limit value has great impact on waiting times, the effect of introducing express checkouts on customer waiting should be known before the actual introduction of the special servers.

> **Thesis 1: I have determined a formula for the M/G/1 and the M/G/*k* queuing models to express the relationship between the average waiting time in queue and the control parameter of express line systems. I have demonstrated that these functions have a minimum and I have determined the optimal limit value which minimizes the average waiting time.**

(Related publications: S1, S4, S8, S12, S15)

The average waiting time in queue (t_S) can be calculated as the weighted average of waiting time in express lines (t_{SE}) and the waiting time in regular lines (t_{SR}) where the weights are calculated according to the possibilities of using the different checkout types,

$$t_S(L) = \sum_{i=1}^{L} p_i t_{SE}(L) + \sum_{j=L+1}^{K} p_j t_{SR}(L), \qquad (1)$$

where the waiting times are the functions of the limit parameter (L), and to calculate them the arrival rates (λ_E and λ_R), the service rates (μ_E and μ_R) and the standard deviations of service times (σ_E and σ_R) are needed. The formulae to determine these values can be found in the dissertation.

Based on theoretical considerations, I have proved that the average waiting time in queue as a function of the limit parameter follows a U-shaped curve (Figure 1). It can also be concluded that a minimal waiting time exists and it can be achieved by using the optimal limit value.

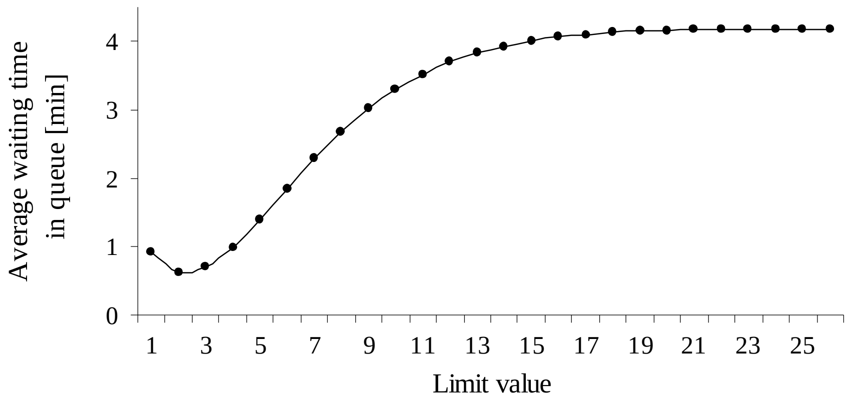

Figure 1: Average waiting time as a function of the limit parameter

The minimum of the deduced formula cannot be determined analytically. However, as the number of the possible limit values (the feasible solutions) is limited, the optimal value can be determined numerically. To analyze the operation of express line systems, I have constructed a numerical model with the help of Microsoft Excel. The structure of the model, with the real data of a do-it-yourself superstore, can be seen in Figure 2. In the case presented in Figure 2, the minimal waiting time can be achieved when customers buying maximum 2 items can use the express checkouts.

3.2. Thesis 2

Models, based on the analytical formulae of queuing theory, cannot take into consideration every detail of the operation of complex queuing systems. Therefore, to analyze the operation of express line systems, simulation also needs to be used.

> **Thesis 2: I have constructed a simulation model which deals with the effect of human behaviour on waiting duration. I have defined some queue selection rules to analyze the waiting time reduction effects of different customer behaviours and studied the conditions of their applications.**
>
> *(Related publications: S1, S5, S7)*

Arrival rate (l) [customer/hour]	95
Average number of items bought (*l*)	3.0890
Fixed element of service time (*a*) [min]	0.5463
Variable element of service time (*b*) [min]	0.1622
Number of lines (*P*)	5
Number of express lines (*E*)	2
Sample size (*N*)	146

Limit parameter (*L*) / Number of items bought (*i*)	**1**	**2**	**3**	**4**	**5**	**6**
Density function (p_i)	0.3237	0.2189	0.1481	0.1001	0.0677	0.0458
Distribution function (P_i)	0.3237	0.5427	0.6907	0.7908	0.8585	0.9043
Service time when *i* item is bought (t_i)	0.7085	0.8707	1.0329	1.1951	1.3573	1.5195
Variation of service time (σ_i^2)	0.0016	0.0012	0.0011	0.0012	0.0015	0.0021
Arrival rate to the express line (λ_E)	0.5126	0.8592	1.0936	1.2522	1.3594	1.4319
Service time in the express lines (t_E)	0.7085	0.7739	0.8294	0.8757	0.9137	0.9444
Service rate in the express lines (μ_E)	1.4114	1.2921	1.2056	1.1419	1.0944	1.0589
Variation of service time (σ_E^2)	0.0016	0.0078	0.0178	0.0305	0.0452	0.0608
Arrival rate to the regular line (λ_R)	1.0708	0.7241	0.4897	0.3312	0.2240	0.1515
Service time in the regular lines (t_R)	1.2095	1.3717	1.5339	1.6961	1.8583	2.0205
Service rate in the regular lines (μ_R)	0.8268	0.7290	0.6519	0.5896	0.5381	0.4949
Variation of service time (σ_R^2)	0.1557	0.1483	0.1373	0.1207	0.0954	0.0562
Average waiting time in the line {M/G/1}						
Express lines (t_{SE})	0.0788	0.1953	0.3531	0.5526	0.7892	1.0529
Regular lines (t_{SR})	0.5083	0.3663	0.2711	0.2036	0.1538	0.1163
All lines (t_S)	0.3693	**0.2735**	0.3278	0.4796	0.6994	0.9633
Average waiting time in the line {M/G/*k*}						
Express lines (t_{SE})	0.0121	0.0487	0.1102	0.1957	0.3024	0.4247
Regular lines (t_{SR})	0.0663	0.0330	0.0160	0.0075	0.0034	0.0015
All lines (t_S)	0.0488	**0.0415**	0.0810	0.1563	0.2601	0.3842

Figure 2: The numerical model

I have constructed a simulation model to analyze the operation of express line systems with the help of Arena (Rockwell Automation) discrete simulation software. The structure of the model can be seen in Figure 3.

To simulate the waiting time reduction effects of customer behaviour, I have studied the impacts of different line selection rules on average waiting times. I have analyzed two built-in and five user-defined line selection rules.

– *RANdom (RAN) rule*. Customers randomly choose among the available waiting lines. This built-in rule assumes that customers cannot or do not make considerable effort to decrease their waiting.

– *Smallest Number in Queue (SNQ) rule*. According to this built-in rule, customers join to the shortest waiting line. However, this rule does not make any difference between the busy and idle servers when their waiting lines are empty.

– *Smallest Number in System (SNS) rule*. I have defined this rule based on the SNQ rule. The SNS rule differentiates idle and busy servers with empty waiting lines by reckoning the number of customers in system instead of the number of customer in line. Consequently, this rule gives a better approximation of customer behaviour when traffic is low.

– *Minimal WorkLoad (MWL) rule*. I have defined the workload presented by each waiting line as the number of items bought by all customers in that waiting line. This rule is preferred to SNQ rule because it takes into consideration the differences among the service times of the certain customers.

– *Fewest Last Items (FLI) rule*. Counting the number of items bought by all customers in the queue is generally impossible. The number of items bought by the last customers in the different queues, however, can be easily observed. In these situations, customers can select a queue according to the FLI rule. This rule generally complements the SNQ or SNS rule and it is used only in cases when there are many identically short waiting lines.

– *Minimal Perceived Amount (MPA) rule*. Even if customers can observe the amounts bought by other customers, it is hard to tell exactly how many items they have. However, it can be easily decided that they have bought few or many items. The weighted sum of these subjective values gives the *perceived* workload presented by a queue.

– *Shortest Service Time (SST) rule*. It takes into account that waiting times have two parts: the first part depends on the number of items bought by previous customers; the other is independent of it. The independent part (caused by the time needed for payment) is influenced by the number of customers in queue. Customers, according to their experiences, can use different weights to calculate the weighted sum of number of customers and number of items, that is, to estimate the other customers' total service times and their own waiting time.

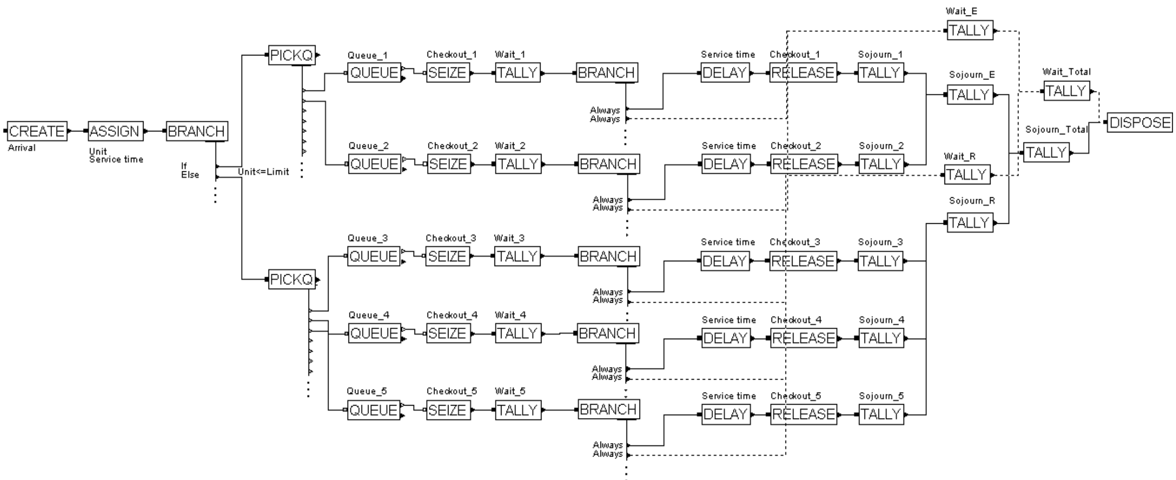

Figure 3: Simulation model

The different line selection rules assume different efforts of customers to reduce their waiting times. The rules, from the more accurate through the simpler ones, however, cover properly the whole range of the possible customers' behaviours to reduce their waiting.

3.3. Thesis 3

With the help of the constructed models, I have analyzed the waiting time as a function of the limit parameter. I have concluded that the limit value has great impact on average waiting time. An express line system with an inappropriate limit value can significantly increase customer waiting. I have illustrated my results with the real data of a do-it-yourself superstore.

> **Thesis 3: I have proved with the results of sensitivity analyses that the changes in the parameters and structure of the model do not influence significantly the optimal value of the limit parameter when the numbers of express and regular checkouts are given.**

(Related publications: S4, S5, S8, S11, S15)

By determining the optimal limit value with different parameter values, the sensitivity of the optimal limit value can be calculated. The results of the sensitivity analyses of the main parameters of the express lines systems are listed in Table 1. Based on these data, I have concluded that the changes of parameter values (when the numbers of express and regular checkouts are given) do not influence the optimal limit value significantly.

Table 1: Results of sensitivity analyses

	Actual value	Independent validity range
Arrival rate [customer/hour]	180	…$25 \le \lambda \le 250$…
Number of items bought	3.089	$2.6 \le l \le 3.5$
Fixed element of service time [min]	0.5463	$0.225 \le a \le 1$…
Variable element of service time [min]	0.1622	$0.05 \le b \le 0.3$…
Number of regular checkouts	3	$3 \le R \le 4$
Number of express checkouts	2	$2 \le E \le 2$
Ratio o express and regular lines	2/3	$2/3 \le E/R \le 2/3$

The sensitivity analysis of the model structure means the study of the changes caused by nonparametric characteristics (stochastic distributions, line selection rules). Based on the results of simulations using different distributions and rules, I have concluded that these characteristics influence the waiting times but do not affect the shape of the curve of the waiting time as a function of the limit parameter and the optimal limit value (Table 2).

Table 2: The effect of line selection rules on waiting times [min]

			Limit value			
			1	2	3	4
Line selection rules	Built-in	RANdom (RAN)	0.3403	**0.2570**	0.3125	0.4614
		Smallest Number in Queue (SNQ)	0.3638	**0.3219**	0.3366	0.3945
	User-defined	Smallest Number in System (SNS)	0.0688	**0.0561**	0.1002	0.1821
		Minimal WorkLoad (MWL)	0.3631	**0.3218**	0.3358	0.3911
		Fewest Last Item (FLI)	0.3636	**0.3218**	0.3356	0.3909
		Minimal Perceived Amount (MPA)	0.3632	**0.3218**	0.3359	0.3916
		Shortest Service Time (SST)	0.3632	**0.3217**	0.3356	0.3908

Based on the results of sensitivity analyses, I have concluded that it can be considered a general characteristic of express line systems that the waiting time as a function of the limit parameter can be described with a U-shaped curve and that an optimal limit value (minimizing average waiting time) exists.

3.4. Thesis 4

Service managers generally use average waiting time to describe customer waiting. Waiting time is, however, a stochastic value. Therefore, besides measures of central tendency, measures of statistical dispersion must be analyzed as well. Furthermore, in their decisions about waiting people are risk-averse. Consequently, for minimizing the risk, minimizing the variance of waiting time should be another important management objective. Moreover, in services where people have to endure waiting, the actual and the perceived waiting times should also be distinguished.

> **Thesis 4: I have deduced the formulae which express the standard deviation of the actual waiting time and the mean of the perceived waiting time as a function of the limit parameter. Based on theoretical considerations and on simulation results, I have proved that the change of the mean and standard deviation of actual and perceived waiting times as a function of the limit value show similar pattern and, in most cases, their values are minimized by the same limit value.**
>
> *(Related publications: S1, S5, S6, S14)*

Using M/G/1 and M/G/k models, the standard deviation of waiting times can be calculated or estimated. For the calculation, the arrival rates (λ_E and λ_R), the service rates (μ_E and μ_R) and the standard deviations of service times (σ_E and σ_R) are needed. The formulae to determine these values can be found in the dissertation. Using these formulae, I have deduced a formula to express the relationship between the standard deviation of waiting times and the limit parameter.

The standard deviation of waiting times can be determined with the help of simulation as well. Based on result gained by simulation, I have concluded that the mean and standard deviation of actual waiting times as a function of the limit value show similar pattern and, in most cases, their values are minimized by the same limit value (Figure 4).

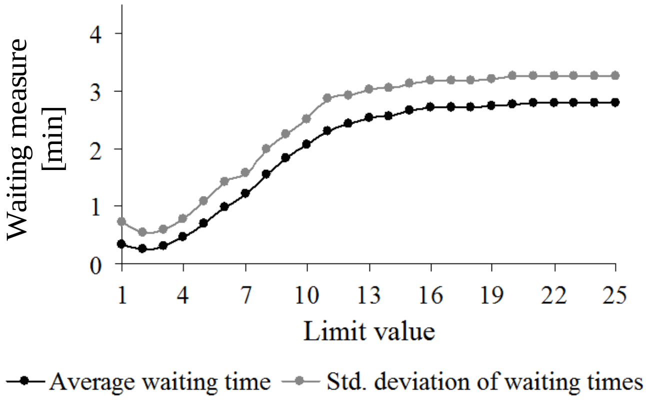

Figure 4: The mean and standard deviation of waiting times as functions of the limit parameter

In my researches, using the result of Antonides et al. (2002), I have described the relationship between actual and perceived waiting time with the following formula,

$$\psi_j^* = t_{Sj}^{\beta_p}, \qquad (2)$$

where ψ^*_j is the (modified) perceived waiting time of customer j, β_p is the perception coefficient, t_{Sj} is the actual waiting time of customer j.

With the help of the simulation model, I have determined the perceived waiting times according to (2) applying different values for the perception coefficient. Using the results of these transformations, I have determined the mean and standard deviation of perceived waiting times. Based on the researches, I have concluded that the mean and standard deviation of actual and perceived waiting times as a function of the limit value show similar pattern, and in most cases their values are minimized by the same limit value (Table 3).

Table 3: The mean of perceived waiting time [min] as a function of the limit value and the perception coefficient

		Limit value			
		1	2	3	4
Perception coefficient	0.1	0.3914	**0.3716**	0.4222	0.5034
	0.2	0.3225	**0.2959**	0.3508	0.4438
	0.3	0.3106	**0.2784**	0.3332	0.4314
	0.4	0.3070	**0.2691**	0.3235	0.4269
	0.5	0.3066	**0.2626**	0.3168	0.4258
	0.6	0.3086	**0.2581**	0.3124	0.4277
	0.7	0.3130	**0.2554**	0.3098	0.4323
	0.8	0.3197	**0.2544**	0.3091	0.4394
	0.9	0.3288	**0.2550**	0.3100	0.4491

3.5. Thesis 5

Using different limit values the mean and standard deviation of the actual and perceived waiting times are highly variable. To prevent from increasing customer waiting the optimal limit value should be determined. However, express line systems operating with the optimal limit value cannot decrease customer waiting significantly. In spite of this, express line systems are popular among customers. This popularity leads to the conclusion that customer waiting should be defined according to the satisfaction of the customers.

> **Thesis 5: Determining the dissatisfaction related to waiting with utility functions, I have deduced a formula to express the relationship between the satisfaction and the limit parameter. Based on theoretical considerations and calculations, I have proved that express line systems using appropriate limit value can decrease customers' dissatisfaction caused by waiting. Consequently, the main benefit of express checkouts is not the decrease of average waiting time but the better allocation of short and long waiting times among the different customer groups.**

(Related publications: S5, S10, S18)

In my researches, using the result of Kumar et al. (1997), I have described the relationship between actual waiting time and customer satisfaction with the following formula,

$$S = -A_1 T_0^{\gamma_1} e^{(-rT_0)} - A_1 T_0^{\gamma_1} e^{(-rT_0)} r \cdot t_x = S_0 + S_1 t_x, \qquad (3)$$

where S is customer satisfaction, A_1 is the value of time, T_0 is the expected waiting time, γ_1 expresses the *direct* effect of expected waiting time on satisfaction, r represents the risk averseness of customers, t_x is the mean of waiting time in queue, S_0 is the initial level of dissatisfaction (independent of the actual waiting time), S_1 is the dissatisfaction depending on waiting time.

By transforming the results of the numerical model according to (3), I have concluded that using an objective function maximizing customer satisfaction does not refine the optimum of the formerly reviewed objective functions (Figure 5). Consequently, there is no need for applying difficult objective functions and complex tools to determine the optimal operation of an express line system. The optimal limit value of an express line system can be determined by minimizing average waiting time in queue and using the constructed numerical model.

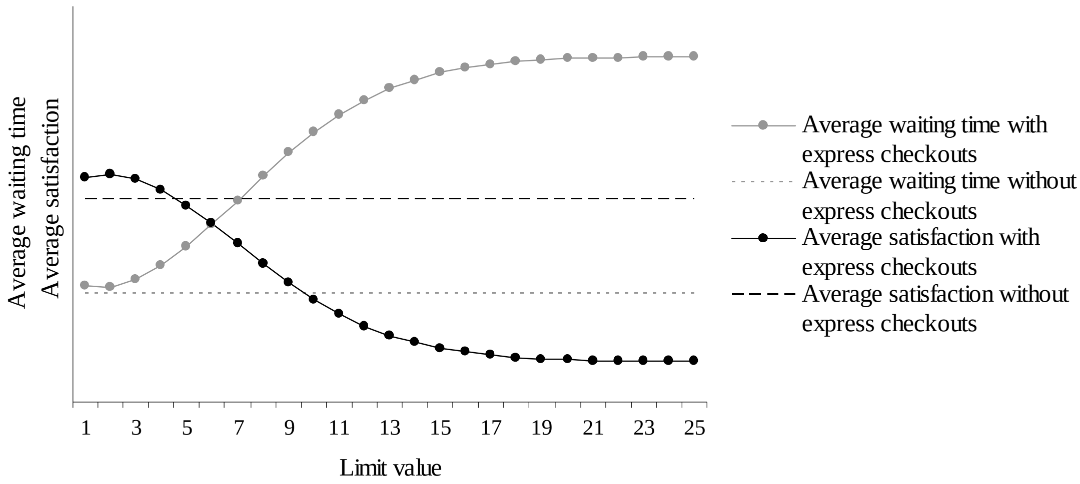

Figure 5: The average waiting time and average satisfaction as functions of the limit parameter

My results have also proved that, in the term of satisfaction, higher service level are offered in queuing systems with express checkouts than in systems without special servers (Figure 5). That is, companies can gain competitive advantage by applying express checkouts.

4. PRACTICAL UTILIZATION AND FURTHER RESEARCH AREAS

The objective of my researches has been to verify scientifically the application of line structuring rules in service systems. The results of my analyses help managers to make decisions related to express line systems.

Theses (1) and (2) are related to the tools for analyzing the operation of express line systems. These tools can help managers to get information about the effects of line structuring rules on customer waiting without actually introducing or changing the rules.

Theses (1), (4), and (5) describe the relationship between the waiting measures and the limit parameter. They also underline that the limit value of an express line system should be determined carefully because inappropriate limit values significantly increase waiting times.

Thesis (3) states that the optimal limit value is robust to the changes of the parameter values and system structure. It means that there is no need for frequent changes in limit value; however, in different queuing systems (when the number of express and regular lines is changing), the optimal limit value should be reconsidered.

Theses (1), (4), and (5) introduce different objective functions to optimize the operation of express line systems. Managers can use the objective most suitable for the demand of their customers. The results of the optimization with the different objective functions, however, underline that, in some cases, there is no need for difficult objective functions and complex tools to determine the optimal operation of a queuing system. In express line systems, the application of simple waiting time minimizing objective function and simple analytical models are enough to determine optimal operation.

Thesis (5) deals with customer satisfaction and underlines that, even in time-based competition, overall waiting time minimization is not necessarily the main objective. In some cases, the better allocation of short and long waiting times among the different customer groups can have more favourable effects.

As the results of my researches, I have constructed a management tool for rapid modelling and a method to thoroughly analyze customer waiting. With their help, the managerial decisions related to the operation of express line systems can be supported.

The investigation of other areas where the results of the dissertation can be used is an important possibility for further research. Other line structuring rules can be analyzed, and the researches can be broadened to production systems as well. An important research area is to analyze when the different objective functions gave the same results. In these cases, the optimization of operation becomes simpler, which help managers' everyday work.

5. LIST OF PUBLICATION RELATED TO THE DISSERTATION

Book chapters

S1. Kalló N. and Koltai T., Rapid Modeling of Express Line Systems for Improving Waiting Processes. In G. Reiner (Ed.): *Rapid Modelling for Increasing Competitiveness*. Springer, 2009, pp. 119-129. L

S2. Koltai T., Kalló N., and Tatay V., Az optimumkeresés problémái a termelés- és szolgáltatásmenedzsmentben (Problems of Optimization in Production and Operations Management). In Veresné dr. Somosi M. (Ed.): *Vezetési ismeretek III.* University of Miskolc, 2009, pp. 104-115.

S3. Koltai T. and Kalló N., Az expressz-pénztárak működtetésének elméleti és gyakorlati megfontolásai (Theoretical and Practical Issues of Operating Express Line Systems). In Sikos T. T. (Ed.): *A bevásárlóközpontok jelene és jövője*. Selye János Egyetem Kutatóintézete, 2007, pp. 160-178. L

International Journal Paper

S4. Koltai T., Kalló N., and Lakatos L., Optimization of Express Line Performance: Numerical Examination and Management Considerations. *Optimization and Engineering* (IF=1,048), Vol. 10, No. 3, 2008, pp. 377-396. L,R

Domestic Published Foreign-Language Journal Paper

S5. Kalló N. and Koltai T., A Review of Management Issues Related to Express Line Systems. *Periodica Polytechnica Social and Management Sciences*, Vol. 16, No. 1, pp. 1-12, 2008. L

Published International Conference Papers

S6. Kalló N. and Koltai T., Management Objectives for Operating Express Line Systems. *microCAD 2009, International Scientific Conference, Economic Challenges in the XXI Century Section*. Miskolc, Hungary, March 19-20, 2009, p. 115-119. L

S7. Koltai T. and Kalló N., The Effect of Queue Selection on Optimal Limit Value of Express Line Systems. *microCAD 2008, International Scientific Conference*, Miskolc, Hungary, March 20-21, 2008, pp. 103-108. L

S8. Koltai T. and Kalló N., Quantitative Analysis of Waiting Time in Express Lines at Cash Desks. *5th ANZAM Operations Management Symposium*, Melbourne, Australia, July 6-7, 2007, pp. 1-12. LH1

S9. Koltai T. and Kalló N., Model Selection for Express Line Optimization. *microCAD 2007, International Scientific Conference, Company Competitiveness in the XXI Century Section*, Miskolc, Hungary, March 22-23, 2007, pp. 149-154. L

S10. Kalló N., Involving Subjective Customer Information in Operations Management Decisions. *4th International Conference for Young Researchers of Economics*, Gödöllő, Hungary, October 2-4, 2006, pp. 153-158. L

S11. Koltai T. and Kalló N., Analysis of Management Decisions Related to Express Line Systems. *microCAD 2006, International Scientific Conference, Economic Challenges Section,* Miskolc, Hungary, March 16-17, 2006, pp. 185-190. L

S12. Koltai T. and Kalló N., Optimizing the Average Waiting Time at the Cash Desk of a Supermarket. *microCAD 2005 International Scientific Conference, Company Competitiveness in the XXI Century Section*, Miskolc, Hungary, 2005, March 10-11, 2005. pp 153-158. L

S13. Koltai T., Lakatos L. and Kalló N., The Application of Line Structuring Rules for Service Improvement: Analysis of Waiting Lines at the Cash Desks of a Supermarket. *microCAD 2004 International Scientific Conference, Company Competitiveness in the XXI Century Section*, Miskolc, Hungary, March 18-19, 2004. pp 111-116. L

Hungarian Journal Papers

S14. Kalló N. and Koltai T., Az expressz pénztárak optimális működtetésének szolgáltatásmenedzsment-vonatkozásai (Service Management Issues of Optimal Operation of Express Line Systems). *Vezetéstudomány*, Vol. XL, June, pp. 79-84., 2009. L

S15. Koltai T. és Kalló N., Az expressz pénztárak várakozásbefolyásolásának kvantitatív elemzése (The Effects of Express Checkouts on Customer Waiting: a Quantitative Analysis). *Szigma*, Vol. 39, No. 3-4, pp. 169-183, 2008. L

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Number of publications: 20
Number of peer reviewed publications: 19
Number of Science Citation Index publications: 1
Number of references: 23
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Context (p. 1413): We refer the reader […] to Koltai and Kalló (2007) for supermarket check-out counter management.

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