A Simulation Study of Depot with Multiple Temperature Modes: Maximum Flow Estimation

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***Abstract*— The aim of this paper is to make a truck loading simulation in a large area with several warehouses each with a given temperature mode of stored goods (frozen, refrigerated, and unrefrigerated goods). When loading goods in different temperature modes, time delays occur when trucks are crossing between ramps (ramps for various temperature modes are separated). The problem is that if the number of ramps is insufficient, queues may arise. The aim of the paper is to quantify the dependence of the loading time on the number of loaded pallets where we consider usually achievable loading area limits of trucks when planning multiple trips. We assume that customer order quantities are given by a Beta distribution. Knowledge of this density estimate allow us to assess the maximum flow through the depot. Arena software is used for the simulation.**

Keywords—depot; flow of goods; minimizing queues; loading simulation

I. INTRODUCTION

In this article, we will analyze loading of goods at ramps from warehouses of goods that are stored in three temperature modes. Our study is closely related to the family of Vehicle routing problems (VRP), Bin packing problems (BPP) and Traveling salesman problems (TSP). The reader can get a survey of the methods used to solve VRP in articles (Angel [2]), (El-Sherbeny [4]), (Serap [7]), and in the book (Simchi-Levi [8]). In the literature devoted to BPP, VRP or TSP, the issue of setting the vehicle exit time is not usually addressed. Various problems have been formulated in connection with the loading of goods, see (Alonso [1]), (Calvet [3]). In (Le-Duc [5]) Order batching problem (OBP) is solved within a 2-block rectangular warehouse with the aim to obtain average throughput time of random order and to assess optimal picking batch size. Contradictory to our assumption that frequency between of arrivals is constant, authors in (Le-Duc [5]) consider the Poisson distribution for order arrival to the system.

The objective of our research is to optimize warehouse productivity by maximizing the flow of goods in the depot and reducing the waiting time of trucks at ramps. Cf. (Stadt [9]). In our study, we will describe the flow in the depot through simulation software. Special attention will be paid to the time between line arrivals so that queues do not occur at ramps. Our study complements the VRP assignment when we need to estimate the maximum number of vehicles loaded simultaneously. Therefore, we will focus only on assessing the impact of distribution of lines with mixes of goods on the loading speed. The inputs for our analysis are ramp counts for warehouses with three different temperature modes, and statistical characteristics describing the number of pallets distributed to customers in these temperature modes. The issue of flow of goods in the depot is also examined from the aspect of heterogeneous vehicle fleet structures. However, we will not perform price analysis in this article. A guide to our analysis was provided by the book (Kelton [6]).

II. MIXES OF GOODS SAMPLE

A. Data

The data for our study will be prepared by simulation taking into account the knowledge we have gained from the information about the actual loading of goods from a certain logistics company. A linear function describing the loading time per vehicle will be available. Four different types of mixes of temperature modes of the loaded goods arise during loading. Each mix of goods has its own mean value of commodity size.

While basic characteristics of mixes of goods were shown in Tab. I, mix percentages are given by Fig. 1. It has been shown that the size of the goods to be distributed can be described by a Beta distribution. This knowledge will be used in simulation, see (Stewart [10]).

By the moment method we can estimate the parameters as follows:

$$\hat{\alpha} = \bar{x}\frac{\bar{x}(1-\bar{x})}{s-1},$$

$$\hat{\beta} = (1-\bar{x})\frac{\bar{x}(1-\bar{x})}{s-1}.$$

The Data preparation procedure will be described and shown in the upcoming section.

TABLE I. A SETTING OF GOODS FEATURE VALUES

	Temperature mode	*Alpha*	*Beta*	*Avg. [pcs.]*	*s [pcs.]*
Pure	Frozen	0.0908	0.4347	5.58	9.86
	Refrigerated	0.1942	0.5342	8.86	11.07
	Unrefrigerated	0.2145	0.2771	14.37	13.57
Mixes	Frozen Refrigerated	0.1603	0.2919	11.72	13.09
	Frozen Unrefrigerated	0.3835	2.4289	4.42	5.89
	Refrigerated Unrefrigerated	0.3904	1.5917	6.45	7.57
	Frozen Refrigerated Unrefrigerated	0.1182	0.1226	16.33	14.91

[a] Source: own.

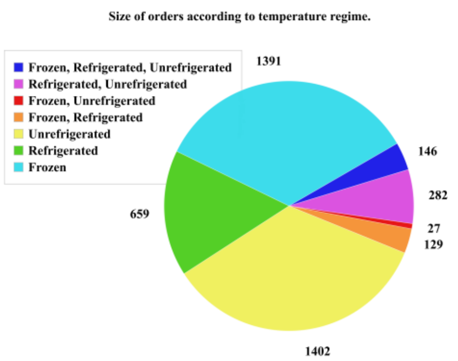

Fig. 1. Distribution of mixes. Source: own.

The most important input parameter is the loading time t of p pallets, which will be described by the function t = 7 + p. Other input parameters are listed in the following tables. Tables II, III, and IV outline the number of customers, vehicles, their capacities, and the number of ramps.

TABLE II. CAPACITIES IN DEPOTS

Depot	*Ramps - frozen*	*Ramps – refrigerated*	*Ramps - unrefrigerated*
Ramps	6	4	5
Hour capacity	198	134	165

[b] Source: own

TABLE III. VEHICLE FLEET STRUCTURE

Vehicle	*No. of cars*	*No. of pallets*
Evaporator semitrailer	56	33
2 evaporators semitrailer	50	33
Lorry A	9	20
Lorry A2	17	18
Lorry B	12	15
Lorry C	6	8

TABLE IV. VARIANTS OF CUMULATION OF GOODS OF DIFFERENT TEMPERATURE REGIMES ON LINES

		V0	*V1*	*V2*	*V3*	*V4*
Pure	Frozen	34 %	20 %	16 %	12 %	4 %
	Refrigerated	17 %	10 %	8 %	6 %	2 %
	Unrefrigerated	34 %	20 %	16 %	12 %	4 %
	Sum of Pure	85 %	50 %	40 %	30 %	10 %
Mixes	Frozen Refrigerated	3 %	10 %	12 %	14 %	18 %
	Frozen Unrefrigerated	7 %	23 %	28 %	33 %	42 %
	Refrigerated Unrefrigerated	1 %	3 %	4 %	5 %	6 %
	Frozen Refrigerated Unrefrigerated	4 %	13 %	16 %	19 %	24 %
	Sum of Mixes	15 %	50 %	60 %	70 %	90 %

[c] Source: own.

III. THE SIMULATION

A. The Design of Simulation

Firstly, we developed a structure of the simulation model. The focus of our simulation study is to find the optimal period for the arrival of vehicles to the depot. First of all, it is necessary to prepare input data. We need to set a strategy for selecting a vehicle from a heterogeneous fleet of vehicles. The vehicle is assigned one of four categories of mixes. Next, we simulate the goods for the selected mix with the characteristics from Tab. I.

The simulation steps are:

1) Allocation of orders from the same temperature regimes to vehicles (cf. last column of Tab. I):

a) Simulation of random number according Beta distribution with parameters from Tab. I for all temperature modes and combinations thereof.

b) Select a vehicle from the fleet of camions described in Tab. III.

c) Randomly assign a temperature mode with probabilities given in Tab. IV.

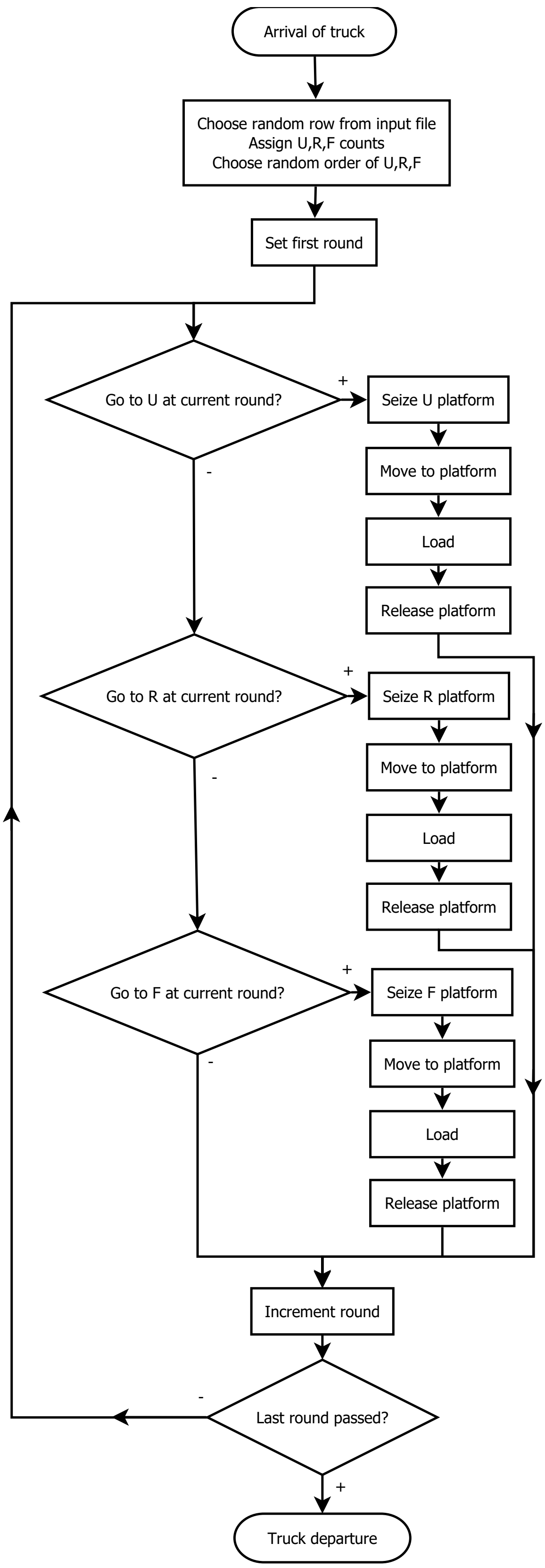

Fig. 2. Flow Chart. Source: own.

d) Packing of the selected vehicle to its capacity from sets of orders (in the temperature mode selected in point 3.), generated under point 1. If the size of the goods reaches 90 percent of the car's capacity, then stop adding more orders.

2) Variants of different proportions of goods lines in a single temperature regime, see Tab. IV:

a) Selection of already created lines in A) point 4 with probabilities from Tab. IV.

b) Creation of lines with mixes of goods with cumulative relative sum in 5 variants reaching values of 50, 60, 70, 80, and 90 percent.

3) Simulation of car arrival at ramps, cf. Tab. III:

a) The pause between car arrivals is set in the depot.

b) Based on the basic file, the type of truck and the type of goods (temperature regimes) it carries are generated.

c) The order in which the truck will go to each type of ramp is randomly selected.

d) The ramps are gradually occupied by the truck according to the assigned order. (the truck backs up to the ramp and loads the appropriate number of pallets of goods.)

e) After loading all goods, the truck leaves the depot.

The implementation of the presented simulation is shown in Fig. 2.

B. *Simulation results*

The results obtained by using Arena software are given in Tables V - IX. For various options in the tables we present load time values of the last pallet, average of simultaneously loaded cars, average wait-time for every ramp, and hourly flow for every temperature mode. The results are also presented graphically in Fig. 3 to 7.

TABLE V. DEPOT 1, VARIANT 0

Delay between arrivals[minutes]	4	5	6	7	8	9
Load time of a last pallet [hours]	5:54	6:12	7:21	8:43	9:57	11:03
Avg. of simultaneously loaded cars	9.73	7.77	6.49	5.56	4.87	4.32
Avg. waittime Frozen [minutes]	0:40	0:04	0:00	0:00	0:00	0:00
Avg. waittime Refrigerated [minutes]	1:01	0:32	0:18	0:14	0:11	0,07
Avg. waittime of Unrefrigerated [minutes]	3:00	0:32	0:07	0:00	0:00	0:00
Hourly flow Frozen	156.22	123.98	104.53	86.96	75.57	67.69
Hourly flow Refrigerated	83.91	68.55	55.77	47.96	42.27	38.32
Hourly flow Unrefrigerated	162.77	131.78	114.10	96.27	84.36	75.93

TABLE VI. DEPOT 1, VARIANT 1

Delay between arrivals [minutes]	4	5	6	7	8	9
Load time of a last pallet [hours]	5:08	6:19	7:28	8:48	10:02	11:21
Avg. of simultaneously loaded cars	11.63	9.56	7.98	6.84	5.97	5.31
Avg. waittime Frozen [minutes]	0:47	0:11	0:04	0:00	0:00	0:00
Avg. waittime Refrigerated [minutes]	1:59	0:43	0:14	0:11	0:07	0:04
Avg. waittime of Unrefrigerated [minutes]	14:17	2:24	0:32	0:11	0:04	0:00
Hourly flow Frozen	128.91	101.94	86.29	73.94	64.64	57.87
Hourly flow Refrigerated	84.10	69.44	58.02	48.04	42.91	38.54
Hourly flow Unrefrigerated	177.62	146.43	124.78	106.06	92.20	80.95

TABLE VII. DEPOT 1, VARIANT 2

Delay between arrivals[minutes]	4	5	6	7	8	9
Load time of a last pallet [hours]	4:55	6:08	7:21	8:38	9:51	11:03
Avg. of simultaneously loaded cars	11.65	9.51	7.89	6.75	5.90	5.24
Avg. waittime Frozen [minutes]	1:05	0:18	0:04	0:00	0:00	0:00
Avg. waittime Refrigerated [minutes]	2:46	0:43	0:18	0:11	0:04	0:00
Avg. waittime of Unrefrigerated [minutes]	10:52	1:48	0:32	0:07	0:04	0:00
Hourly flow Frozen	133.31	107.99	90.05	76.47	67.80	61.56
Hourly flow Refrigerated	100.57	79.10	66.14	55.20	47.40	42.21
Hourly flow Unrefrigerated	174.51	140.64	116.79	100.79	88.50	78.37

The simulated results showed that the highest hourly flow occurs at the frequency of exits being one per 4 minutes. However, the estimated hourly flows exceed the maximum allowable flow of 165 pallets for unrefrigerated goods. With an exit frequency of 4 minutes, the large hourly flow rate and the shortest loading time of the last pallet are redeemed by the longest waiting time of up to 5 minutes.

Therefore, it seems preferable to set the simulation to 5 minutes, where the waiting of the vehicles in front of the ramps was approximately 1 minute. With a 5-minute frequency selection, it appeared that the local maximum of total hourly flow occurred in Variant 2 (70 percent of mixes).

TABLE VIII. DEPOT 1, VARIANT 3

Delay between arrivals[minutes]	4	5	6	7	8	9
Load time of a last pallet [hours]	5:42	6:18	7:29	8:49	10:01	11:20
Avg. of simultaneously loaded cars	11.06	9.05	7.57	6.50	5.68	5.05
Avg. waittime Frozen [minutes]	0:47	0:07	0:04	0:00	0:00	0:00
Avg. waittime Refrigerated [minutes]	2:42	0:54	0:32	0:14	0:04	0:04
Avg. waittime of Unrefrigerated [minutes]	12:36	2:28	0:43	0:14	0:04	0:00
Hourly flow Frozen	111.74	99.94	83.95	71.36	62.55	56.28
Hourly flow Refrigerated	74.83	65.26	54.83	46.58	42.02	36.89
Hourly flow Unrefrigerated	165.50	153.88	128.82	110.23	95.90	83.96

TABLE IX. DEPOT 1, VARIANT 4

Delay between arrivals[minutes]	4	5	6	7	8	9
Load time of a last pallet [hours]	4:59	6:15	7:30	8:57	10:06	11:22
Avg. of simultaneously loaded cars	11.03	8.84	7.37	6.31	5.51	4.90
Avg. waittime Frozen [minutes]	0:29	0:07	0:00	0:00	0:00	0:00
Avg. waittime Refrigerated [minutes]	1:41	0:32	0:14	0:07	0:04	0:00
Avg. waittime of Unrefrigerated [minutes]	6:07	1:05	0:14	0:04	0:00	0:00
Hourly flow Frozen	138.79	110.96	90.87	76.23	67.23	61.13
Hourly flow Refrigerated	93.41	71.49	61.30	50.16	43.90	38.99
Hourly flow Unrefrigerated	170.34	138.10	115.31	98.36	87.66	76.27

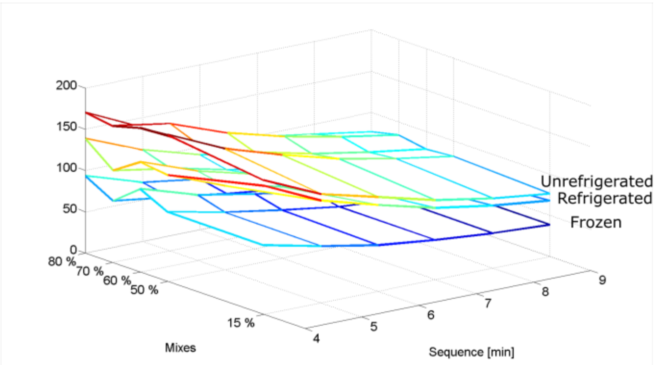

Fig. 3. Hourly flow – Unrefrigerated, Refrigerated, Frozen. Source: own.

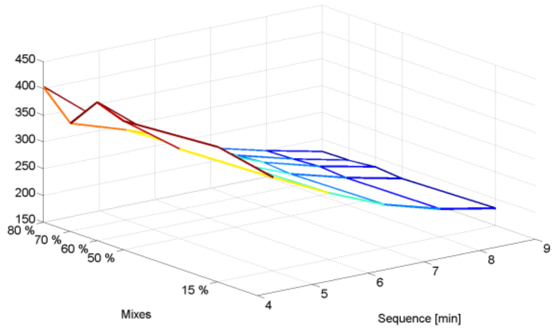

Fig. 4. Sum of hourly flow. Source: own.

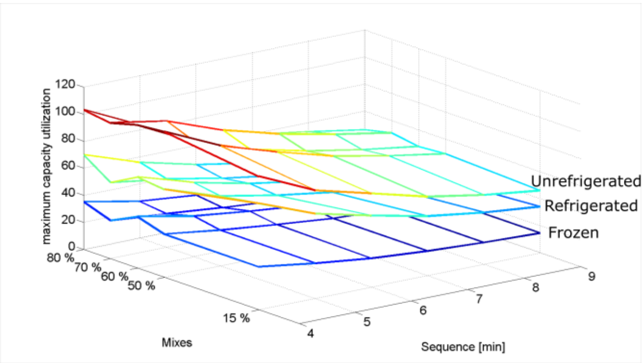

Fig. 5. Percentage usage of the ramp capacity. Source: own.

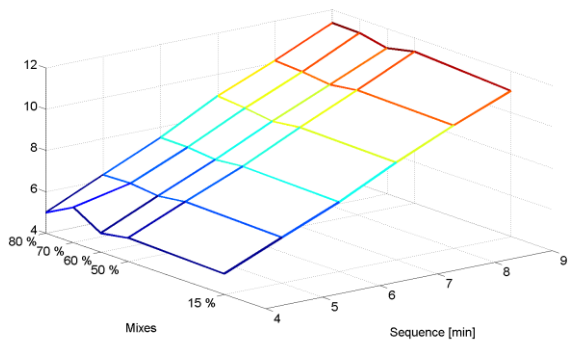

Fig. 6. Loading time of the last pallet [in hours]. Source: own.

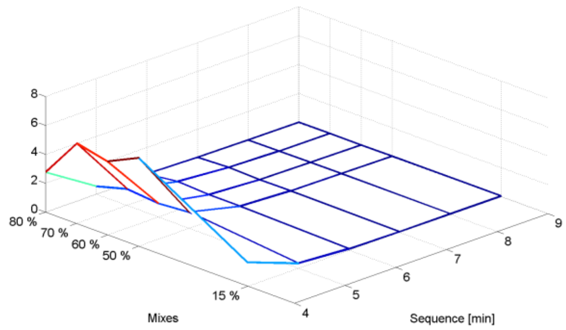

Fig. 7. Average waiting time of the car on all three ramps [in hours]. Source: own.

IV. CONCLUDING REMARKS

Our goal was to prepare the basic pillars for the possibility of building an algorithm for VRP solution, which will guarantee loading without queues. Use of the simulation software brought interesting and fruitful results. We found out that there will be no queues on the ramps if the lines are serviced with a period of 6 minutes.

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References

[1] M. T. Alonso, R. Alvarez-Valdes, F. Parreño, and J. M. Tamarit, "Algorithms for pallet building and truck loading in an interdepot transportation problem," Mathematical Problems in Engineering, vol. 2016, Article ID 3264214, 11 pages, 2016.

[2] A. Juan Angel, E. Grasman Scott, J. Faulin, D. Riera, C. A. Méndez, and B. Ruiz, "Applying simulation and reliability to vehicle routing problems with stochastic demands." Proceedings of the 16th RCRA workshop on Experimental Evaluation of Algorithms for Solving Problems with Combinatorial Explosion, RCRA@AI*IA 2009, Reggio Emilia, Italy, December 11-12, 2009.

[3] L. Calvet, D., Wang, A. Juan, and L. Bové, "Solving the multidepot vehicle routing problem with limited depot capacity and stochastic demands." International Transactions in Operational Research, vol. 26, no. 2, pp. 458-484, 2019.

[4] N. A. El-Sherbeny, "Vehicle routing with time windows: An overviewof exact, heuristic and metaheuristic methods". Journal of King Saud University, Volume 22, pp. 123-131, 2010.

[5] T. Le-Duc, and R. De Koster, "Travel time estimation and order batching in a 2-block warehouse." European Journal of Operational Research, vol. 176, no. 1, pp. 374-388, 2007.

[6] W. D. Kelton, P. Randal, R. Sadowski, and N. B. Zupick, "Simulation with Arena." Sixth edition. New York, N.Y: McGraw-Hill Education, 2015.

[7] E.C. Serap, R.Y. Harun, S. Írem, and S. Hanife, "A new approach for solution of vehicle routing problem with hard time window: an application in a supermarket chain". Sadhana, vol. 42, no. 12, pp. 2067-2080, 2017.

[8] D. Simchi-Levi, X. Chen, and J. Bramel, "The logic of logistics: theory, algorithms, and applications for logistics management (Springer series in operations research and financial engineering) ." Prentice-Hall, Inc., 2013.

[9] F. H. Staudt, M. di Mascolo, G. B. Alpan, and C.M.T. Rodriguez, "Warehouse performance measurement: classification and mathematical expressions of indicators". In ILS 2014 - 5th International Conference Information Systems, Logistics and Supply Chain. Dinalog Beta Trail, Breda, Netherlands, pp. 1-9, Aug. 2014.

[10] W. J. Stewart, "Probability, Markov chains, queues, and simulation: the mathematical basis of performance modeling." Princeton, Princeton University Press, 2009.