FRAMEWORK FOR SIMULATION ANALYSIS OF PRIORITY QUEUES STRATEGIES IN DETERIORATING GOODS SUPPLY

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Abstract: The Queuing theory has been considered as one of the most important methods with very wide application in making different improvements of the system performances, which are very often related to decreasing waiting times in queues. In order to reduce waiting time, many different techniques have been studied while the priority queuing models appear to be the most popular. Waiting times are of particular importance in case of deteriorating goods which lose its quality during the time, decreasing its economic value. Therefore, in this paper we propose concept of a simulation model which can analyse effects of priority queues strategies, on waiting times in deteriorating goods supply. The analysis is based on simulation model implemented in ARENA 15.1. Simulation experiments were realized on numerical examples of sugar beet supply.

Keywords: *Discrete event simulation, Priority queues, Deteriorating goods supply*

1. INTRODUCTION

As it is well known, queues are part of our everyday experience and exists in different real world systems and situations as a consequence of limited available resources. Examples are numerous and include telephone calls, ticket counters, vehicles requiring loading dock, aircrafts requiring gates or permission to take off or land, patients requiring attention by a doctor, etc. For improving the system performances and making it more efficient, which usually means lesser waiting time in queue, different queuing theory methods are available. The Queuing theory was introduced by Erlang (1909) more than hundred years ago. Since than it has been considered as one of the most important methods with very wide application which can give the answers to the questions related to design of different real systems. The main questions in queuing systems design are related to balance between level of service to customers and economy. Lesser number of

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customers waiting in queue and shorter waiting times mean more servers which is more costly, and vice versa. Waiting in queue causes different negative effects. Thus, waiting of emergency vehicle in traffic jam, or for green light, may have severe consequences to a patient in the car; trucking company charges detention fees when has to wait until the loading/unloading of a shipment; waiting of goods which lose its quality during the time (deteriorating goods), decreases its economic value. Furthermore, in healthcare systems the condition of the patients may deteriorate while they wait (Haviv, Ravner, 2016).

In order to reduce waiting time, many different techniques have been studied by researchers, where classical priority queuing models appear to be the most popular approach in such a system (Li, 2015). Classical, or absolute priority queuing model is first studied by Cobham (1954). In this model a customer of a given class is selected if only customers of higher priority classes are not waiting. Since then, different priority queuing models, like time dependent priority queues (Kleinrock, Finkelstein, 1967), accumulating priority queues (Haviv, Ravner, 2016) have been analysed. In parallel with widening of priority queues application areas, research effort has been also directed to developing algorithms for priority queue implementation in simulation software as a typical tool for queuing system analysis, beside analytical methods with limited practical applications.

Here, we use simulation to analyse effects of introducing different priority queues strategies in deteriorating goods supply. The idea is to model the supply system in which goods lose its quality during the supply process with multiple vehicle tours realization. Each tour includes loading of goods at storage locations, transportation from the locations to processing plant, sampling goods to determine its quality, weighing and unloading of goods at processing plant, as well as empty vehicle trip realization. The simulation model is implemented in ARENA 15.1, while the simulation experiments were realized on numerical examples based on sugar beet supply process, since the sugar content in harvested beet deteriorates throughout the time.

While the simulation analysis of sugar cane supply chains, particularly related to the trucks waiting times in various queues, is of particular interest and has been the subject of numerous researches, sugar beet supply is not in focus. Iannoni and Morabito, (2006) simulated three scenarios of sugar cane supply, related to changes in truck's fleet structure, and analyzed effects on waiting times and unloading capacity. Barnes et al. (1998) and Hansen et al. (2002) used simulation to study methods of reducing harvest–to–crush delays in the sugar industry. Diaz and Perez (2000) applied simulation to gain insights into the relations between various processes and the presence of bottlenecks in supply chain operations. However, there is no papers analysing effects of priority queues strategies management on deterioration level of raw materials supplied, which is novelty proposed in this research.

The remaining part of the paper is organised as follows: Section 2 defines the problem, while the concept and the structure of the simulation model is presented in Section 3. Characteristics of the supply system being simulated, together with results of simulation experiments are presented and discussed in Section 4. Finally, main conclusions are highlighted in Section 5.

2. THE PROBLEM STATEMENT

Different logistics supply systems manage goods that lose its quality during the time. Typical example is deteriorating goods in agro industries, where supply from harvesting to processing plant causes decreasing its economic value. Iannoni and Morabito (2006) mentioned orange, sugarcane and wood industries as the examples. Sugar beet, which is the main plant in European, as well as in Serbian sugar production, also belongs to deteriorating goods since the sugar content in beetroot, i.e. digestion, decreases during the time. Loss in digestion is expressed in the percentage (%) of roots' weight, and varies depending on weather conditions and characteristics of the beet. According to Pan et al. (2015), sugar content in beet on temperature of 4°C is approximately normally distributed with mean value of 20.43% and standard deviation of 1.48%. Under lower temperatures, sugar loss is 100-200 gr per ton of beet daily, but on higher temperatures, near 30°C, it can reach 2kg per ton of beet daily (Asadi, 2007).

Decreasing of sugar content is very important because usual campaign of collecting harvested beet lasts 3-6 days, while processing of beet which contains less than 14% of sugar is not economical. Based on Asadi (2007), functional relation between the sugar loss and time can be expressed by equation (1).

$$\rho_s = \rho_s^0 (1-\beta)^t \tag{1}$$

where:

ρ_s the amount of sucrose in harvested beet stored on the storage pile s, after the time t;

ρ_s^0 the initial amount of sucrose in harvested beet stored on the storage pile s in t=0;

β the loss in sucrose content per time unit;

t the time elapsed after storing the beet.

During the campaign about 100 vehicles make more than 200 tours in average every day, for a daily sugar mill capacity of 7000 tons. Transport demand is extremely high because sugar beet should be immediately, or as soon as possible, delivered from the fields to sugar mills. For such a system, where sugar beet lose sucrose content during the time, managing the supply chain from the piles where beet is stored after harvesting to the beet processing in sugar mill, represents important opportunity to increase efficiency of the sugar production process. Sugar beet supply chain includes following main phases (Figure 1): loading of beet at storage piles, transportation from storage locations to processing plant, sampling goods to determine its quality, weighing and then unloading of goods at processing plant - mill, and return of empty vehicle to storage piles where it starts a new tour.

Each operation requires certain time for its realization, but additionally, because of congestion, limited capacities of available resources and stochasticity of processes in supply chain, vehicles spend in queues a certain time, waiting for a service. More detailed representation of the sugar beet supply chain phases, processes and average times needed for its realization can be found in the paper of Žitňák and Korenko (2011).

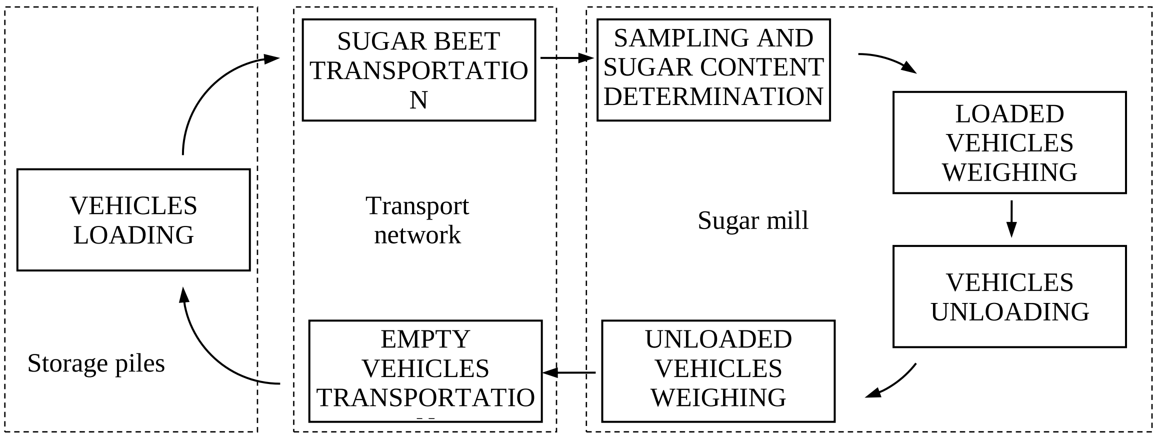

Figure 1. The main phases in sugar beet supply chain

Some of supply chain processes' realization times cannot be directly controlled, like supply vehicles travel times, while the other depend on resources' capacity. On the other hand, waiting times in different queues are controllable to some extent, even without changing resources capacities. Loading vehicles at storage piles and vehicles unloading in a mill are processes of that type. The most important process regarding waiting times is vehicles unloading in a mill. It is why Iannoni and Morabito (2006) correctly stated that the truck waiting times in various queues of the reception area are of special concern, particularly asserting the case of deteriorating goods.

In order to decrease quality deterioration, which is here related to the sugar loss minimization, we analyse the idea of dynamically changing the priority of vehicles which arrive in mill and wait in a queue to be unloaded. Instead of using FIFO service principle, we analyse priority based service strategy. Priority is based on the general principle "*larger sugar content - higher unloading priority*". This general principle is implemented through defining measure *CurrSugCont* whose value is then used as priority attribute assigned to each vehicle entering mill's unloading queues.

CurrSugCont Denotes estimated current sugar content in a beet. It is assumed that the amount of sucrose in the moment when harvested beet is stored on a source storage pile is known (*SugOnPile*). Based on that, knowing time passed from the moment when beet is stored, by using eq. (1) it is possible to estimate current sugar content for each vehicle tour, every time when vehicle arrives in a queue.

In order to perform analysis of possible effects of dynamically changing the service priority of vehicles waiting in queue, ARENA Queue option *Highest attribute value* is used for simulation model. This option gives service priority to the entity in queue (loaded vehicle) with the highest value of the certain attribute, which here corresponds to the values of attributes *CurrSugCont*.

3. SIMULATION MODEL

A simulation can be understood as imitation of a real world system or situation represented by computer model. It belongs to a class of descriptive models which are used to describe or analyse behaviour of the system being simulated. It provides to analyst an opportunity of making experiments on the model, instead on the real system. It has very wide application in analysis of effects which results from modification of different policies and strategies. This feature of simulation modelling approach is utilized in this research with the idea of analysing the effects of dynamically changing the service priority of vehicles waiting in mill's queues, based on the idea presented in the Figure 2.

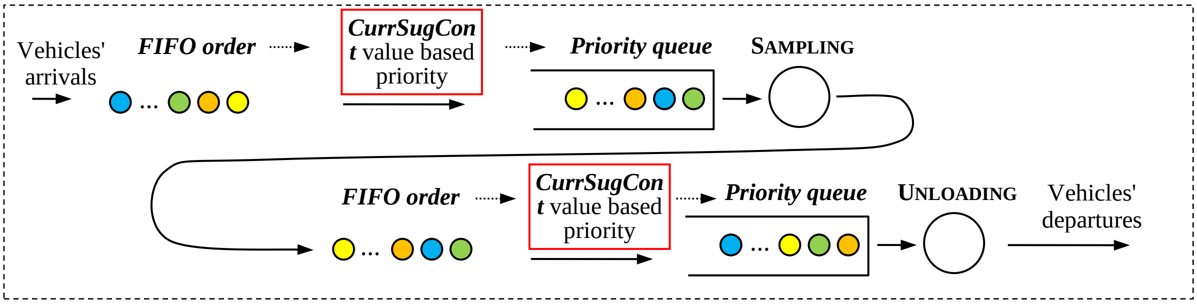

Figure 2. Dynamic change of service priority of vehicles waiting in the mill's queues

The simulation model of the sugar beet supply chain conceptually follows the processes and activities shown in Figure 1. The simulation model entities are trucks that upon entering the system make sugar beet collection tours until all beet is transferred from storage piles to the mill. Each tour includes vehicle loading at storage pile, movement of loaded trucks transporting beet to sugar mill, sampling of loaded vehicles to estimate sugar content, weighing vehicles, before and after unloading, vehicles unloading and then movement of empty vehicles to a sugar pile. It means that the sugar beet supply chain is considered as closed system. The simulation model has been developed in ARENA 15.1, while its simplified version which corresponds to a beet supply chain based on one storage pile is shown in Figure 3.

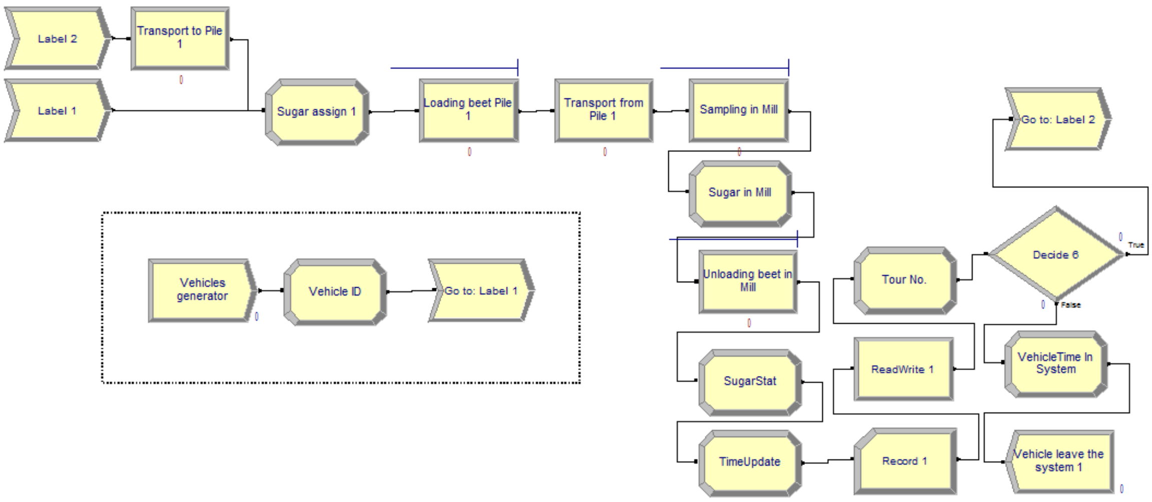

Figure 3. Simplified simulation model developed in ARENA based on one storage pile

Fleet of vehicles is generated prior the beginning of supply process. Each vehicle has been assigned its own ID. First tour of all vehicles starts from storage pile, not from the mill, where vehicle entity is assigned *SugOnPile* and current time (*CollTime*) attribute values. Sugar beet loading is realized by resource of ARENA process using FIFO service principle. Transport times are considered as ARENA processes of *Delay* type. After a vehicle entity enters the mill, it is assigned *CurrSugCont* attribute value, calculated by eq. (1). The servicing order is dynamically changed before the vehicle enters SAMPLING process. After sampling, vehicles enter mill's weighing and unloading queues, considered here as UNLOADING process. Unloading service order again depends on the priority, based on the new attribute value *CurrSugCont*, calculated by eq. (1). After the vehicle entity releases mill's processes model collects statistics and depending on the number of tours realized, entity is disposed or directed to the next storage pile according to the predefined schedule.

The model runs using FIFO, and defined prioritization strategy based service order with the idea of comparing effects that priority queue application strategy has on sugar loss.

4. SIMULATION EXPERIMENTS AND RESULTS

Data used in simulation experiments are based on an arbitrary mill with daily processing capacity of 6250 and 12500 tons which corresponds to realization of a 250 and 500 supply tours respectively, using vehicles of 25 tons capacity. Those processing capacities are slightly lower, and little higher than a typical mill which usually has capacity of 7000 tons daily, but give an opportunity for analyzing effects of priority queues strategy application. Mill supply area includes five storage piles (1,2,3,4,5), with the distances of 15, 12, 38, 39 and 59 kilometers from the mill, respectively. Average sugar content (%) on piles at the beginning of the supply process is assumed to be normally distributed with the mean value of 20.43% and standard deviation of 1.48%, accordingly to findings of Pan et al. (2015). Particular values of the sugar content for all piles obtained by simulation (*SugarOnStart*) are following: 18.73, 21.32, 19.41, 22.69, 21.38, for storage piles 1,2,3,4 and 5 respectively. As the sugar content in beet deteriorates in time, current content is estimated by simulation. It is assumed that deteriorated sugar content is also normally distributed with mean value decreased by extent calculated by eq.(1), and the same variation coefficient of 0.07.

Vehicles' schedule which defines visiting order of storage piles is randomly generated, and has a form given in Table 1. The vehicles' schedule is based on the concept of equal usage of vehicles, each performing ten tours. Numbers in Table 1 denote storage piles to be visited.

Table 1. Vehicles schedule

	Tours visiting storage piles									
Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Vehicle 1	5	4	3	5	5	1	3	2	1	5
Vehicle 2	5	3	1	2	5	5	2	3	1	3
Vehicle 3	1	2	1	5	1	5	3	5	1	2
Vehicle 4	2	5	3	4	2	2	2	1	5	2
Vehicle 5	4	2	4	1	4	4	5	1	2	2
Vehicle 6	4	3	3	5	1	3	4	2	1	2
Vehicle 7	5	5	3	1	2	4	3	2	4	5
Vehicle 8	2	4	2	3	5	3	4	4	5	3
...	...	...	...	...	...	...	...	...	...	...

Inputs related to sugar beet loading and unloading times as well as sampling and weighing times and its probability distributions are based on results of Žitňák and Korenko (2011).

Accordingly to their findings, average time for beet sampling was 1.92 min and average weighing time is 1.93 min, where both processes are assumed to be normally distributed with given means and variation coefficient 0.1. Loading beet on storage piles follows Lognormal probability distribution with mean of 11.67min and st.dev 4.53min of corresponding Normal distribution. Typical unloading time of vehicles in mill, using dry concept, accordingly to Asadi (2007), is assumed to be normally distributed with mean of 8min and variation coefficient 0.2. Those mill processes service times are about 14min in total and they are used in the first scenario (*14' service time*), while in the second we doubled service times (*28' service times*) from the first scenario. The loss in sucrose content per time unit is based on Asadi (2007), while in this research we analysed the expected daily loss (β) of 0.5% 1% and 2%. Vehicle speed in [km/h] is assumed to be uniformly distributed in range 40-50km/h and 30-40km/h for empty and loaded vehicles respectively.

Terminating condition for all simulations experiments was realization of all scheduled beet collection tours. Number of replications in each particular simulation experiment was 5.

As a measure of prioritization strategies application effects, we analyze total sugar loss in supply chain, which is measured relatively to sugar content at the beginning of supply process, by using equation (2).

$$TotLossF,P = 100 \cdot \frac{AvailableSug - DeliveredF,P}{AvailableSug} \, [\%] \tag{2}$$

Effects of applying priority service strategy in mills' queues on savings of sugar content in a beet are estimated as absolute (*Saving effects - t*), as well as relative values (*Saving effects - %*). Absolute savings (*AbsSav*) in tons of sugar are calculated as difference between the quantities of delivered sugar under **PRIORITY** service strategy (*DeliveredP*) and **FIFO** service strategy (*DeliveredF*). Relative savings (*RelSav*) in % are calculated by using equation (3).

$$\mathrm{Re}lSav = 100 \cdot \frac{DeliveredP - DeliveredF}{AvailableSug} \, [\%] \tag{3}$$

where:

TotLossF,P	Total loss of sugar content during the supply process realization, under FIFO (F), and Priority (P), service strategies
AvailableSug	Sugar content in beet stored on piles at the beginning of supply process
DeliveredF,P	Content of sugar in mill after unloading, under FIFO (F), and Priority (P), service strategies
RelSav	Relative savings in percentage of delivered sugar as a result of application of the Priority service strategy
AbsSav	Absolute savings in tons of sugar delivered, as a result of application of the Priority service strategy

The results for two groups of simulation experiments which corresponds to 6250 (*lower supply intensity*) and 12500 (*higher supply intensity*) tons of beet supply are shown in Tables 2 and 3, respectively. In each mentioned group of experiments, we analyzed six scenarios that correspond to different values of the loss in sucrose content per time unit β and different service rates in mill processes. For the case of lower supply intensity (6250 t daily) was analyzed only single unloading channel in the mill, while in the case of higher supply intensity (12500 t daily), two variants were analysed: single unloading channel in the mill, and two unloading channels of the same capacity in the mill.

Table 2. Results of simulation experiments (*lower supply intensity of 6250 t*)

Single unloading channel in the mill	Available sugar on piles (t)	**FIFO** service		**PRIORITY** service		RelSav effects (%)	AbsSav effects (t)
		DeliveredF (t)	TotLossF (%)	DeliveredP (t)	TotLossP (%)		
β=0.5%, 14' service time	1287.3050	1282.5438	0.3699	1282.5563	0.3689	0.0010	0.0125
β=0.5%, 28' service time	1287.3050	1274.8625	0.9666	1274.9688	0.9583	0.0083	0.1063
β=1%, 14' service time	1287.3050	1274.7375	0.9763	1274.7563	0.9748	0.0015	0.0187
β=1%, 28' service time	1287.3050	1259.5250	2.1580	1259.6375	2.1493	0.0015	0.1125
β=2%, 14' service time	1287.3050	1259.2000	2.1832	1259.3813	2.1692	0.0087	0.1812
β=2%, 28' service time	1287.3050	1229.3500	4.5020	1230.1313	4.4414	0.0141	0.7813

Table 3. Results of simulation experiments (*higher supply intensity of 12500 t*)

Single unloading channel in the mill	Available sugar on piles (t)	**FIFO** service		**PRIORITY** service		RelSav effects (%)	AbsSav effects (t)
		DeliveredF (t)	TotLossF (%)	DeliveredP (t)	TotLossP (%)		
β=0.5%, 14' service in mill	2582.0225	2552.8500	1.1298	2553.4500	1.1066	0.0232	0.6000
β=0.5%, 28' service in mill	2582.0225	2522.5375	2.3038	2523.1625	2.2796	0.0242	0.6250
β=1%, 14' service in mill	2582.0225	2522.0000	2.3246	2523.0625	2.2835	0.0411	1.0625
β=1%, 28' service in mill	2582.0225	2462.6750	4.6222	2464.3750	4.5564	0.0411	1.7000
β=2%, 14' service in mill	2582.0225	2461.3250	4.6745	2462.8125	4.6169	0.0658	1.4875
β=2%, 28' service in mill	2582.0225	2347.7250	9.0742	2350.9875	8.9478	0.0576	3.2625
Two unloading channels in the mill	Available sugar on piles (t)	**FIFO** service		**PRIORITY** service		RelSav effects (%)	AbsSav effects (t)
		DeliveredF (t)	TotLossF (%)	DeliveredP (t)	TotLossP (%)		
β=0.5%, 14' service in mill	2582.0225	2552.8750	1.1289	2552.9375	1.1264	0.0024	0.0625
β=0.5%, 28' service in mill	2582.0225	2568.1750	0.5363	2568.3125	0.5310	0.0053	0.1375
β=1%, 14' service in mill	2582.0225	2522.0375	2.3232	2522.2375	2.3154	0.0077	0.2000
β=1%, 28' service in mill	2582.0225	2552.3500	1.1492	2552.6250	1.1385	0.0106	0.2750
β=2%, 14' service in mill	2582.0225	2520.8500	2.3692	2521.4000	2.3479	0.0213	0.5500
β=2%, 28' service in mill	2582.0225	2461.4000	4.6716	2462.7625	4.6188	0.0528	1.3625

The results obtained by simulation obviously show that the application of service priority strategy in deteriorating goods supply could introduce positive effects as a results, as it was the authors main hypothesis in this research. Service priority strategy outperforms FIFO strategy (Figure 4), and since its application is based only on organizational activities, it can be considered as very promising rationalization potential.

Maybe the main problem of the practical application of this concept is in estimating quality of deteriorating goods at the beginning of supply process, and in finding appropriate function that can be used to estimate quality deterioration in time. In the case of sugar beet, as appropriate, we propose eq.(1), although the beet quality also depends on other factors, like humidity, temperature, etc. On the other side, recent advances in technology offer mobile instruments which can measure certain quality of goods attributes, so that, in case of sugar beet, some authors analyse usage of portable visible and near-infrared spectroscopy (Pan et al., 2015). Hence, instead of modelling deterioration, in this way it can be measured, and priority could be defined on that base. Nevertheless, priority queues, i.e. service based on the priority is promising concept which can decrease deterioration of goods, as it has been shown in this research, which could be considered as a beginning of more wider research in this area.

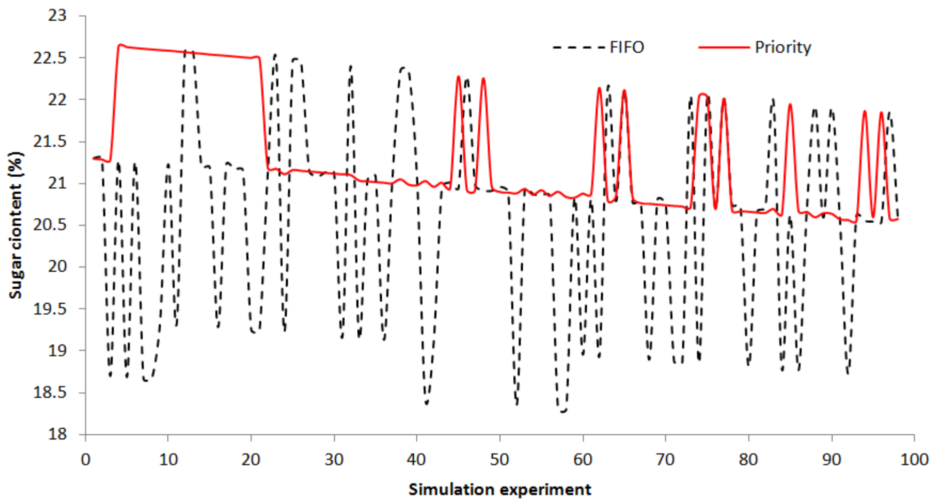

Figure 4. Example of simulated sugar content in realized 100 vehicle tours under FIFO and Priority service strategies

5. CONCLUDING REMARKS

This research represents an attempt to develop a framework for simulation analysis of potentials which are related with introducing the priority service strategies in deteriorating goods supply. This idea may have wide application in different supply systems oriented to deteriorating products, mostly agricultural, in which goods lose its quality during a time. The paper delivers two main contribution. One is related to the concept of the simulation model used to estimate potential effects of priority service, while the other is related with the practical implementation, since the simulation analysis of the concept shows positive effects which need only changes in organization.

The concept proposed in this research, helps dispatcher in defining vehicles schedule making the supply process more efficient and economical. In this way, processes which are essentially uncertain and very complex, can be improved in an relatively modest way.

Further research should analyse other possibilities in optimization of deteriorating goods supply. One is to analyse possibilities and effect of using portable instruments for quality determination. Also, an important research direction is in combining of simulation and optimization with the objective of optimal scheduling of supply vehicles in real stochastic supply systems, considering the service priority as one of improvement potentials.

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