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Design of Simulation Model and Experimenting with Model in Order to Solve Logistics Issues in Healthcare Sector

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ABSTRACT

Nowadays, by progressive development, logistics is oriented on customer market – service provision. Services area implies also healthcare provision. This environment expands dynamically, negotiate reforming; there's evidence of logistics approaches concerning material and information flow (pharmaceutics, consumer medical supplies, information systems, transport), less scientific studies focus on human material flow - patients' flow. Application of existing methods and system approach in services area is not conventional. Utilizing of simulation models, queuing theory knowledge, process models, dataflow diagrams of existing processes and statistical data processing facilitate effective planning and management of material and information flow as in industrial as in services area.

KEY WORDS

service logistics, queuing systems, software WITNESS, simulation model, simulation experiment.

INTRODUCTION

Application of existing methods and system approach in services area is not conventional. Particularly, optimization of integrated logistics systems process, in what a time saving, reducing costs and improving quality of customer service are followed. Furthermore, prices for delivering services have increased, similarly grows competition. Hence, if service provider intends to preserve customers, eventually raise new one, he must provide services at certain quality for adequate price and effectively, that may be significantly reached with use of modern logistical methods.

Object of research in this paper is Rehabilitation ambulance in Geriatric Centre of St. Lucas in Kosice (GCKE), its service facilities that provide service to incoming elements - patients. **Subject of research** is operation logistics of Rehabilitation ambulance GCKE (RA-GCKE) with focusing on implementing a new medical procedure. The main goal is to analyze patient flow by creating and using a simulation model in the structure patient - doctor - medical personnel - rehabilitation workplaces.

Rehabilitation ambulance GCKE constitutes independently functioning unit with particular organization of work and own personnel in relation to the Geriatric Centre complex. Its role is a provision of rehabilitation services for external customers (patients), as well as internal customers (patients), who were admitted to the GCKE over a couple of nights in respect to their diagnosis. Work team in GCKE consists of one doctor and his nurse, together with seven physiotherapists, who provides operating service of rehabilitation equipment. Physiotherapists rotate when operating respective rehabilitation equipment, except for provision of massage services, where this activity is always being provided by the same specialized physiotherapist.

Management GCKE, in order to regular obligatory reporting of services provided to Health Insurance Companies distinguishes their services into four categories:

- EL (Electrotherapeutics): myoskeletal therapy, electrotherapy, etc.
- FT (Physiotherapy): paraffin, cryotherapy.
- LTV (therapeutic physical training): dynamic therapy, massages, ergo-therapy.
- Muscle tests G1L1.

As performing muscle tests G1L1 is related to therapeutic physical training, number of operations will be summarized in the total performance of LTV activities.

DESCRIPTION

First, **process model of Rehabilitation Ambulance GCKE** was built and adapted according to process model of hospital designed by Madar [2]. The built model constitutes as a background for simulation of a patients flow in the structure patient - doctor - medical personnel - rehabilitation workplaces (Fig. 2). The main process is represented by rehabilitation of the patient. Key operations are, as follows:

- examination by doctor (setting a diagnosis and medical procedures)
- completing the therapy (usually 7 repetitions of the same rehabilitation procedure)
- final examination by doctor.

The change of patient's condition is characterized by following events:

1. patient's arrival to waiting-room,
2. entering the doctor and initiating examination by doctor,
3. completion of examination and prescribing the rehabilitation procedure,
4. patient's arrival to waiting-room of rehabilitation department,
5. entering the specialized rehabilitation unit and setting the rehabilitation device according to patient's prescribed treatment,
6. completing the rehabilitation procedure,
7. repetition of the events 5 and 6 till completion of the treatment,
8. patient's arrival to the waiting–room,
9. entering the doctor and initiating concluding examination by doctor,
10. termination of examination and treatment.

RESULTS AND DISCUSSION

From a perspective of service facilities' arrangement, GCKE model can be described as one single service facility, followed by multiple parallel server facilities with one or two servers (Fig. 3). Basic pre-defined elements in applied version of system WITNESS Manufacturing Performance Edition 2007 are being used for building the simulation environment for machine engineering manufacturing plant (Fig. 1). In respect of application in healthcare services, there was draught respective methodical proceeding, which can be characterized, as follows:

1. Draught of services process model.
2. Defining entities for queueing system in healthcare services.
3. Design of specific graphic environment.

Fig. 1: *Basic designer elements.*

Based on process model, projection of service facilities' arrangement and system WITNESS' features, following terminology for main entities of proposed queueing system (QS) was adopted:

- **PARTS**
  Flow through the model. They can represent, for example: products, product batches, calls in a telephone exchange, a project processing through a large corporation, etc.
  ⇒ in the GCKE model they can be PATIENTS; in the QS they can be SERVICE DEMANDS.

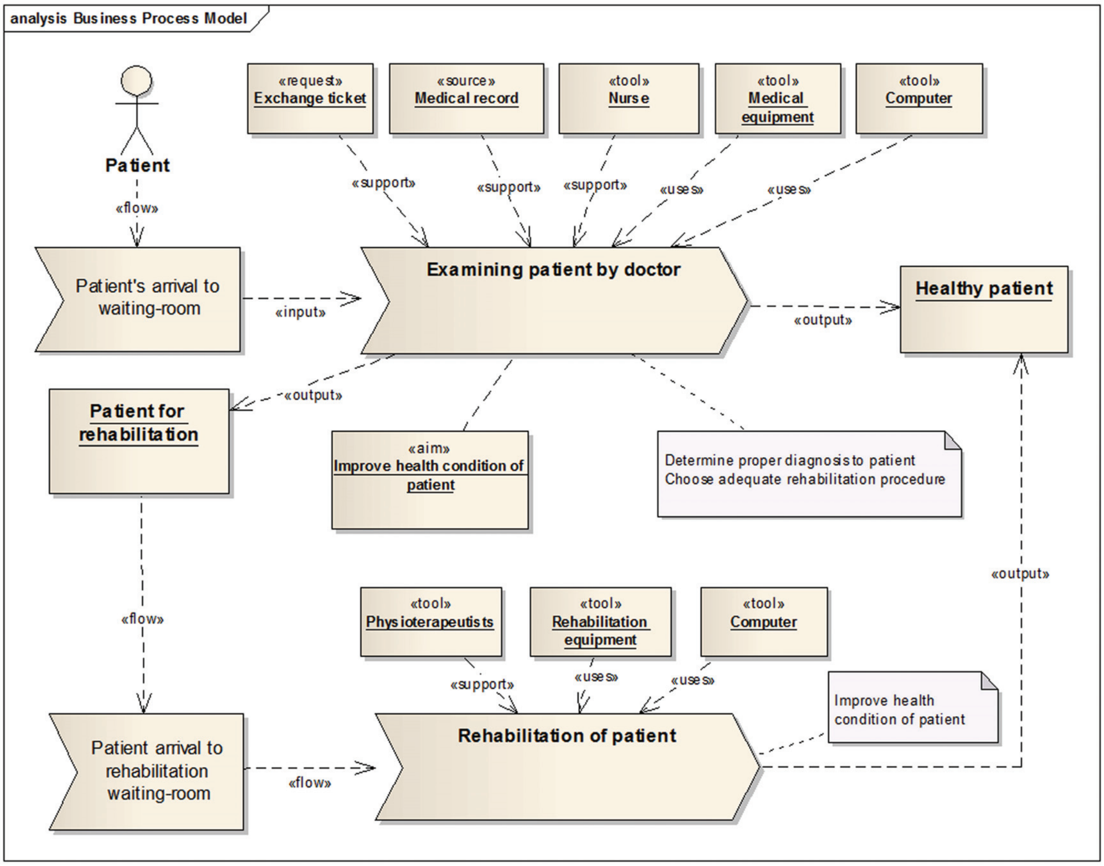


Fig. 2: *Process model of Rehabilitation Ambulance GCKE.*

- **BUFFERS**
  These are places where parts can be held, for example: parts awaiting an operation on a factory floor, people in a queue, etc.
  ⇒ *in the GCKE model they can be WAITING ROOMS; in the QS they can be QUEUES IN FRONT OF THE SERVICE FACILITIES.*

- **MACHINES**
  These are powerful elements which used to represent anything that takes part from somewhere, process them and sends them on to their next destination. For example: a machine tool, lathe or a press, a complete shop or a single supermarket checkout, an entire plant or an individual work cell.
  ⇒ *in the GCKE model they can be EXAMINING DOCTOR or REHABILITATION UNIT WITH OR WITHOUT MACHINE EQUIPMENT (i.e. LTV, massage); in the QS they can be SERVICE FACILITIES.*

- **LABOR**
  This element can be used to model both human and physical resources (i.e. tools, people or equipment) which may be required by other elements for processing, setting up, repair, cleaning and so on.
  ⇒ *in the GCKE model they can be OPERATOR OF REHABILITATION DEVICES or PHYSIOTERAPIST (massage); in QS they can be SERVICE "SOURCE".*

Patients' arrival in simulation model is represented in WITNESS by arrival of **service demands (parts)** to the system. Each part can be characterized by a particular set of attributes, quantity and arrival time. Part may input the system with active

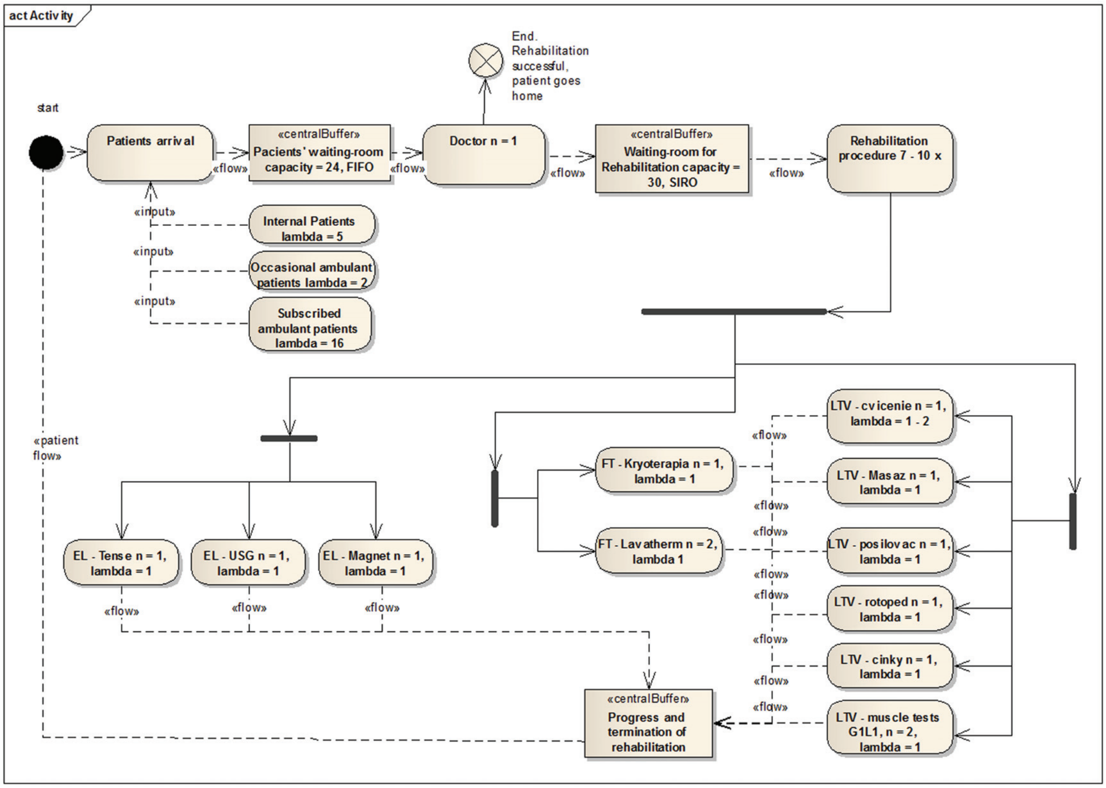


Fig. 3: *Combined queuing system in GCKE.*

or passive profile. In this case, all parts arrive to the system with active profile, as follows:

a) **Internal patients** (arrival rate Poisson distribution: mean value of number x-occurrences of event A for time unit, $E(x) = \lambda$, interarrivaltime: Exponential distribution, mean value of time interval between two events $E(t) = 1/\lambda, t \geq 0$).

b) **Subscribed ambulant patients** (parts arrival was defined by arrival profile 2 patients per hour, 16 per day, in terms of ordering the patients by doctor/his nurse).

c) **Occasional ambulant patients** (arrival rate Poisson distribution, interarrivaltime 510 minutes of simulation time, what represents 1 day in model).

Patients enter **waiting-room at doctor's** called **"CakarenLekar"**, which is represented in WITNESS by **Buffer**. Buffers can be set its capacity – restricted the quantity of stored parts, selection priority for ordering the members of the queue for service. Parts can enter the buffer, and machines can take them based on specified logical rules. Buffer is not the active element, cannot send parts further. Capacity of the buffer is set for the number of 24 patients.

Machine Lekar empties the buffer, in this case according to FIFO (first-in-first-out) queue discipline. Element Lekar have defined input and output logic rules in order to provide target activity that is serving patients by determining the patient's diagnosis and prescribing adequate rehabilitation treatment. Defining rules is being done by using built in logical elements and modules as attributes, variables, files, distributions, functions, part files, shifts, modules, manipulating elements as rules, actions, expressions; eventually create own functions, algorithms using similar programming language to BASIC, but reads more like English and incorporates help facilities [1].

Single machine **Lekar** determines the diagnosis based on random numbers generating algorithm from interval $\langle 0,1\rangle$ according to percentual rate of performance executed in previous years 2007, 2008 by GCKE. Patients with assigned diagnosis are sent to **rehabilitation waiting-room**.

Rehabilitation waiting-room is in WITNESS represented by buffer with set SIRO (selection-in-random-order) queue discipline for selection of patient for relevant rehabilitation procedure. Capacity of the buffer is set for the number of 30 patients. Buffer stores patients who wait for their rehabilitation procedure.

Rehabilitation unit is being modeled by element **machine** and its behavior is defined by input and output logic rules. This machine empties buffer "CakarenRehab" continuously, always after the service for previous demand - patients have been finished. The number of requested patients is set when detailing the machine. Patients are dispatched there at the same day the doctor prescribes the diagnosis to them, or next possible day in case the capacity of rehabilitation waiting-room is full.

Rehabilitation units Tense, Magnet, USG belong to the group performing EL - electrotherapy, and **variable PocetEL** counts the number of executed service performance for abovementioned units altogether. Rehabilitation units Lavatherm, Kryoterapia belong to the group performing FT – physical therapy, and **variable PocetFT** counts the number of executed service performance for abovementioned units altogether. Rehabilitation units LTV, Masaz, LTV_rotoped, LTV_posilovac, LTV_cinky belong to the group performing LTV_M – dynamic motion therapy, and variable PocetLTV_M counts the number of executed service performance for abovementioned units altogether. Rehabilitation unit G_1L_1 performs muscle tests for patients before they start and after they end rehabilitation treatment cycle and according to the needs, and **variable PocetG$_1$L$_1$** counts the number of executed service performance for abovementioned units altogether.

Simulation model also embodies the performance of each rehabilitation unit separately after the end of a simulation run. Each rehabilitation unit is defined by own service time and time for set-up of the equipment before direct rehabilitation. **Service time** for all machines in the model is defined by **continuous uniform distribution**, which mean rate of variable X,

$$E(X) = \frac{A+B}{2}, \qquad (1)$$

while A indicates the beginning of the scope and B indicates the end of the scope. Result of studied phenomena is a real number X from $\langle A,B\rangle$ interval. In case of continuous uniform distribution for each member of the family, all intervals of the same length in a field from A to B on the distribution's support are equally probable.

Both, **physiotherapists and Masseur** represent **labor**, which is allocated to single machines in order to operate them. In fact, without labor it is impossible to provide the service to the patients. Labor has defined working hours and breaks, like all elements in the simulation model, what is secured with shifts. Rehabilitation unit employ six physiotherapists and one certified masseur.

Simulation time in the GCKE model does not follow calendar time, but effective working time fund (pure working time with essential planned breaks). Working shift profile is defined by design element called **Shifts**, where it is possible to set number of hours and breaks per day, week(-s).

Simulation time was set to indicate minutes, and time unit can be defined in general settings for the model. Total duration of the working shift in the GCKE model is 510 minutes (8,5 hours), with one 30 minutes and two 15 minutes breaks. Working week takes 5 days; subsequently simulation year lasts 251 days, hence 128010 minutes.

After the given time for the single simulation run, the system WITNESS offers a possibility of statistical numerical and graphical reports of simulation results, in the system called **Statistics**. These may be: number of operations, machines' performance percentage – busy rate, idle rate, setup rate, cycle wait labor rate, etc.

Reports contain the details of the calculations to generate the report which is usually based on the value of other functions or variables in a model, and may either have the default display of a table of values or a chart. **Pie charts** are useful to represent the percentage of time that an element spends in a certain state (for example, that amount of time that is spent in a busy or idle state). **Histogram** presents simulation results on the screen in the form of a bar chart. This is useful for determining the range of values observed for some parameter of the simulation. **Timeseries** present simulation results on the screen in the form of a graph which plots values taken from the simulation against time. Up to seven values may be plotted with seven different colors. Timeseries are useful for determining the trends or cycles underlying the model since they provide a history of the specified value as well as a mean and standard deviation.

Output of the accomplished Rehabilitation Department of GCKE simulation model (Fig. 4) approaches an output data of real performance of Rehabilitation Department (comparing with years 2007, 2008) on a large scale. **Verification chart** (Table 1) indicates percentage deviation calculation of target parameter values of the simulation process from comparing mean value of two years (2007, 2008) of the real RA-GCKE performance according to the data from their annual report.

A statistical hypothesis test **Two-sample unpooled t-test with unequal variances** [corresponding to source [1]], was used for the purpose of comparing the mean values of two basic data files (real annual performance for years 2007, 2008 and output data from simulation model run set for 251 days); those are being estimated using mean values of single independent samples. When comparing two mean values μ_1 and μ_2 the null hypothesis is contrasted

$$H_0: \quad \mu_1 = \mu_2 \tag{2}$$

against bilateral alternative hypothesis

$$H_1: \quad \mu_1 \neq \mu_2, \tag{3}$$

which assumes, that estimated mean values 1 and 2 are not equal. Next step consist in determination of significance level, which express a risk of error rejection of the null hypothesis H_0, if that is true.

$$z = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_1^2}{n_1}}}, \tag{4}$$

where

$\sigma_{1,2}$ – variance,

$n_{1,2}$ – sample size,

$\bar{x}_{1,2}$ – sample mean value.

Then, testing statistics is being estimated based on known evidence (means, standard deviation, file ranges) and compared with a critical value (4).

Results from tests have detected, that *mean values of annual performance of the rehabilitation units EL and LTV_M* may *be considered as equal* and *mean values of annual performance of the rehabilitation unit FT* may not *be considered as equal at the significance level 0,05 (reliability level is 95 %).*

EXPERIMENTING WITH THE MODEL

A **failure rate of a mechatronic shoe** is a main key issue of researchers at the Technical University of Kosice, Slovakia, who work on international project SMILING – 7th frame programm, founded by European Commission. If the failure rate is excessively frequent, it would endanger testing experiments and time schedule for testing the patients using the mechatronic shoe. Afterwards, the training tests would last longer time-period, and testing could fail by reason of insufficient budget for behind schedule training days.

Experiments according to abovementioned circumstances were accomplished for the time period of 100 days with following breakdowns modalities, set by SMILING project researchers:

1. **Mean time between failures** $E(t) = 150$ **min (2,5 hours). Repair time** T**:**
   - **a) 30 min,**
   - **b) 510 min.**
2. **Mean time between failures** $E(t) = 3000$ **min (50 hours). Repair time** T**:**
   - **a) 30 min,**
   - **b) 510 min.**

Reports from running of single experiments with different breakdown interval and repair time are depicted in the Fig. 5, as a graphic percentage output about behavior of the mechatronic shoe.

Failure rate is graphically illustrated with a red-colour array, light blue array represents percentage of setups on machine, yellow colour shows machine state idle, and green colour machine state busy.

Table 1: *Verification chart of the parameters of the simulated process and the GCKE annual report for years 2007, 2008, where $\bar{x}$ – mean value, s – standard deviation.*

	Report 2007	Report 2008	$\bar{x}$ [n]	s [n]	SimMod results	$\bar{x}$ [n]	s [n]	Deviation [%]
Performance EL per year [n]	9380	10265	9822,5	442,5	9407	9271	55	5,61
Performance FT per year [n]	2146	2224	2185	39	2644	2591,8	83,89	18,62
Performance LTV per year [n]	43973	45366	44669,5	696,5	44722	45014,6	69,18	0,77

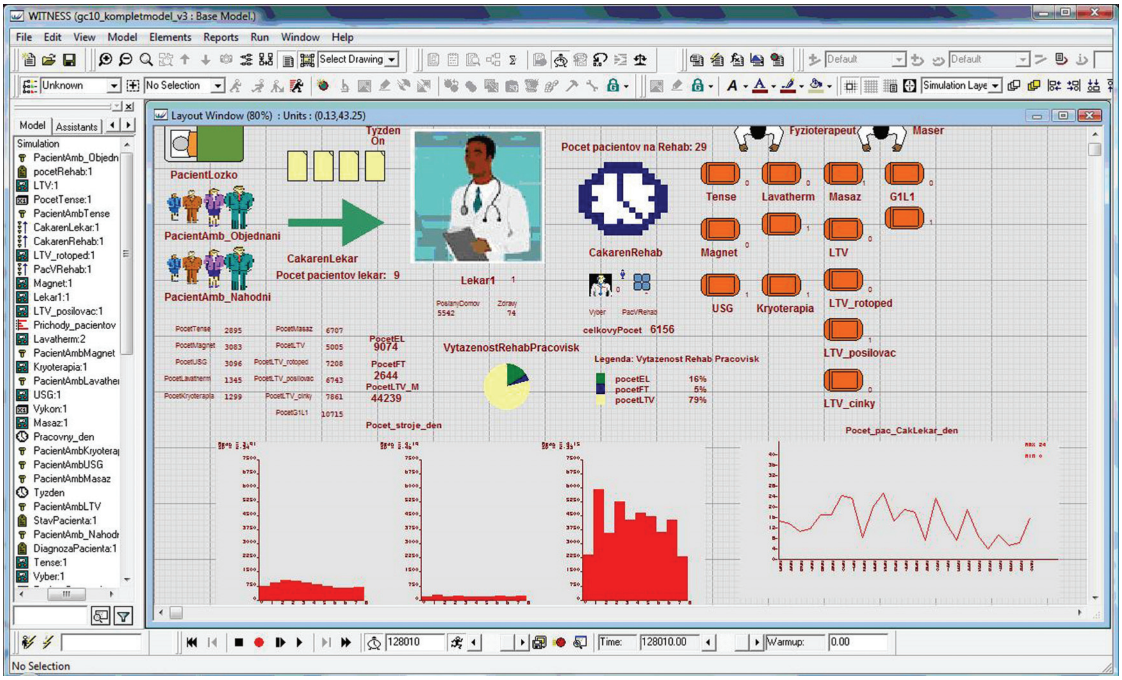
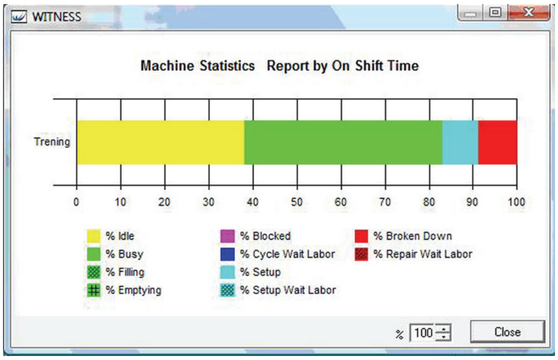


Fig. 4: *Simulation model of the RA-GCKE in software WITNESS together with output reports from the system – left Pie chart, Histogram and Timeseries.*

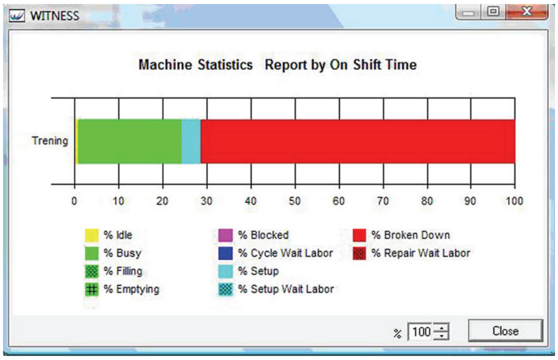
As the most preferable alternative in term of trouble free operation, confirmed by experiment, seems the alternative 2a with the mean time between failures NEGEXP (3000) – Negative exponential distribution, and the repair time ERLANG (30,3) distribution.

The alternative 1b with the mean time between failures NEGEXP (150), and the repair time ERLANG (510, 30) poses the most threatening scenario of the breakdowns frequency during testing a gait of seniors with mechatronic shoe; in a such case the training plan would be accomplished according to the result's chart 3 and 4 on 47,50 % within considered time period (a length of testing period 20 weeks, so 100 days). In order to accomplish the determined plan, the training personnel together with the technician would need another 29 – 30 days.

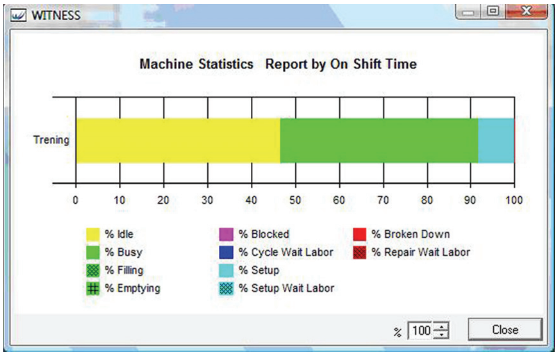
When considering the alternative 1a with the mean time between failures NEGEXP (150) and repair time ERLANG (30, 3), in this case the risk of breakdowns frequency seems 50 % bigger than at operation with the mean time between failures NEGEXP (150) and the repair time ERLANG (510,3). All the other alternatives of the assumed breakdown frequency in compliance with the run experiments do not pose the threat of the unrealizable testing training plan within the planned period of 20 weeks (100 days).



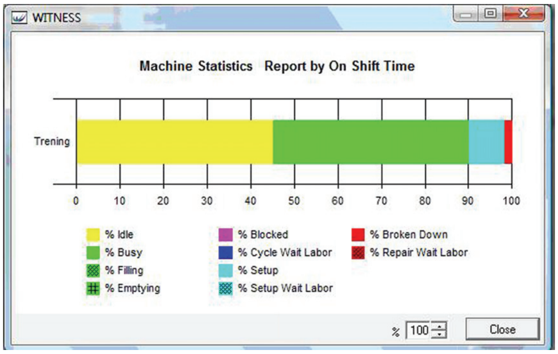
1a) *Experiment mean time between failures NEGEXP (150), Repair time ERLANG (30,3).*



1b) *Experiment mean time between failures NEGEXP (150), Repair time ERLANG (510,3).*



2a) *Experiment mean time between failures NEGEXP (3000), Repair time ERLANG (30,3).*



2b) *Experiment mean time between failures NEGEXP (3000), Repair time ERLANG (510,3).*

Fig. 5: *Statistical graphic presentation of set breakdown alternatives.*

The value *Difference* in the Tables 2, 3 and 4 defines the change of a new state of a system including experiments against the initial one without experiments.

Now, our interest is a reliability of determined measuring average, as its best value, it means average error rate in respect of a real *mean value* μ. As the average is burdened by random error, it deviates apart from the real value, and when measurements are widely distributed, then is not very reliable.

The bigger the number of measurements is, the more accurately can be the mean value determined, that results from the *mean average error rate* se_x calculation formula [1].

$$se_x = \frac{s_x}{\sqrt{n}}. \tag{5}$$

The real measured value μ occurs with the big probability inside the interval $\bar{x} \pm se_x$. Mean average error rate is indicated in the same measure as the measured parameter.

Table 2: *Percentual load and performance of single machines and their labor for purpose of comparing various alternatives of the breakdowns.*

Machines	Busy [%]	Idle [%]	Broken Down [%]	Performance 100 days [n]	Difference [n]	Difference [%]
Trening_porucha150_30	44,92	38,11	8,68	480	0	0,00
Trening_porucha150_510	23,64	0,74	71,30	252	-228	-47,50
Trening_porucha3000_30	44,92	46,70	0,10	480	0	0,00
Trening_porucha3000_510	44,92	45,16	1,64	480	0	0,00
Labor						
Technik1_150_30	61,89	38,11		1208	16	1,34
Fyzioter1_150_30	44,92	55,08		598	4	0,67
Technik1_150_510	99,26	0,74		787	-405	-33,98
Fyzioter1_150_510	23,64	76,36		307	-287	-48,32
Technik1_3000_30	53,30	46,70		1094	-98	-8,22
Fyzioter1_3000_30	44,92	55,08		594	0	0,00
Technik1_3000_510	54,84	45,16		1098	-94	-7,89
Fyzioter1_3000_510	44,92	55,08		594	0	0,00

Table 3: *Number of patients, who run through system, or inhere in the waiting room for purpose of comparing various alternatives of the breakdowns.*

Waiting rooms/Patients	Mean labor time 100 days [n]	Differen-ce [n]	Differen-ce [%]	Mean wai-tingroom/labor/pa-tients 100 days [n]	Differen-ce [n]	Differen-ce [%]
TestCakaren_150_30	51,57	17,19	50,00	0,49	0,17	53,13
TestCakaren_150_510	15005,87	14971,49	43547,09	141,23	140,91	44034,38
TestCakaren_3000_30	29,64	-4,74	-13,79	0,28	-0,04	-12,50
TestCakaren_3000_510	43,11	8,73	25,39	0,41	0,09	28,13
TestPacient_150_30	70,62	14,62	26,11	1,06	0,22	26,19
TestPacient_150_510	9580,31	9524,31	17007,70	143,12	142,28	16938,10
TestPacient_3000_30	50,07	-5,93	-10,59	0,75	-0,09	-10,71
TestPacient_3000_510	59,39	3,39	6,05	0,89	0,05	5,95

Table 4: *Specimen of replication results run within period of 100 days for the purpose of statistical calculations of breakdowns, where p – relative coincidence rate, $E(X)$ – mean coincidence rate value of time axis in Histogram Pocet_stroje_den, S – standard deviation, S2 – variance, R – variation coefficient.*

Attribute (N)	Trening_porucha_150_510	Trening_porucha_150_510 (p) [%]	Trening_porucha_150_510 ($E(X)$)	TestCakaren_150_30	TestCakaren_150_30 (p) [%]	TestCakaren_150_30 ($E(X)$)	TestCakaren_150_510	TestCakaren_150_510 (p) [%]	TestCakaren_150_510 ($E(X)$)
1	232	0,2252	52,25631	60,44	0,2042	12,34286	16053,00	0,186	2985,84
2	216	0,2097	45,29709	51,68	0,1746	9,024268	15437,00	0,1788	2761,09
3	197	0,1913	37,67864	51,97	0,1756	9,125831	18609,00	0,2156	4012,36
4	154	0,1495	23,02524	69,86	0,2361	16,49013	20199,00	0,2340	4727,31
5	231	0,2243	51,8068	62,01	0,2095	12,99243	16009,00	0,1855	2969,49
Mean (X)	206,00			59,19			17261,40		
Median (x)	216,00			60,44			16053,00		
$S2$	147,74			9,59			715050,63		
S	12,15			3,10			845,61		
R	78			18,18			4762		

Mean average error rate can be also used for an approximate estimation of an estimation accuracy. The estimation may be considered as very good, if the mean error is less than 5 % of average size, see formula

$$se_x = \leq 0,05 \cdot \bar{x}. \tag{6}$$

The estimation may be considered as good, if the mean error is less than 10 % of average size. Sufficient estimation may be considered, if the mean error falls between 10 – 15 % of average size. Insufficient estimation has mean error bigger than 15 %.

Standard deviation details an error range, within what the next measuring value falls with a big probability. *Variation coefficient* V_x is the another useful variability rate; is being used for example at statistical verification of the quality of laboratory experiments

$$V_x = \frac{s_x}{\bar{x}} 100\%. \tag{7}$$

Processing the results of the experiments (Table 4) may be determined the accuracy of the average estimation of monitored parameters. The average estimation for all monitored parameters is very good (mean error is less than 10 %), except the parameter se_x (TestCakaren_3000_510) = 92,8821 and the accuracy estimation is 36,5123 % (insufficient). Inaccuracy of the estimation of the parameter TestCakaren_3000_510 is caused by deviation of one measured value from 3th replication.

When that value would be excluded, recalculation shows following results: se_x(TestCakaren_3000_510) = 11,8592, accuracy estimation increase to 9,6155 % (very good), and V_x = 19,2309 %.

CONCLUSION

Proposed simulation model with application of queueing theory in the programm WITNESS dynamically illustrates the flow of material/ customers through the system, states of single elements, performed operations, actual use of sources. At the same time, all events that occurred in the system are being recorded.

Resultant model of the Rehabilitation ambulance GCKE was based on obtained data, after several consultations with the management and personnel of RA-GCKE, collecting information from patients through questionnaire, verificated and validated, and in such form used for experimenting.

Similar approach can be used for extending the existing model about another GCKE logistical controlling components, for example pharmaceutics and medical equipment supply management, provision of transport, laundry, etc. Continuous use of the simulation model is equally possible at analogical premises of rehabilitation departments in hospitals, respectively with analysis of other service systems, even outside healthcare sector – for analysis of any processes, where it is necessary to measure an impact of proposed changes and evidently quantify the alternatives of solutions.

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