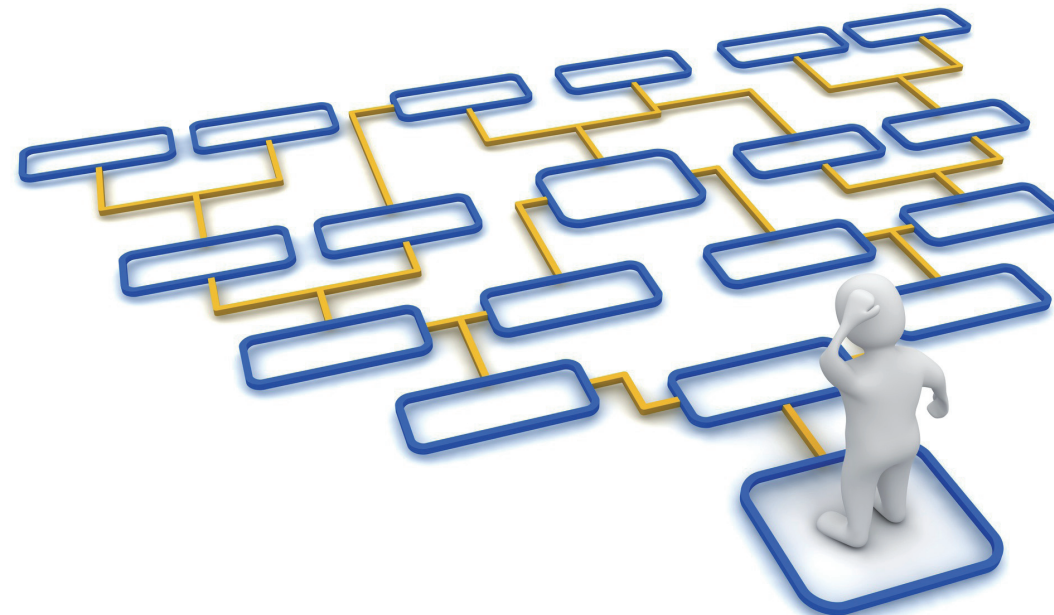


The main advantage of simulation over analytical modeling is universality in the sense of the possibility of studying any complex queueing systems, taking into account such factors and conditions that are difficult or impossible to consider by analytical modeling. GPSS World is the General Purpose Simulation System for creating simulation models designed for use in Windows environments. Each person is inclined to perceive information differently. Most people are easier to learn new things on concrete examples. The proposed book is constructed as a collection of programs for the GPSS World environment, containing the author's models of various queueing systems. Each model is accompanied by detailed step by step explanations. Considerable attention is paid to the creation of models of systems and certain aspects of modeling, insufficient lighting in the literature: systems with threshold strategies of functioning, with batch arrivals, with a separate queue for each channel, retrial systems, closed systems, determination of employment characteristics of separate channels and an entire system. The book is intended for researchers and students engaged in simulation of queueing systems.



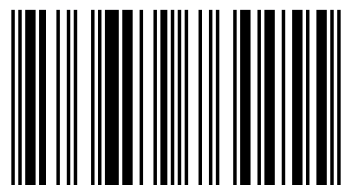
Yuriy Zhernovyi

# Creating models of queueing systems using GPSS World

Programs, detailed explanations and analysis of  
results



Zhernovyi Yuriy. Ph.D. in Mathematics, associate professor of Department of Theoretical and Applied Statistics of Ivan Franko National University of Lviv, Ukraine. Author of more than 90 scientific papers and 5 books.



978-3-659-76445-5

**Yuriy Zhernovyi**

**Creating models of queueing systems using GPSS World**



**Yuriy Zhernovyi**

# **Creating models of queueing systems using GPSS World**

**Programs, detailed explanations and analysis of  
results**

**LAP LAMBERT Academic Publishing**

## **Impressum / Imprint**

Bibliografische Information der Deutschen Nationalbibliothek: Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.d-nb.de> abrufbar.

Alle in diesem Buch genannten Marken und Produktnamen unterliegen warenzeichen-, marken- oder patentrechtlichem Schutz bzw. sind Warenzeichen oder eingetragene Warenzeichen der jeweiligen Inhaber. Die Wiedergabe von Marken, Produktnamen, Gebrauchsnamen, Handelsnamen, Warenbezeichnungen u.s.w. in diesem Werk berechtigt auch ohne besondere Kennzeichnung nicht zu der Annahme, dass solche Namen im Sinne der Warenzeichen- und Markenschutzgesetzgebung als frei zu betrachten wären und daher von jedermann benutzt werden dürften.

Bibliographic information published by the Deutsche Nationalbibliothek: The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Any brand names and product names mentioned in this book are subject to trademark, brand or patent protection and are trademarks or registered trademarks of their respective holders. The use of brand names, product names, common names, trade names, product descriptions etc. even without a particular marking in this work is in no way to be construed to mean that such names may be regarded as unrestricted in respect of trademark and brand protection legislation and could thus be used by anyone.

Coverbild / Cover image: [www.ingimage.com](http://www.ingimage.com)

Verlag / Publisher:

LAP LAMBERT Academic Publishing

ist ein Imprint der / is a trademark of

OmniScriptum GmbH & Co. KG

Heinrich-Böcking-Str. 6-8, 66121 Saarbrücken, Deutschland / Germany

Email: [info@lap-publishing.com](mailto:info@lap-publishing.com)

Herstellung: siehe letzte Seite /

Printed at: see last page

**ISBN: 978-3-659-76445-5**

Copyright © 2015 OmniScriptum GmbH & Co. KG

Alle Rechte vorbehalten. / All rights reserved. Saarbrücken 2015

# Contents

<b>INTRODUCTION</b> .....	6
<b>1 SYSTEMS WITH REJECTIONS</b> .....	10
<b>1.1 A multichannel system with rejections</b> .....	10
1.1.1 Description of the system.....	10
1.1.2 The simulation model.....	10
1.1.3 Description of the Model 1.1.1 .....	11
1.1.4 The results of the Model 1.1.1 .....	12
1.1.5 The single-channel system .....	13
1.1.6 Obtaining statistics for each channel .....	15
<b>1.2 A system with rejections and equiprobable distribution of customers</b> .....	18
1.2.1 Description of the system.....	18
1.2.2 The simulation model.....	18
1.2.3 Description of the Model 1.2.1 .....	19
1.2.4 The results of the Model 1.2.1 .....	20
<b>1.3 A retrial system with rejections</b> .....	20
1.3.1 Description of the system.....	20
1.3.2 The simulation model.....	21
1.3.3 Description of the Model 1.3.1 .....	21
1.3.4 The results of the Model 1.3.1 .....	22
1.3.5 A system with a given number of retries .....	22
<b>1.4 A system with rejections and heterogeneous customers</b> .....	24
1.4.1 Description of the system.....	24
1.4.2 The simulation model.....	24
1.4.3 Description of the Model 1.4.1 .....	25
1.4.4 The results of the Model 1.4.1 .....	26
<b>1.5 Determination of employment characteristics of a single-channel system</b> .....	26
1.5.1 The idle and the busy periods .....	26
1.5.2 The simulation model.....	27
1.5.3 Description of the Model 1.5.1 .....	27
1.5.4 The results of the Model 1.5.1 .....	29
1.5.5 The case of Poisson arrival process .....	30

<b>1.6 Determination of load characteristics of a multichannel system...</b>	<b>31</b>
1.6.1 The idle period, incomplete load period and full load period.....	31
1.6.2 The simulation model.....	32
1.6.3 Description of the Model 1.6.1 .....	33
1.6.4 The results of the Model 1.6.1 .....	35
<b>2 SYSTEMS WITH WAITING .....</b>	<b>38</b>
<b>2.1 A finite-buffer system .....</b>	<b>38</b>
2.1.1 Description of the system.....	38
2.1.2 The simulation model.....	38
2.1.3 Description of the Model 2.1.1 .....	39
2.1.4 The results of the Model 2.1.1 .....	40
2.1.5 Obtaining statistics for each channel .....	41
<b>2.2 An infinite-buffer system .....</b>	<b>43</b>
2.2.1 Description of the system.....	43
2.2.2 The simulation model.....	44
2.2.3 Description of the Model 2.2.1 .....	44
2.2.4 The results of the Model 2.2.1 .....	45
2.2.5 Determination of sojourn time distribution of a customer in the queue and in the system .....	46
2.2.6 A system with limited waiting time in queue .....	48
2.2.7 A system with restrictions on the utilization factors of channels.....	53
<b>2.3 A batch-arrival infinite-buffer system .....</b>	<b>56</b>
2.3.1 Description of the system.....	56
2.3.2 The simulation model.....	56
2.3.3 Description of the Model 2.3.1 .....	57
2.3.4 The results of the Model 2.3.1 .....	58
<b>2.4 A multiphase infinite-buffer system .....</b>	<b>61</b>
2.4.1 Description of the system.....	61
2.4.2 The simulation model.....	62
2.4.3 Description of the Model 2.4.1 .....	63
2.4.4 The results of the Model 2.4.1 .....	64
<b>2.5 A system with waiting and heterogeneous customers.....</b>	<b>65</b>
2.5.1 Description of the system.....	65

2.5.2	The simulation model.....	66
2.5.3	Description of the Model 2.5.1 .....	66
2.5.4	The results of the Model 2.5.1 .....	67
2.5.5	Separate statistics on customers of each type .....	68
2.5.6	Priority service by types of customers .....	70
<b>2.6</b>	<b>A multichannel system with separate queues for each channel.....</b>	<b>74</b>
2.6.1	Equiprobable distribution of customers by all channels.....	74
2.6.2	Distribution of customers to the channel with the least queue .....	77
2.6.3	A batch-arrival finite-buffer system with discarding batches of customers .....	80
<b>2.7</b>	<b>Determination of employment characteristics of a single-channel infinite-buffer system .....</b>	<b>85</b>
2.7.1	The idle period, busy period and queue presence period .....	85
2.7.2	The simulation model.....	86
2.7.3	Description of the Model 2.7.1 .....	87
2.7.4	The results of the Model 2.7.1 .....	89
2.7.5	The average duration of the stay of the system in states $S_k$ .....	91
2.7.6	The case of a Poisson arrival process .....	92
<b>2.8</b>	<b>Determination of load characteristics of a multichannel infinite-buffer system .....</b>	<b>95</b>
2.8.1	The idle period, incomplete load period and full load period.....	95
2.8.2	The simulation model.....	96
2.8.3	Description of the Model 2.8.1 .....	97
2.8.4	The results of the Model 2.8.1 .....	99
2.8.5	The idle period, turnover cycle and average length of the stay in states $S_k$ .....	102
<b>2.9</b>	<b>A system with heterogeneous channels .....</b>	<b>106</b>
2.9.1	Description of the system.....	106
2.9.2	The simulation model.....	106
2.9.3	Description of the Model 2.9.1 and the results of its realization .....	107
2.9.4	Determination of employment characteristics for each channel .....	108



<b>2.10 A closed system</b> .....	115
2.10.1 Description of the system.....	115
2.10.2 The simulation model.....	116
2.10.3 Description of the Model 2.10.1 .....	116
2.10.4 The results of the Model 2.10.1 .....	117
2.10.5 A closed system with heterogeneous channels .....	118
2.10.6 A closed system with heterogeneous channels and separate queues for each channel .....	120
 <b>3 SYSTEMS WITH THRESHOLD STRATEGIES OF FUNCTIONING</b> .....	 126
<b>3.1 An infinite-buffer system with a threshold change of the number of channels</b> .....	 126
3.1.1 Description of the system.....	126
3.1.2 The simulation model.....	126
3.1.3 Description of the Model 3.1.1 .....	130
3.1.4 The results of the Model 3.1.1 .....	133
3.1.5 Determination of the duration of the stay in states of usual mode and overload mode .....	134
<b>3.2 A system with a threshold switching of the service time</b> .....	143
3.2.1 Description of the system.....	143
3.2.2 The simulation models .....	144
3.2.3 Description of the Models 3.2.1 and 3.2.2 .....	146
3.2.4 The results of the realization of the Models 3.2.1 and 3.2.2.....	147
3.2.5 Determination of the duration of the stay of each channel in overload state.....	151
3.2.6 A system with a threshold blocking of an input flow .....	158
<b>3.3 A system with switchings of the service time depending on the queue length</b> .....	 164
3.3.1 Description of the system.....	164
3.3.2 The simulation model.....	165
3.3.3 Description of the Model 3.3.1 .....	167
3.3.4 The results of the Model 3.3.1 .....	169
<b>3.4 A system with a two-threshold hysteretic strategy of switching of the service time</b> .....	 170

3.4.1 Description of the system.....	170
3.4.2 The simulation model.....	170
3.4.3 Description of the Model 3.4.1 .....	173
3.4.4 The results of the Model 3.4.1 .....	174
3.4.5 Employment characteristics of the single-channel system .....	176
3.4.6 A system with a threshold blocking of an input flow .....	183
<b>3.5 A system with a threshold control of two independent input flows .....</b>	<b>186</b>
3.5.1 Description of the system.....	186
3.5.2 The simulation model.....	187
3.5.3 Description of the Model 3.5.1 .....	188
3.5.4 The results of the Model 3.5.1 .....	190
3.5.5 Two-threshold hysteretic control for the infinite-buffer system.....	192
3.5.6 Two-loop hysteretic control for the finite-buffer system.....	196
<b>3.6 A system with using the random dropping of customers to reduce the queue .....</b>	<b>200</b>
3.6.1 Description of the system.....	200
3.6.2 The simulation model.....	201
3.6.3 Description of the Model 3.6.1 .....	201
3.6.4 The results of the Model 3.6.1 .....	202
3.6.5 The batch-arrival system.....	203
<b>Appendix A. Basic GPSS language Block Statements and Commands .....</b>	<b>207</b>
<b>Appendix B. Main GPSS System Numerical Attributes .....</b>	<b>208</b>
<b>References .....</b>	<b>211</b>

## INTRODUCTION

In 2000 the company Minuteman Software has developed a system simulation GPSS World. GPSS World is based on the seminal language of computer simulation, GPSS, which stands for General Purpose Simulation System.

This language was created by Geoffrey Gordon in 1960. The basis of simulation algorithms in GPSS is a discrete-event approach. In GPSS developers were able to very clearly and gracefully pass on the verge of the correspondence with the problem area (in the terminology, by destination, by research methodology) and the effectiveness of programming (modeling convenience, speed, use of computer resources). GPSS World is the most modern version of GPSS for Windows.

A dynamic element of a model created in the environment of GPSS World, is a transaction. A transaction is an abstract object that moves between static elements, reproducing the various events of the real object being modeled. Static elements of a model are sources of Transactions, Storages, Queues and others. Their location in the model is defined by Blocks.

Model, Simulation, and Report Objects form the 3 basic types that are used in all GPSS World simulations. Typically, a Model is developed by editing the statements in a Model Object. Then, a Create Simulation command is issued, thereby creating a Simulation Object structured according to the statements in the Model. Normally, when a simulation completes, a Report Object is created automatically.

GPSS World has a scheduler that performs the following functions:

- ensuring of movement of dynamic objects (transactions) by the routes specified by the developer;
- planning of events, occurring in the model, by recording the time of occurrence of each event and fulfillment of them in increasing time sequence;
- registration of statistical information on the operation of the model;
- promotion of model time during simulation.

The system clock, keeping the values of the absolute system clock, ensures the correct processing sequence of events in time.

There are now sufficient textbooks in which the basics of building and operation of the GPSS World system are set out [2, 3, 5, 6, 11]. Study a user manual on GPSS World with a detailed description of all blocks and their interaction takes a lot of time and is boring, if the process of learning is not backed by specific examples. Therefore, the proposed book is built as a collection of author simulation models of various queueing systems. Each model is accompanied by detailed step by step explanations. Considerable

attention is paid to the creation of models of systems and certain aspects of modeling, insufficient lighting in the literature: systems with threshold strategies of functioning [7–10, 13], with batch arrivals, with a separate queue for each channel, with heterogeneous channels, retrial systems, closed systems, determination of employment characteristics of separate channels and an entire system.

Before you begin the computation of stationary characteristics of a queueing system using a simulation model, we must ensure that a random process describing the operation of the system, has a limiting stationary process. The operating mode of the system, corresponding to this process, is called a *steady-state* or *stationary*. For each studied queueing system without restrictions on the queue length, we specify conditions for the existence of a steady state. For systems with rejections and with restriction on the queue length a steady state exists for all values of the parameters of the input flow and service time.

In considering each queueing system we adhere to the following sequence: a description of the system, simulation model, explanation to the constructed model, model results and discussion.

In the explanations to simulation models, we try to avoid repetitions, stopping only on the features of the functioning of those blocks and operators which appear for the first time.

For better understanding of the material we recommend to a reader to study the basics of construction and principles of operation of the GPSS World system [2, 3, 5, 6, 11], the analytical methods of queueing theory [1, 12] and the elementary concepts of probability theory [4].

The book consists of three Sections devoted to the creation of models of systems with rejections, with waiting and with the threshold functioning strategies respectively.

Let us consider the basic assumptions and the notation used in the text.

We assume that *an input flow of customers* is the ordinary (simultaneous arrival of two or more customers is impossible) stationary flow with limited aftereffects (stationary flow of Palma) [12, Section 1.1]. Stationary flow of Palma with an exponentially distributed time intervals between events is called *simplest* or *Poisson stationary*. We also consider systems with batch arrivals.

The interarrival times  $T_{ar}$  and the service times  $T_{sv}$  assumed to be independent identically distributed random variables with finite mean values.

Let  $F(x)$  be the probability distribution function of the random variable  $T_{ar}$  and  $G(x)$  be the probability distribution function of the random variable  $T_{sv}$ . Further, these distributions for convenience we call  $F$  distribution and

$G$  distribution, respectively, and their mathematical expectations we denote by  $E_F$  and  $E_G$ .

Depending on the *number of channels*  $n$ , involved in the process of customer service, we distinguish *single-channel* ( $n=1$ ) and *multichannel* ( $n>1$ ) queueing systems.

A *simulation time*  $T_{\text{mod}}$ , for which obtained results provide approximate values of stationary characteristic of a system with a given accuracy, is selected by increasing the time of modeling and comparing the results of successive large its values. If with further increase of the simulation time, the module of difference of characteristic values does not exceed the specified accuracy, we can stop on the selected value.

We use the abbreviation SNA for a *System Numerical Attribute*, NSB for a *Next Sequential Block* and note that a single-channel device simulated in GPSS World by a Facility Entity and a multichannel device simulated in GPSS World by a Storage Entity.

Introduce the notation for stationary characteristics of queueing systems:

$P_{\text{sv}}$  = the probability of service for arrived customer;

$P_{\text{rej}}=1-P_{\text{sv}}$  = the probability of rejection;

$E(X)$  = the average value (mathematical expectation) of the random variable  $X$ ;

$N_c$  = the number of customers in a system;

$\sigma_c$  = the standart deviation of the random variable  $N_c$ ;

$S_k$  = the state of the system, in which  $N_c=k$ ;

$T_k$  = the time spent by the system in the state  $S_k$ ;

$p_k=P\{N_c=k\}$  = the stationary probability of the state  $S_k$ , i.e. the presence of  $k$  customers in the system;

$n_{\text{oc}}$  = the number of busy channels;

$K_u=E(n_{\text{oc}})/n$  = the system utilization factor (the probability that a channel is busy);

$Q$  = the number of customers in the queue (the queue length);

$W$  = the waiting time in queue (the time spent waiting in the queue before service begins);

$Q_{\text{max}}$  = the maximum length of the queue for the simulation time;

$T_{\text{rd}}$  = the length of a turnover cycle of the system;

$T_{\text{std}}$  = the length of an idle period;

$T_{\text{oc}}$  = the length of a busy period;

$T_{\text{pq}}$  = the length of the queue presence period;

$T_{\text{inc}}$  = the length of an incomplete load period;

$T_{\text{ful}}$  = the length of a full load period;

$\sigma_\alpha$  = the standart deviation of the random variable  $T_\alpha$ ;

$T_{us}, T_{ov}$  = the time spent one-time by the system in the state of usual mode or overload mode respectively;

$T_{ovk}$  = the time spent one-time by the channel number  $k$  in the state of overload mode;

$T_{stdk}, T_{ock}$  = the lengths of an idle period and busy period for the channel number  $k$ ;

$T_{ocu}, T_{oco}$  = the lengths of the parts of the busy period corresponding to the stay of the system in the states of usual mode and overload mode.

# 1 SYSTEMS WITH REJECTIONS

## 1.1 A multichannel system with rejections

### 1.1.1 Description of the system

A system, in which an arrived customer is rejected if at the arrival time all channels are busy by earlier accepted customers, is called the *queueing system with rejections* [12, Section 4.2]. There is no queue in the queueing system.

We define the stationary characteristics of the system:  $P_{sv}$  is the probability of service,  $P_{rej}=1-P_{sv}$  is the probability of rejection,  $E(n_{oc})$  is the average number of busy channels,  $p_k$  ( $0 \leq k \leq n$ ) is the probability of the presence of  $k$  customers in the system.

In the case of exponential distributions  $F$  and  $G$ , these characteristics can be found by the known formulas [12, Section 4.2].

*Parameters of the system:*

$n=5$ ;

$F$  is an uniform distribution on the interval [1, 2];

$G$  is an uniform distribution on the interval [7, 10].

### 1.1.2 The simulation model

**; Model 1.1.1**

```
Sys STORAGE 5
Dis TABLE S$Sys 0,1,6
Tm EQU 100000
GENERATE 1
TABULATE Dis
TERMINATE
Lal GENERATE (Uniform(1,1,2))
GATE SNF Sys,OUT
ENTER Sys
ADVANCE (Uniform(2,7,10))
LEAVE Sys
Lsv TERMINATE
OUT TERMINATE
GENERATE Tm
SAVEVALUE Psv,(N$Lsv/N$Lal)
SAVEVALUE Sav,SA$Sys
TERMINATE 1
START 1
```

### 1.1.3 Description of the Model 1.1.1

Below each fragment of the model, which we are interested, we give its description.

**Sys STORAGE 5**

We define a five-channel system (the Storage Entity named **Sys**, which can take no more than five transactions simultaneously).

**Dis TABLE S\$Sys 0,1,6**

We define parameters of Table named **Dis**, which contains the distribution of the random variable **S\$Sys** (the current value of the contents of Storage Entity **Sys**, that is, the number of busy channels). The random variable can take on integer values from 0 to 5. Here 0 is the upper bound of the first interval, 1 is the length of the interval, 6 is the number of frequency slots.

**Tm EQU 100000**

The **EQU** Command defines the name **Tm** and assigns the value 100 000 to it (the value of the simulation time).

**GENERATE 1**

Through each unit time the **GENERATE** Block creates a transaction that serves the Table **Dis**.

**TABULATE Dis**

**TERMINATE**

The transaction, which enters the **TABULATE** block, corrects the statistics of Table **Dis**. When the transaction enters the **TERMINATE** block it is removed from the simulation.

**LaI GENERATE (Uniform(1,1,2))**

This block creates transactions with interarrival time for the new transaction uniformly distributed on the interval [1, 2]. The number of the Random Number Generator is equal to 1.

**GATE SNF Sys,OUT**

The operator **SNF** puts the condition that the Storage Entity **Sys** is not filled. In the case of fulfillment of this condition the **GATE** block skips the transaction to the next block. If the predetermined condition is not satisfied, the **GATE** block sends the transaction to the label **OUT** for destruction.

**ENTER Sys**

**ADVANCE (Uniform(2,7,10))**

**LEAVE Sys**

The combination of these three blocks provides the operation of the Storage Entity **Sys** as the five-channel system, in which each channel service time (time delay of transaction) is uniformly distributed in the interval [7, 10]. The number of the Random Number Generator is equal to 2.



Lsv TERMINATE  
OUT TERMINATE

Each of these blocks destroys entering transactions (customers leave the system). Separation of blocks caused by the necessity to compute the service probability.

GENERATE Tm

This block creates a transaction at the time specified by the value Tm (i.e., at the simulation completion time).

SAVEVALUE Psv,(N\$Lsv/N\$Lal)

When a transaction enters this block (the entry time is the simulation completion time), the probability of service is assigned to the Savevalue Entity named Psv. The probability is defined as the ratio of the number of served customers (the number of transactions passed through the label Lsv) to the number of arrived customers (the number of transactions passed through the label Lal).

SAVEVALUE Sav,SA\$Sys

When a transaction enters this block (the entry time is the simulation completion time), the current value of the *System Numerical Attribute* (SNA) SA as the average number of busy channels of the Storage Entity Sys is assigned to the Savevalue Entity named Sav. In considered model, we can drop this block, since the value of SA\$Sys is automatically displayed in a standard report among the characteristics of the Storage Entity Sys.

TERMINATE 1

START 1

Thanks to these blocks and GENERATE Tm block we implement the simulation time specified by the user variable Tm. The value 1 of operand A of the TERMINATE block specifies the number of units for which the block reduces the value of the Termination Count (i.e. the value of the operand A of the START command) when a transaction enters this TERMINATE block. Thus, the value of the Termination Count becomes 0 and the simulation is stopped.

#### 1.1.4 The results of the Model 1.1.1

Let us present the fragment of a standard GPSS World report, generated by the Model 1.1.1 ( $T_{\text{mod}}=100\ 000$ ).

STORAGE	CAP.	REM.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	UTIL.	RETRY	DELAY
SYS	5	1	0	5	51060	1	4.338	0.868	0	0

TABLE	MEAN	STD.DEV.	RANGE		RETRY	FREQUENCY	CUM.%
DIS	4.338	0.683	-	-	0		
			0.000	-	0.000	1	0.00
			1.000	-	1.000	2	0.00
			2.000	-	2.000	521	0.52
			3.000	-	3.000	10567	11.09
			4.000	-	4.000	43461	54.55
			5.000	-	5.000	45447	100.00

SAVEVALUE	RETRY	VALUE
PSV	0	0.766
SAV	0	4.338

In Table STORAGE/SYS we find the following useful information: the number of customers accepted for service equals 51060,  $E(n_{oc})=4.338$  is the average number of busy channels,  $K_u=E(n_{oc})/n=0.868$  is the utilization factor of the system (or the probability that a channel is busy).

Tables SAVEVALUE/PSV, SAV give the service probability value  $P_{sv}=0.766$  (therefore, the rejection probability  $P_{rej}=0.234$ ) and value  $E(n_{oc})=4.338$ , which we specifically allocate separately in Savevalue Entity.

With the help of TABLE/DIS we can determine the stationary distribution probabilities of the number of customers in the system:  $p_0=0.00001$ ,  $p_1=0.00002$ ,  $p_2=0.00521$ ,  $p_3=0.10567$ ,  $p_4=0.43461$ ,  $p_5=0.45447$ . To do this, we divide the corresponding values of column FREQUENCY on the simulation time value. The average number of customers in the system  $E(N_c)=4.338$  for the system with rejections coincides with the average number of busy channels  $E(n_{oc})$ .

### 1.1.5 The single-channel system

For a single-channel system, we construct a simulation model by making minor changes to the Model 1.1.1.

It is sufficient for this to replace

**Sys STORAGE 5**

block by

**Sys STORAGE 1**

The second way is associated with the peculiarities of representation of some blocks and operators which are only used for a single-channel system, and requires a larger number of changes. As a result, we obtain the following model:

**; Model 1.1.2**

**Dis TABLE F\$Sys 0,1,2**

**Tm EQU 100000**

```

GENERATE 1
TABULATE Dis
TERMINATE
Lal GENERATE (Uniform(1,1,2))
GATE NU Sys,OUT
SEIZE Sys
ADVANCE (Uniform(2,7,10))
RELEASE Sys
Lsv TERMINATE
OUT TERMINATE
GENERATE Tm
SAVEVALUE Psv,(N$Lsv/N$Lal)
SAVEVALUE Fav,(FR$Sys/1000)
TERMINATE 1
START 1

```

Let us present the fragment of a standard GPSS World report, generated by the Model 1.1.2 ( $T_{\text{mod}}=100\ 000$ ).

FACILITY	ENTRIES	UTIL.	AVE. TIME	AVAIL.	OWNER	PEND	INTER	RETRY	DELAY
SYS	10787	0.916	8.489	1	166670	0	0	0	0

TABLE	MEAN	STD.DEV.	RANGE	RETRY	FREQUENCY	CUM.%
DIS	0.915	0.279		0		
			0.000 - -	0.000	8513	8.51
					91487	100.00

SAVEVALUE	RETRY	VALUE
PSV	0	0.162
FAV	0	0.916

Here, in Table FACILITY/SYS we can find information which was not in the table for the multichannel system. The average time during which one transaction occupies the Facility Entity (a single-channel device) equals 8.489 (approximately equal to the mean for the uniform distribution on the interval  $[7, 10]$ ). The number of transaction which occupies the Facility Entity at the simulation completion time equals 166670. The average number of busy channels, which for a single-channel system coincides with the utilization factor of the system, is equal to 0.916. The same value we find in Table SAVEVALUE/PSV, FAV, and here we have the service probability  $P_{sv}=0.162$ , which, of course, is much less than for the five-channel system.

Let us now consider the changes made to the Model 1.1.1.

The string

```
Dis TABLE S$Sys 0,1,6
```

is replaced by the following:

```
Dis TABLE F$Sys 0,1,2
```

This replacement is associated with using of others SNAs for Facilities. The SNA F takes the value 1 if a Facility Entity is busy, and value 0 if a Facility Entity is free.

For the same reason, we have made changes to

```
SAVEVALUE Sav,SA$Sys
```

block. Now in this block there is the SNA FR, which defines the utilization factor of a Facility Entity in parts-per-thousand.

Instead of a pair of blocks

```
ENTER Sys
```

```
LEAVE Sys
```

for a Facility Entity there are the following:

```
SEIZE Sys
```

```
RELEASE Sys
```

In this case, description, which indicates a name and number of a Storage channels,

```
Sys STORAGE 5
```

is not used.

The last change is related to using

```
GATE NU Sys,OUT
```

block. Here the SNA NU means that the Facility Entity Sys is free.

### **1.1.6 Obtaining statistics for each channel**

For the system, which is described in Section 1.1.1, we construct a model, allowing us to collect statistical information for each channel separately.

#### **; Model 1.1.3**

```
Dis TABLE (F1+F2+F3+F4+F5) 0,1,6
```

```
Tm EQU 100000
```

```
GENERATE 1
```

```
TABULATE Dis
```

```
TERMINATE
```

```
Lal GENERATE (Uniform(1,1,2))
```

```
GATE NU 1,TR2
```

```
SEIZE 1
```

```
ASSIGN 1,1
```

```
TRANSFER ,ADV
```

```
TR2 GATE NU 2,TR3
```

```
SEIZE 2
```

```
ASSIGN 1,2
```

```

TRANSFER ,ADV
TR3  GATE NU 3,TR4
SEIZE 3
ASSIGN 1,3
TRANSFER ,ADV
TR4  GATE NU 4,TR5
SEIZE 4
ASSIGN 1,4
TRANSFER ,ADV
TR5  GATE NU 5,OUT
SEIZE 5
ASSIGN 1,5
ADV  ADVANCE (Uniform(2,7,10))
Lsv  RELEASE P1
OUT  TERMINATE
GENERATE Tm
SAVEVALUE Psv,(N$Lsv/N$Lal)
SAVEVALUE Fav,((FR1+FR2+FR3+FR4+FR5)/1000)
TERMINATE 1
START 1

```

Let us give a description of the Model 1.1.3, confining blocks, additionally introduced in comparison with the Model 1.1.1.

```
Dis  TABLE (F1+F2+F3+F4+F5) 0,1,6
```

The SNA F takes the value 1 if a Facility Entity is busy, and value 0 if a Facility Entity is free. As a result of summation we get the current value of the number of customers in the five-channel system.

```
GATE NU 1,TR2
```

The GATE block provides operation of the first channel in the mode of a system with rejections. The SNA NU means that the Facility Entity 1 is free. If it is free, then the transaction enters the next block. Otherwise it goes to the label TR2, where the similar test is performed for the second channel.

```
SEIZE 1
```

This block enables a transaction to acquire ownership of a Facility Entity 1 (it registers customers entered the first channel).

```
ASSIGN 1,1
```

The value 1 (a channel number) is assigned to parameter number 1 of the entering transaction.

```
TRANSFER ,ADV
```

When a transaction enters this block, it is immediately scheduled for the block at location ADV.

## TR5 GATE NU 5,OUT

The GATE block provides operation of the fifth channel in the mode of a system with rejections. If the channel is busy, then the active transaction is directed to the label OUT for the destruction.

## Lsv RELEASE P1

This block registers the transactions, which leave the Facility Entity after a delay for service. The SNA P1 denotes a value of the parameter number 1 of the active transaction. This parameter takes the values from 1 to 5 depending on which of the blocks from SEIZE 1 to SEIZE 5 the transaction is registered.

## SAVEVALUE Fav,((FR1+FR2+FR3+FR4+FR5)/1000)

The SNA FR defines the utilization factor of a Facility Entity in parts-per-thousand. The Savevalue Entity named Fav allows us to define the average number of busy channels ( $E(n_{oc})$ ) for the five-channel system. To compute  $E(n_{oc})$  in other way is sufficient to add the values obtained in a standard report for each channel in the column UTIL.

Here is the fragment of a standard report for the Model 1.1.3:

FACILITY	ENTRIES	UTIL.	AVE. TIME	AVAIL.	OWNER	PEND	INTER	RETRY	DELAY
1	10782	0.916	8.498	1	0	0	0	0	0
2	10561	0.898	8.504	1	166681	0	0	0	0
3	10315	0.876	8.492	1	166684	0	0	0	0
4	9950	0.845	8.488	1	166688	0	0	0	0
5	9452	0.803	8.493	1	166686	0	0	0	0

TABLE	MEAN	STD.DEV.	RANGE	RETRY	FREQUENCY	CUM.%
DIS	4.338	0.683		0		
			—	0.000	1	0.00
			0.000	1.000	2	0.00
			1.000	2.000	521	0.52
			2.000	3.000	10567	11.09
			3.000	4.000	43461	54.55
			4.000	—	45447	100.00

SAVEVALUE	RETRY	VALUE
PSV	0	0.766
FAV	0	4.338

Statistical data given in Tables TABLE/DIS and SAVEVALUE/PSV, FAV, coincide with the data given in Section 1.1.2. In Table FACILITY we find the data for each channel separately. Here ENTRIES is the number of customers entered each channel, UTIL. is the utilization factor of each channel (the sum of these characteristics gives the value of the average number of busy channels, presented in Table SAVEVALUE/FAV), AVE.TIME is the average service time of one customer for each channel, OWNER is a list of numbers of transactions which occupy the Facilities at the simulation completion time.

**Buy the book**

To copy the address, click "Text Viewer"

<https://www.morebooks.de/store/ru/book/creating-models-of-queueing-systems-using-gpss-world/isbn/978-3-659-76445-5>