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Распределенные компьютерные и телекоммуникационные сети: управление, вычисление, связь (DCCN-2021) = Distributed computer and communication networks: control, computation, communications (DCCN-2021) **:** материалы XXIV Междунар. научн. конфер, 20–24 сент. 2021 г., Москва / под общ. ред. В.М. Вишневского, К.Е. Самуйлова; Ин-т проблем упр. им. В.А. Трапезникова Рос. акад. наук Минобрнауки РФ – Электрон. текстовые дан. (1 файл: 24,9 Мб). – М.: ИПУ РАН, 2021. – 1 электрон. опт. диск (CD-R). – Систем. требования: Pentium 4; 1,3 ГГц и выше; Acrobat Reader 4.0 или выше. – Загл. с экрана. – ISBN 978-5-91450-258-1. – № госрегистрации 0322103543. – Текст : электронный.

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Software Packages for Teaching Queueing Theory

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Abstract

The goal of the present paper is to give a short review of software packages for teaching Queueing Theory and to introduce an application called Queueing Systems Assistance (QSA). The software is integrated into a lecture note with the aim to calculate and visualize the main performance measures. In addition, it helps to minimize a quite general mean total cost per unit time with linear objective function. Several examples are given to illustrate the advantage of the graphical module included in the package.

Keywords: modeling, queueing, teaching, software, visualization

1. Introduction

The teaching of Queueing Theory (QT) needs innovation and new methods to attract the attention of the students. The field of applications has changed a lot in the past years and I am convinced that more and more students and practitioners need to use the methods and models of QT. The development of computational possibilities has greatly contributed to a better understanding of the theory.

In his lecture note Sztrik [1] discussed a number of basic queueing models that have proved to be useful in analysing a wide variety of stochastic service systems. The author feels that there is a need for such a treatment in view of the increased use of queueing models in modern technology. Actually, the application of queueing theory in the performance analysis of computer and communication systems has stimulated much practically oriented research on computational aspects of queueing models.

Furthermore, a software package called **QSA** (Queueing Systems Assistance) developed in 2021 is integrated into the lecture note of Sztrik [1] with the aim to calculate and visualize the main performance measures. In addition, it helps to minimize a quite general mean total cost per unit time with linear objective function.

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The greatest advantage of this application that these scripts can run in all modern devices including smart phones, too, thus the application is very convenient for students and improve the efficiency of a teacher.

To solve practical problems the first step is to identify the appropriate queueing system and then to calculate the performance measures. Of course the level of modeling heavily depends on the assumptions. It is recommended to start with a simple system and then if the results do not fit to the problem continue with a more complicated one. Various software packages help the interested readers in different level. The following links worth a visit

`http://web2.uwindsor.ca/math/hlynka/qsoft.html`

We have collected some basic books on QT in which software support is mentioned, for example, **Mathemica** in Allen [2], Harchol-Balter [3], **MatLab** in Bhat [4], Kobayashi and Mark [5], Kulkarni [6], Stidham [7].

A reasonable choice for calculations in teaching is the usage of spreadsheets. We highly recommend an Excel-based software package called QTSPlus to determine the main performance measures of basic models. It is associated to the book of Gross, Shortle, Thompson and Harris [8] and can be downloaded here

`ftp://ftp.wiley.com/public/sci_tech_med/queueing_theory/`

For application and problem solving oriented teaching courses we have also developed a software package called QSA (**Queueing Systems Assistance**) see, Szilágyi *et. al.* [9] to calculate and visualize the performance measures together with optimal decisions not only for elementary but more advanced queueing systems as well. It is available at

`https://qsa.inf.unideb.hu`

The **main advantages** of QSA over QTSPlus are the following

- It runs on desktops, laptops, mobile devices
- It calculates not only the mean but the variance of the corresponding random variables
- It gives the distribution function of the waiting/response times (if possible)
- It visualizes all the main performance measures
- It graphically supports the decision making

2. QSA in action, problem solving

QSA is a user interface, a web-based application written in TypeScript. Any browser (Firefox, Chrome, Edge, etc.) on every platform (Windows, Linux, Android, iOS) is supported, which means one can use mobile and desktop devices for performing any calculations which are executed on the server. There are no hardware limitations, the source code is available on GitHub, under the MIT license, so anyone interested can check out the code or help to develop the application. QSA is integrated into the lecture note of Sztrik [1].

In this section we show some examples how to use the application. After the opening one can select between the following modules

- **Table** - to calculate selected performance measures based on input values. The result is exportable into different file formats so that one can use it for further work
- **Chart** - to generate figures and compare the performance measures with each other. Also, it is useful for demonstration or learning purposes.
- **Compare Tables** - to compare two systems' performance measures with each other

One of the special features of the software is that the performance measures of $M/G/1/K/K$ systems with deterministic, Erlang, Hypo-exponential, Hyper-exponential, and gamma distributed service times are calculated. Distribution function of the waiting/response times of the $M/M/c/K$, $M/M/c/m/K$ systems and the performance measures of $M/M/c/K$, $M/M/c/m/K$ with balking and reneging are determined as well. It was our aim to determine, where it is possible, the distribution function of the waiting/response time to solve decision problems. In addition, not only the mean but the variances of the measures are derived. What is also unique is the calculation of the mean total cost per unit time in steady-state. For illustration let us see the following example.

Example Customers arrive to a 3 server system according to a Poisson process with rate 5. The service times are exponentially distributed with parameter 2. Find the minimum capacity of the system for which the probability of blocking is less than 0.01 and the probability that the waiting time exceeds 1.5 minutes is less than 0.05.
Solution: It is an $M/M/3/K$ system and the problem is that by increasing the capacity the blocking probability is decreasing but the waiting time is increasing thus the probability that it exceeds a certain level is increasing. First of all we have to switch to the distribution function of the waiting time and that is why its value should be at least 0.95 at 1.5.

It should be mentioned that for this system there is no closed-form analytical expression for the distribution function of the waiting time as in $M/M/c$ systems. However, it can be computed by the following formula, see Sztrik [1]

$$F_W(t) = 1 - \sum_{n=c}^{K-1} \Pi_n \sum_{i=0}^{n-c} \frac{(c\mu t)^i e^{-c\mu t}}{i!}, \quad \Pi_n = \frac{P_n}{1 - P_K}, \qquad (n \leq K-1).$$

Clearly we have to use the **Chart** module and to visualize the curves as the function of the capacity K. Of course the step is 1, after giving the required parameters λ, μ, c and time slot $t = 1.5$ we generate the chart showing only the measures in question. We can switch on/off the grid, too. Then we get the following Figure 1 showing that there is no solution under these conditions. However, if we change the blocking probability to 0.03 the solution is $K = 12$. Similar questions could be put for the service intensity, and the number of servers, too.

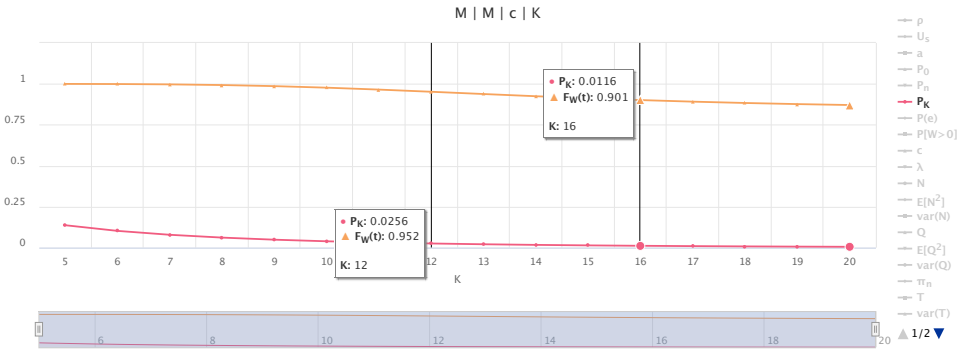

Fig. 1. Solution to the $M/M/5/K$ system

3. Conclusion

In this paper we introduced a new application to help teaching Queueing Theory. One of the main advantages of the software is that it runs on most platforms including smart phones and became very popular among the students. It is easy-to-use and in addition to the calculation of the main steady-state performance measures it visualizes the results and thus supports decision making and optimization of cost functions. The software is integrated into a lecture note where the theoretical part, formulas, and proofs can be found.

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