Chapter 2
Queueing Networks Modeling Software for Manufacturing

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Abstract This paper reviews the evolution of queueing networks software and its use in manufacturing. In particular, we will discuss two different groups of software tools. First, there are queueing networks software packages which require a good level of familiarity with the theory. In the other hand, there are some packages designed for manufacturing where the model development process is automated. Issues related to practical considerations will be adressed and recommendations will be given.

2.1 Introduction

In a period of continuous change in global business environment, organizations, large and small, are finding it increasingly difficult to deal with, and adjust to the demands for such changes (Bosilj-Vuksic et al, 2007). In order to improve performance of a complex manufacturing system, the dynamic dependencies need to be understood well (e.g., utilization, variability, lead time, throughput, WIP, operating expenses, quality, etc). In this manner rapid modeling techniques like queueing theory, can be applied to improve such an understanding. For instance queueing

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networks are useful to model and measure the performance of manufacturing systems and also complex service processes. Apparently, queuing-theory-based software packages for manufacturing processes (e.g., MPX) automate model development process and help users (e.g. managers, academics) identify relatively easy analytical insights (Vokurka et al, 1996).

Queuing software can be used by industrial analysts, managers, and educators. It is also a good tool to help students understand factory physics along with modeling and analysis techniques (see, e.g., de Treville and Van Ackere, 2006). Despite certain challenges over of queuing-theory-based modeling (e.g. need strong mathematical background, hard to maintain certain level of understanding on theories), training in queuing-theory-based modeling is likely to yield better competitiveness in lead time reduction (de Treville and Van Ackere, 2006). Business executives do not always make the best possible decisions. That is, managers can fail to understand the implications of mathematical laws and take actions that increase lead times (see, de Treville and Van Ackere, 2006; Suri, 1998).

Complex real life service and manufacturing systems have a number of specific features as compared to 'simplistic cases', posing important methodological challenges. Basic queuing theory provides key insights to practitioners but not complete and depth understanding of the system. Also the complexity of queuing theory based methods has caused companies to use other tools (e.g. simulation) rather than queuing theory.

Finally, queuing theory becomes that much popular in academic and research areas, especially for operations modeling, because complexity and size of the real life problems can be reduced to relatively simple yet complex enough models. Compared to a similar simulation model, those will be in less detail, lacking transition behavior of the system but on the other hand simple and sufficient enough to make a decision (de Treville and Van Ackere, 2006). Basically, relatively simple and quick solutions are much more preferred as an initial system analysis or for quick decisions.

The rest of this paper is organized as follows: In Section 22.2, we give a brief review of the evolution of queuing network theory, focusing on decomposition methods. In Section 22.3, we list selected queueing software packages. All of them are freely available for download on the Internet. Some manufacturing software packages based on queueing theory are presented in Section 2.4. Finally, we provide a conclusion and give recommendations in Section 2.5.

2.2 Queueing Networks Theory

Queueing networks have been extensively studied in literature since Jackson's seminal paper (Jackson, 1957). The first significant results were those of Jackson (Jackson, 1957, 1963) who showed that under special assumptions (exponnential inter-arrival and service times, markovian routing, first-come-first-served descipline,...) a queueing network may be analyzed by considering its stations each in isolation (product form). Gordon and Newell showed that the product form solution also holds for closed queuing networks (i.e., networks where the number of jobs is fixed) with exponential interarrival and service durations (Gordon and Newell, 1967). Those results have been extended in (Baskett et al, 1975) and (Kelly, 1975) to other special cases (open, closed and mixed networks of queues with multiple job classes and different service disciplines). Since this kind of results was possible only under restrictive assumptions, other researchers tried to extend product form solutions to more general networks (decomposition methods). Several authors (Kuehn (1979),Whitt (1983), Pujolle and Wu (1986), Gelenbe and Pujolle (1987) and Chylla (1986) among others) proposed decomposition procedures for open $G/G/1$ ($G/G/m$) queueing networks. Closed networks of queues have also been analyzed by decomposition (see, e.g., Marie, 1979). This approach has been modified in different ways since though (e.g., multiple job classes (Bitran and Tirupati, 1988; Whitt, 1994). In (Kim, 2004) and (Kim et al, 2005) it is shown that the classical Whitt's decomposition method performs poorly in some situations (high variability and heavy traffic) and the innovations method is proposed as improvement, by replacing relations among squared coefficients of variability with approximate regression relationships among in the underlying point processes. This relationships allow to add information about correlations.

It seems that the application of this method gives satisfactory results in various cases. However, there are still some situations where the existing tools fail. Other approaches which have been proposed include diffusion approximations (Reiser and Kobayashi, 1974) and Brownian approximations (Dai and Harrison, 1993; Harrison and Nguyen, 1990; Dai, 2002).

Queueing theory is a well-known method for evaluating the performance of manufacturing systems under the influence of randomness (see, e.g., Buzacott and Shanthikumar, 1993; Suri, 1998). The randomness mainly comes from natural variability of interarrival times and service durations. Queueing networks modeling has its origins in manufacturing applications: Jackson's papers (Jackson, 1957, 1963) targeted the analysis of job shops; a class of discrete manufacturing systems. Suri et al (1993) gave a detailed survey of analytical models for manufacturing including queueing network models. Govil and Fu (1999) presented a survey on the use of queueing theory in manufacturing. Shanthikumar et al (2007) surveyed applications of queuing networks theory for semiconductor manufacturing systems and discussed open problems.

2.3 Queueing Networks Software

The developed theory motivated the development of many software packages for the analysis of queueing networks. These packages suppose a good level of familiarity with queueing theory. There are some early packages that were based on original algorithms. The Queueing Network Analyzer (QNA) has been proposed by Whitt as implementation of his two-node decomposition method (Whitt, 1983). QNET is another software package for performance analysis of queueing networks. It is the implementation of the analysis algorithm based on Brownian approximation of queueing networks (Dai and Harrison, 1993; Harrison and Nguyen, 1990) (motivated by heavy traffic theory). This package is written in text mode and its source code is available for free download. However, it seems that since mid 90s this software has not been rewritten and it is easy to guess that its use has remained very limited. See also, Govil and Fu (1999) for description of other queueing network packages.

PEPSY-QNS /WinPEPSY: It has been developed at the University of Erlangen-Nurnberg in early 90s. It has a comfortable and easy to use graphical environment. This package includes more than 50 different analysis algorithms. The Windows version (WinPEPSY) has particular features : a user friendly graphical interface, a graphical network editor, charts for results...

QNAT : The Queueing Network Analysis Tool (QNAT) is a Windows graphical package for analysing a wide variety of queueing networks. QNAT uses Mathematica as its computing platform and can handle general configurations of open and closed networks of both finite and infinite capacity queues. Incorporation of fork-join nodes, multiclass customers, mixed customer classes and blocking mechanisms of different types are some of the other features available in this software tool.

RAQS : Rapid Analysis of Queueing Systems (RAQS) is a Windows graphical queueing software (Kamath et al, 1995) based on the Whitt's QNA method and its version in Segal and Whitt. (1989). It also implements decomposition algorithms for closed queuing networks and for tandem finite buffer queueing networks. It's freely available for download. RAQS' user interface provides less explanation for inexperienced users. Most probably, input and output interfaces are more suitable for experienced users who owns considerable amount of knowledge on basics of queueing theory.

QTS : Queueing Theory Software, is written as Excel spreadsheet for solving a wide range of queueing models and other probability models (Markov chains, birth and death processes,...). The software is based on the textbook of Gross et al (2008). One advantage of this software is that the user has all-in-one model and several performance indicators (e.g., server utilization, mean number of jobs in the system and in the queue, mean waiting time in the system and in the queue...) in a simple sheet.

JMT : The Java Modeling Tools is a free open source suite implementing several algorithms for the exact, asymptotic and simulative analysis of queueing network models. Models can be described either through wizard dialogs or with a graphical interface. The workload analysis tool is based on clustering techniques. The JMT tool is user-friendly including a visual design tool. Also, visual sliding buttons for simulation parameters (e.g. avg. arrival rate, avg. service time, buffer size and simulation time) makes what-if analysis easy for the user.

Notice that those packages implement known (published) algorithms and are all freely available for download (some are open source, e.g., QTS, JMT). The difference is then in the number of implemented algorithms (the number of network types which can be analyzed), the user interface and the presentation of the results.

Table 2.1 Download links for some free QN software

WinPEPSY	http://www7.informatik.uni-erlangen.de/ prbazan/pepsy/download.shtml
RAQS	http://www.okstate.edu/cocim/raqs/raqs.htm
QST	http://www.geocities.com/qtsplus/ (Also: http://qtsplus4calc.sourceforge.net/)
JMT	http://jmt.sourceforge.net/

The important question is whether these software tools are practical and capable enough to satisfy the complex industry needs. Moreover, among the majority of functionalities that they offer, which one is suitable under which circumstances? When performing in a practical context the user of this kind of software is assumed to have an acceptable level of knowledge in queueing theory. The modeling has to be done separately and the results are generally given in a brute form. It is obvious that those drawbacks do not permit a wide use in a company given that managers are in general not queueing specialists.

2.4 Queueing Networks Software for Manufacturing

Additionally the previous software tools, more specific software packages were designed for manufacturing based on queueing networks theory. Such modeling aid is automatic and embedded in the software and provides the user a unique ability to model the manufacturing system without worrying about the theoretical side. They are particularly suitable for use by industrials with little or no queueing knowledge.

Snowdon and Ammons (1988) survey eight queueing network packages existing at that time. Some of the queueing network software packages are public domain while others are commercially sold by a software vendor. CAN-Q is a recursive algorithm for solving a product-form stochastic model of production systems (Co and Wysk, 1986) based on the results of Jackson and Gordon and Newell. A version of QNA supporting some features of manufacturing systems has also been proposed Segal and Whitt. (1989) but there are no indices that this package has been sold as commercial product or distributed for large use. Other early packages include Q-LOTS (Karmarkar et al, 1985), MANUPLAN (Suri et al, 1986) and Operations Planner (Jackman and Johnson, 1993).

MANUPLAN includes an embedded dynamic model that is based on queueing network theory and provides common performance results such as WIP, tool utilization, production rate. The tool also provides trade-off analysis among inventory levels, flow times, reliability of the tools, etc. (Suri et al, 1986).

MPX is perhaps the most popular software package in its category. It is the successor of MANUPLAN. Users greatly appreciate the speed of calculations and the ease of modeling despite of several missing improvements possibilities in its behavior and interface. The exact MPX's algorithm is not published. Apparently, it uses the classical decomposition algorithm (Whitt, 1983) coupled to the operator/workstation algorithm (Suri et al, 1993) with some changes to support additional features. It also provides a procedure to compute optimal lot sizes and transfer batch sizes.

Still that the existing software model is quite generic and does not integrate high level of complexity. For instance, MPX does not provide support for some manufacturing features like finite capacity of buffers, service disciplines other than first-come-first-served and dynamic lot sizing nor for some popular production systems (e.g., Kanban).

On the other hand several industries prefer to use systems design software such as SAP-APO, IBM's A-Team, etc., (Pinedo, 2002) and those generate their solution based on heuristics, relaxations or approximations different than queueing software solutions. However, usually those approaches have limitations. Their performance change based on certain settings and in general, user needs to complete several experiments to determine the most suitable algorithm. Additionally computation speed becomes one of the most important practical considerations. Instead of those all-in-one, multi functional software designs, queueing software can provide quick and easy solutions while covering dynamics and related effects but not higher levels of system details (Suri et al, 1995).

2.5 Further Remarks

When using queueing networks software in a practical setting, the resulting models are less accurate and detailed than simulation and give no insights into transition behavior, but they often suffice as decision support tools and can yield results that are useful in real-world applications (de Treville and Van Ackere, 2006). They provide a rapid and easy way to understand systems' dynamics and predict their performance, in the opposition of complex simulation models which necessitate vast amount of modeling, advanced knowledge and computer time. It is important in today's world to be able to rapidly evaluate different alternatives as manufacturing systems are in continuous change. This software packages are also an important tool for training and teaching the impact of some decisions on lead time and cost reduction.

Queueing networks software is still has limited usage in practical complex manufacturing applications. It is not mature for practitioners how a queueing software can cover complex industry related constraints among with several tradeoffs regarding to several performance objectives. Other issues like data requirements may also be the cause. Software that passes the test of accuracy and detail can fail miserably in the field because it requires data beyond what are easily available (Suri et al, 1995). Those are basically limitations related to practical implications.

Close contact between researchers and industrial users has been critical to the growth in use of the software. Emphasis on such contact, along with better linkages to operational systems, will ensure continued growth of manufacturing applications of queuing software (Suri et al, 1995). The use of the software in education may also help to enlarge its use in companies. When students realize the usefulness of this tool, it becomes natural that they will use it after they join work in the industry or they become managers.

When recognizing the importance of those tools and the opportunities they offer, the existing software packages are still limited in their modeling capabilities. It is important for software creators for enlarging the usability of their packages to offer support of different real manufacturing systems. While handing problems of modeling, a specified software design should be based on realistic assumptions (i.e. buffers capacity, priority rules, integration of forecasting and inventory policies). The combination of queueing networks analysis with statistical and optimization tools... can provide better solutions and attract more practical applications.

The presentation of the computations' output is also an important factor. Customizable reports and graphical charts help to better understand the results. It should be also possible for the software to provide some insights in the interpretation of the results and to warn the user about the limits of its performance (for example, MPX shows a warning when the utilization is very high saying that the results may not be accurate). Performance measures given by queueing packages are based on only steady-state value measurements given as the average values of such measures WIP, flow time. However, it can be desired to have variance (or variability) information about the output performance measures. Also, the provided average values are just approximate and it may be useful to provide trustable bounds for them.

The success of a software package depends on many factors other than the accuracy of its computational method. Users look for a powerful tool with evidence of efficiency but also a user-friendly, easy-to-learn and well supported product (documentation and tutorial, demo version, consultancy/training course). The integration with other packages like spreadsheet packages, statistical packages, DBMS, legacy applications, ERP... is also a highly desired feature. Finally, the ability of the software to import/export data from/to other packages allows the users to gain in time and effort.

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