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**Final Report for Period:** 05/2000 - 03/2006

**Submitted on:** 10/04/2006

**Principal Investigator:** Ayhan, Hayriye .

**Award ID:** 9984352

**Organization:** GA Tech Res Corp - GIT

**Title:**

**CAREER:** Approximations and Bounds for Stationary and Transient Characteristics of a Class of Queueing Networks

### Project Participants

#### Senior Personnel

**Name:** Ayhan, Hayriye

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

#### Post-doc

**Name:** Seo, Dong-Won

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

Dong-Won Seo has done both numerical and theoretical contributions in preparation of two papers based on the research topic of this project. Currently, he is working on the preparation of the third paper. Dong-Won Seo has earned his doctorate degree in August 2002. From August 2002 to December 2002, he has been a post doctoral fellow at Georgia Tech.

#### Graduate Student

**Name:** Chang, Junxia

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

Junxia Chang has become the new PhD student involved in the project after Dong-won Seo's graduation. Junxia is working on control of non-stationary queueing systems. So far, in this project we have focused on approximating certain performance measures in a class of queueing networks. Junxia is using these approximations to make optimal control decisions.

**Name:** Ziya, Serhan

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

During his last semester as a PhD student at Georgia Tech, Serhan has participated in this project. He has mainly helped with the research that the PI has conducted on assembly type queues with subexponential service times.

#### Undergraduate Student

#### Technician, Programmer

#### Other Participant

#### Research Experience for Undergraduates

### Organizational Partners

#### Other Collaborators or Contacts

I have collaborated with Dr. Sabine Schlegel, Dr. Zbigniew Palmowski and Professor Jim Dai on papers related to this project.

## Activities and Findings

### **Research and Education Activities:**

This research focused on queueing systems that could arise in manufacturing and telecommunications settings. In particular, we focused on (max,+) linear systems which have Poisson arrival processes and closed networks which could be modeled as (max,+) linear systems.

For (max,+) linear systems with Poisson input, we derived approximations for transient and stationary characteristics of a large class of queueing networks. For closed (max,+) linear systems, we considered systems with subexponential service times and obtained tail asymptotics of transient and stationary cycle times. Finally, we also considered the control of queues whose corresponding fluid limit is stochastic and obtained the optimal policy for the fluid model in certain cases.

Our results were presented at numerous conferences and meetings such as Conference and Workshop on Stochastic Networks that was held at the university of Wisconsin, Madison campus in June 2000, and 2001, 2002, 2003, 2004 INFORMS National meetings, Workshop on (max,+) algebras in Prague in August 2001, and 2002 IFORS conference.

This grant has partially supported three PhD students one of whom was also later supported as a postdoc through this grant. Moreover, especially the results on closed (max,+) linear systems with subexponential service times have been presented by the PI in a special topics course in the School of Industrial and Systems Engineering at Georgia Institute of Technology in Spring 2006.

### **Findings:**

For (max,+) linear systems with Poisson arrival process, we developed approximations in the form of Taylor series expansions for

1. Joint Laplace transform of transient and stationary waiting times
2. Higher order moments of transient and stationary waiting times
3. Tail probabilities of transient and stationary waiting times

Moreover, combining our expansion formulae with some standard stochastic ordering results, we also obtained bounds on these characteristics.

For closed (max,+) linear systems with subexponential service times, we obtained the tail asymptotics of

1. Transient and stationary cycle times
2. Transient and stationary waiting times

Finally, in our novel work on queues whose fluid limit model could be stochastic, we investigated how one can find the fluid optimal policy and how this policy could be translated to the discrete network.

### **Training and Development:**

This project has supported the doctoral studies of Dong-Won Seo, Junxia Chang and Serhan Ziya (for a semester) and also the post doctoral work of Dong-Won Seo (for one year). Working on this research project, all these three former PhD students have gained experience on conducting research. Dong-Won has successfully finished his PhD studies in August 2002, Serhan has finished his PhD studies in August 2003 and Junxia earned her PhD degree in December 2004. Currently, Dong-Won is an assistant professor at the College of Management and International Relations at the Kyung Hee University in Korea, Serhan is an assistant professor at the Department of Statistics and Operations Research at the University of North Carolina, Chapel Hill and Junxia works for Norfolk Southern Corporation.

### **Outreach Activities:**

## Journal Publications

Hayriye Ayhan and Dong-Won Seo, "Laplace Transform and Moments of Waiting Times in Poisson Driven (max,+)-Linear Systems", QUESTA, p. 405, vol. 37, (2001). Published

Hayriye Ayhan and Dong-Won Seo, "Tail Probability of Transient and Stationary Waiting Times in (max,+)-Linear Systems", IEEE Transactions on Automatic Control, p. 151, vol. 47, (2002). Published

- A.F. de Kort, B. Heidergott and H. Ayhan, "A Probabilistic (max,+) Approach for Determining Railway Infrastructure Capacity", European Journal of Operational Research, p. 644, vol. 148, (2003). Published
- Hayriye Ayhan and Dong-Won Seo, "Characteristics of transient and stationary waiting times in Poisson driven (max,+) linear systems", Proceedings of the IEEE Symposium on System Structure and Control, p. 227, vol. 1, (2001). Published
- Hayriye Ayhan, Zbigniew Palmowski and Sabine Schlegel, "Cyclic Queueing Networks with Subexponential Service Times", Journal of Applied Probability, p. 791, vol. 41, (2004). Published
- S. Ziya, H. Ayhan and R. D. Foley, "Relationships Among Three Assumptions in Revenue Management", Operations Research, p. 804, vol. 52, (2004). Published
- S. Ziya, H. Ayhan and R. D. Foley, "Optimal Prices for Finite Capacity Queueing Systems", OR Letters, p. 214, vol. 34, (2006). Published
- S. Andradottir and H. Ayhan, "Throughput Maximization for Tandem Lines with Two Stations and Flexible Servers", Operations Research, p. 516, vol. 53, (2005). Published
- S. Andradottir, H. Ayhan and D. G. Down, "Dynamic Server Allocation for Queueing Networks with Flexible Servers", Operations Research, p. 952, vol. 51, (2003). Published
- J. Chang, H. Ayhan, J.G. Dai and C.H.Xia, "Dynamic Scheduling of a Multiclass Fluid Model with Transient Overload", Queueing Systems: Theory and Applications, p. 263, vol. 48, (2004). Published
- H. Ayhan, "Asymptotics of Closed Fork and Join Queues with Subexponential Service Times", Stochastic Models, p. , vol. , ( ). Submitted
- S. Andradottir, H. Ayhan, and D.G. Down, "Compensating for Failures with Flexible Servers", Operations Research, p. , vol. , (2005). Accepted
- S. Andradottir, H. Ayhan and D. G. Down, "Dynamic Assignment of Dedicated and Flexible Servers in Tandem Lines", Probability in Engineering and Informational Sciences, p. , vol. , (2006). Submitted

### **Books or Other One-time Publications**

### **Web/Internet Site**

**URL(s):**

[http://www.isye.gatech.edu/people/faculty/Hayriye\\_Ayhan/](http://www.isye.gatech.edu/people/faculty/Hayriye_Ayhan/)

**Description:**

This is the web page of the principal investigator. NSF can access to this web page to review the publications related to this and other projects of the PI.

### **Other Specific Products**

### **Contributions**

**Contributions within Discipline:**

In this research, we have focused on developing analytical models of queueing systems that are prevalent in many manufacturing systems such as networks operating under WIP limiting control strategies, assembly operations that are prevalent in electronics and automobile industries, queueing networks operating under blocking strategies. The research involved derivation of computationally tractable

approximations and bounds for various performance measures of queueing systems. Since there is a wide gap between the types of manufacturing systems that can be modeled using the existing analytical models and the ones that arise in actual settings, our results will bridge this gap. We have focused on characteristics of transient and stationary waiting times. Our approximations for these characteristics are in terms of Taylor series which yield exact results in certain settings. We also developed efficient numerical algorithms to compute coefficients of these series expansions. These approximations can be used to test the performance of various policies and ultimately could be used to develop optimal control strategies for queueing systems that could arise in manufacturing settings.

We also investigated the tail asymptotics of several performance measures in closed queueing networks with subexponential service time distributions. Subexponential service times can arise in various telecommunication applications. Towards this end, we focused on closed queueing networks with subexponential service times and characterized the asymptotic tail behaviour of cycle times and waiting times.

Our approximations for characteristics of waiting times in a general class of queueing networks and our expressions for the asymptotic tail behaviour of cycle times and waiting times in closed networks with subexponential service times have advanced the state of the art in queueing theory.

#### **Contributions to Other Disciplines:**

##### **Contributions to Human Resource Development:**

This project has provided research experience and financial support to former PhD students Dong-Won Seo, Junxia Chang and Serhan Ziya. Moreover, since our main contributions have been presented in many classes taught by the PI at Georgia Institute of Technology, many of our students got exposed to a new way of modeling queueing systems (namely  $(\max,+)$  linear systems).

##### **Contributions to Resources for Research and Education:**

Some of our research results have already been imparted to classroom students. Type of queueing networks that we consider have been introduced to undergraduate and graduate students and details were provided on computing the characteristics of these queueing networks. Since these networks can arise in various manufacturing settings, students got exposed to some real life scenarios. Moreover, some significant results of this project were presented in PhD level courses at Georgia Institute of Technology. Hence, our PhD students learned a new approach in analyzing queueing networks which is significantly different from the standard queueing network analysis.

Since subexponential service times appear in telecommunication applications (for example the file download times have been observed to have Pareto distribution which is subexponential), we also considered closed networks with subexponential service time distributions. Our findings on this topic have been reported in two papers and shared with some advanced PhD students in a special topics course that Dr. Ayhan taught in the Spring 2006 semester.

#### **Contributions Beyond Science and Engineering:**

##### Categories for which nothing is reported:

Organizational Partners

Activities and Findings: Any Outreach Activities

Any Book

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering