

# Research Overview of Complex System Design and Analysis Laboratory

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## 1 Introduction

Dr. Sang Won Yoon established the Complex System Design and Analysis (CSDA) laboratory under the Department of Systems Science and Industrial Engineering at the State University of New York at Binghamton in Fall 2010. Since then, he has been granted \$2.6 million over 30 research projects from a variety of sponsors, including Samsung, Xerox, Analog Devices, Raymond, Innovation Associates, Sanmina-SCI, U.S. Xpress, LiveOnNY, United Health Services, Montefiore Medical Center, Virtua Health, etc.

His research team has been studying a variety of emerging research domains including 1) distributed decision making, coordination protocol design and collaborative control theory, 2) large-scale data analytics and predictive modeling, 3) mail-order pharmacy system design and analysis, 4) healthcare systems optimization, 5) production & manufacturing systems optimization, and 6) warehouse management and transportation. This research overview will outline a brief description of six research domains, followed by future research plans.

## 2 Collaboration and Coordination Control Theory

The objective of this research is to study how to maximize marginal profits, resource utilization efficiency, and mutual benefits in a collaborative network. Through the formation of Collaborative Enterprise Network (CEN), enterprises can overcome uncertainties surrounding the arbitrary nature of market conditions and cope with innovation needs, changing demands, customized products, and fierce international competition. In this research, CENs are defined as homogeneous and heterogeneous collaborative enterprise networks (HoCEN and HeCEN). To design an effective enterprise collaboration, work and information flow need to be controlled by well-defined decision-making processes and coordination protocols. For this purpose, this research has focused on designing 1) demand and capacity sharing protocols, 2) affiliation/dissociation decision models and algorithms, and 3) an inventory allocation algorithm. An overview of the enterprise collaboration research is summarized in Figure 1.

Especially, cooperative production switchover coordination and demand and capacity sharing protocols have been designed to enhance the benefits of enterprise cooperation and collaboration. In addition, affiliation/dissociation decision models have been studied to help an enterprise or a set of enterprises to evaluate the anticipated reward of enterprise collaboration. This study helps the enterprise to decide whether to affiliate with or dissociate from the collaborative network based on the service level and profit. Experimental results show that an enterprise would increase its service level by affiliating with the network but the network should dissociate a member from the network if its mean demand or capacity is less than other collaborating enterprises. Recently, inventory allocation algorithms have also been designed including proportional inventory deficit satisfaction algorithm and minimal inventory allocation algorithm. This study shows that increasing network membership has a positive effect on demand fulfill-

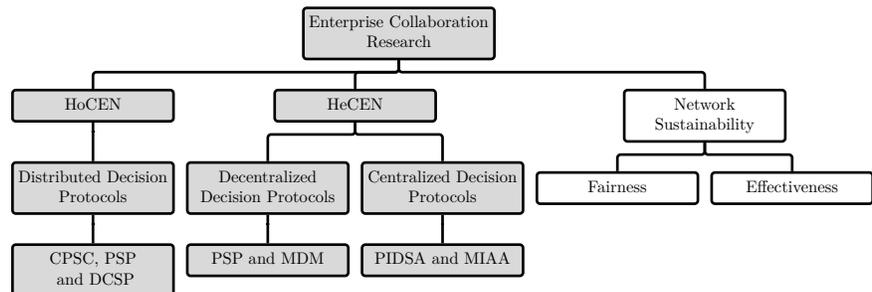


Figure 1: An overview of the collaboration and coordination control research. The on-going research areas are highlighted in this figure.

ment and inventory utilization, as well as a total profit in any CEN.

## Future Research

Future study will focus on network sustainability when a member of CEN can join, remain or leave the network over time according to fair resource allocation and enterprise effectiveness. This research will investigate characteristics of sustainable collaborative networks by addressing fairness and effectiveness. The outcomes of this research would be significant on finding fair cost and profit sharing strategies. In addition, different types of network coordination strategies and typologies will be studied to determine properties of collaboration conditions.

## Relevant Publication

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- S. W. Yoon, J. D. Velasquez, H. S. Ko, X. Chen, and S. Nof, “Collaborative distributed-training control system for transportation and emergency response,” in *Proceedings of Industrial Engineering Research Conference*, (Miami, Florida), 2009

## 3 Large-scale Data Analytics and Predictive Modeling

The objective of this research is to extract useful insights from expanding data sets to support intelligent decision making processes. This research not only resides in better understanding large-scale data set by using statistical learning methodologies, but also leverages optimization, soft computing, simulation, and complex theories with conventional machine learning algorithms. As the popularity of social media usage

keeps increasing, it becomes a useful tool for understanding personal opinions, daily demand, and customized preferences. From social media, the relationship between individuals of communities can be formed using complex network theories. The individual impact on a community can be further evaluated and studied among social networks. When a government policy or a marketing campaign is released, its impact is usually better targeted and controlled when using information-spreading channels. It helps create an easy reach to the targeted audience. From the individual perspective, more customized information can be delivered based on historical preferences. Based on the social network information, for instance, machine learning algorithms can be used to predict what customers would like to eat for lunch based on their posts and friends' updates on Twitter. As an example, call centers have been considered as one of the most labor intensive industries, which attracted a number of researchers to improve efficiency and efficacy in the areas of demand forecasting, staffing, routing strategies, service time, etc. Figure 2 shows a representation of the proposed decision support system of the call center using large-scale data analytics and visualization.

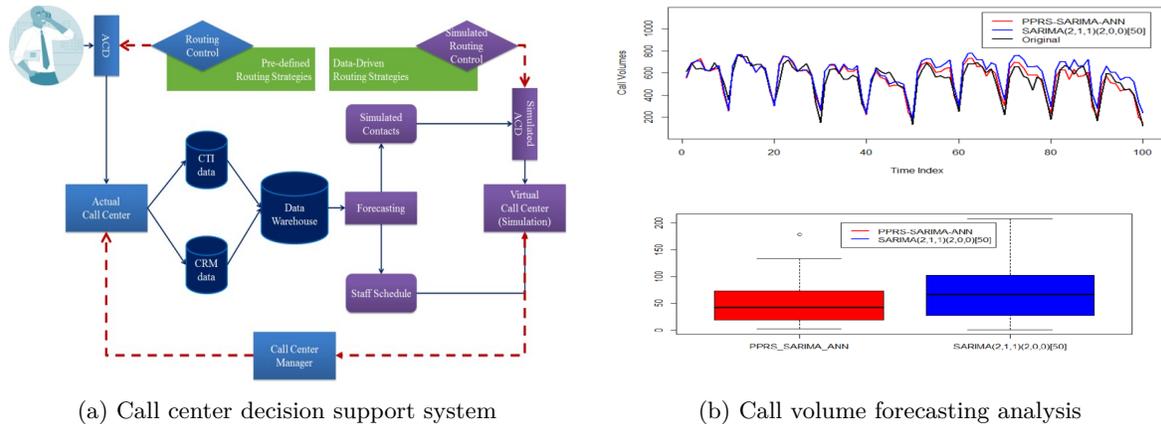


Figure 2: An illustration of call center large-scale data analytics

Large-scale data analytics has also been conducted on pharmacy prescription datasets to extract medication dispensing patterns that can improve different strategies in pharmacy automation. This study involved the use of a data mining algorithm, which is a Frequent Pattern Growth (FP-growth) approach to examine possible associations within the prescribed drug regime for different patients. A distributed parallel computing environment of the proposed algorithm was designed to obtain better performance and shorter execution time through the use of Hadoop and MapReduce paradigm. Figure 3 shows performance comparison of FP-growth when applied to large-scale prescription data.

## Future Research

Future research will utilize data mining algorithms with a meta-heuristic parameter optimizer as an important technique to automate the parameter tuning process in the domain of data mining. This research will also develop sophisticated decision support systems based on large-scale data analytics to generate useful insights for government and business decision makers.

## Relevant Publication

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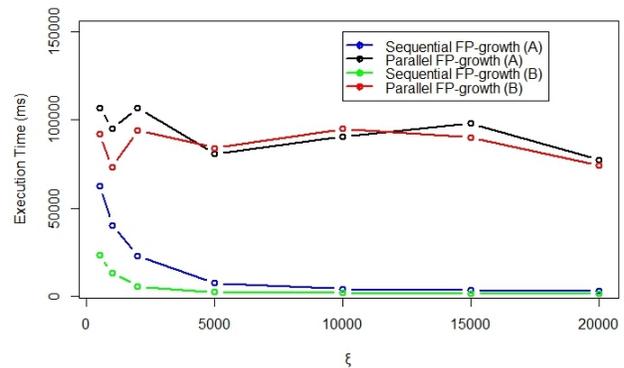
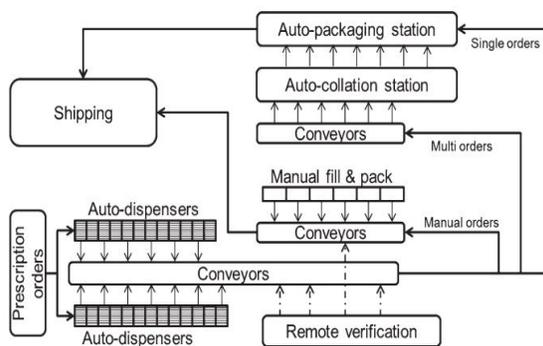


Figure 3: A comparison of execution times of FP-growth

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## 4 Mail-order Pharmacy System Design and Analysis

The objective of this research is to optimize the performance of pharmacy automation systems in central fill pharmacies. Typically, the central fill pharmacy is a make-to-order manufacturing system that fulfills tens of thousands of customized prescriptions every day by utilizing robotic dispensing systems, which integrate auto-dispensers and facilitate the simultaneous dispensing of medications. In this research, simulation modeling and optimization has been utilized to study and evaluate the performance of existing and proposed pharmacy automation systems through performing capacity planning analysis, analyzing material flow and facility layout, and evaluating resources allocations.



(a) Typical pharmacy automation system



(b) Simulation model of pharmacy automation system

Figure 4: A general layout of the mail-order pharmacy and its simulation model (e.g., Demo3D)

Especially, order collation delay, which is defined as the completion time difference between dispensing the first and the last medication within one prescription order, has been studied. Through the effective parallel machine planogram design, job order sequencing can actually be optimized, which in turns reduces collation delays and increases system efficiency. Figure 4 shows a general layout of the mail-order pharmacy automation system and its simulation model developed.

## Future Research

Future study will focus on developing more efficient algorithms and effective control systems to enhance the performance of the pharmacy automation system. In addition, this research will extend to optimize planogram design to effectively enhance the order sequencing optimization process. Potential approaches could be a stochastic ensemble forecasting model, as well as exact solution and meta-heuristic approaches for short-term demand prediction, optimal machine planogram, and order sequencing.

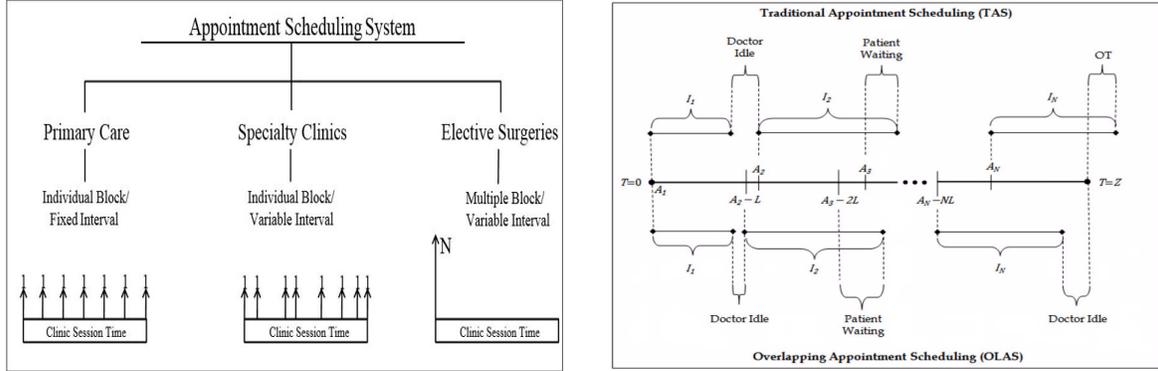
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- K. Mei, D. Li, S. Yoon, and J. Ryu, “A multi-objective optimization model to minimize fill-time window and makespan in mail-order pharmacy automation system,” *International Journal of Advanced Manufacturing Technology* (in press), 2015
- D. Li and S. W. Yoon, “A novel fill-time window minimisation problem and adaptive parallel tabu search algorithm in mail-order pharmacy automation system,” *International Journal of Production Research*, no. ahead-of-print, pp. 1–17, 2014
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## 5 Healthcare Systems Optimization

The US healthcare system is characterized by complexity, poor quality, and increase in usage and costs, which requires systems science and engineering tools and techniques to optimize its policies and practices. Hence, the objective of this research is to study a variety of the US healthcare problems and provide effective solutions to increase its efficiency and effectiveness. The CSDA laboratory focuses on two main healthcare problems including 1) appointment scheduling optimization and 2) healthcare analytics. For instance, an optimal appointment booking scheduling model for multi-provider clinics has been studied, which incorporates various probabilities of walk-in and no-show patients. This study is applicable to any clinic with low patient-provider preference. In addition, a new scheduling concept of overlapping appointment schedules was proposed, in which appointments are scheduled earlier than the expected end time of the previous appointment as shown in Figure 5, which minimizes patient waiting time and doctor idle time, and consequently reduces costs.

Another focus area of research in the CSDA laboratory is healthcare analytics. For instance, a novel hybrid distance-based attribute selection model has also been developed to determine critical attributes of patient readmission risk with selection from multiple databases. The proposed model overcomes the high computational complexity associated with performing an exhaustive search of all possible attribute subsets and produces a low correlation among the conditional variables and high correlation between the decision variable and set of conditional variables. Also, a hybrid of k-means and support vector machine (K-SVM) algorithms has been developed to extract useful information and diagnose the breast cancer tumor. This research improves the diagnosis accuracy to 97.38% when tested on the Wisconsin Diagnostic Breast Center dataset from the University of California - Irvine machine learning repository.



(a) Illustration of appointment scheduling systems in healthcare

(b) A comparison of traditional appointment scheduling with overlapping appointment scheduling

Figure 5: Appointment scheduling problem in healthcare

## Future Research

Future research will develop more efficient models and solutions to mitigate the complexity of the healthcare system. To further improve the healthcare system scheduling, future research will consider variable service time and variations in start and end times. Patient preference for providers can also be considered. Another future direction will utilize meta-heuristics for neural network training in developing the decision support system to overcome the hybrid attribute selection model's limitation of producing a local optimum.

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- M. Rezaeiahari and S. W. Yoon, "Two-stage surgical scheduling for balancing post-anesthesia care unit staffing," in *Proceedings of Industrial and Systems Engineering Research Conference*, (Nashville, Tennessee), 2015
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## 6 Production & Manufacturing Systems Optimization

The objective of this research is to develop novel techniques to improve and control the production and manufacturing systems. Large-scale manufacturing systems are complex, dynamic and stochastic. This research focuses on 1) improving shop floor performance, 2) maximizing throughput of bottleneck resources, and 3) manufacturing process aid system. To deal with the stochastic nature of rework and reprocessing time in a job shop scheduling problem, a heuristic method is developed that takes into consideration the total estimated processing time (TEPT), a linear combination of processing, rework, and reprocessing times. Experimental results indicate that the proposed algorithm outperforms different commonly used dispatch rules in terms of solution quality and computation time.

Moreover, deterministic and large-scale problems are studied in this research, for instance, a surface mount technology (SMT) placement machine optimization in printed circuit boards (PCB) assembly industry. Since SMT placement machines are often considered the bottleneck of a PCB assembly line, one key to profitable manufacturing is to maximize the utilization of SMT placement machines. The objective of SMT machines’ optimization is to find the optimal nozzle and feeder setups and pick-and-place sequences to minimize cycle time or total moving distance of machine gantries, considering key manufacturing constraints. A typical structure and an optimal pick-and-place cycle of SMT placement machines are illustrated in Figure 6. The problem is computationally intensive because the number of solutions could grow exponentially with the problem size. A typical problem has around 3 million decision variables given that 300 electronics components are needed to be placed. As a result, to find efficient components allocation and gantry routing strategies, meta-heuristic and heuristic approaches have been designed. Experimental results show that the proposed heuristics could improve solution quality while not increasing computation time compared to the current industrial solutions.

### Future Research

Future research will explore other methodologies, such as meta-heuristics and exact algorithms, to improve solutions further in terms of both quality and computation time. On the other hand, a lower bound of the minimization problems will be further investigated, so that a key question as to how far away the near-optimal solutions we achieved are from the optimum could be answered.

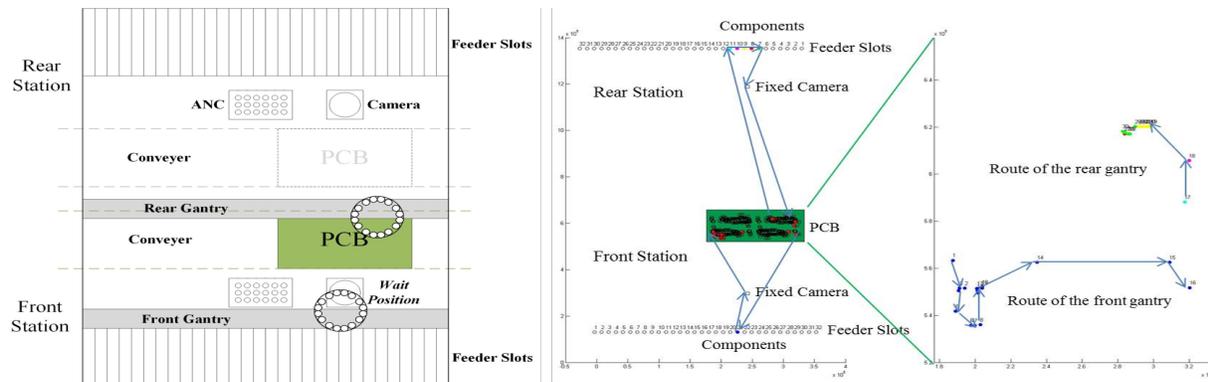


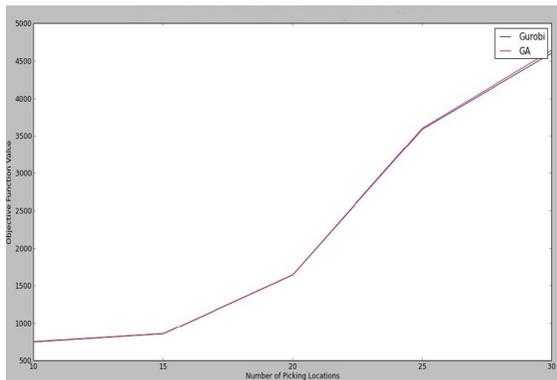
Figure 6: An example of a dual-delivery type SMT placement machine optimization

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- V. A. Raghvan, S. W. Yoon, and K. Srihari, “A job shop scheduling model with rework time in electronics manufacturing,” in *Proceedings of Industrial and Systems Engineering Research Conference*, (San Juan, Puerto Rico), 2013
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## 7 Warehouse Management and Transportation

Warehouse and material deployment operations are among the most important activities in supply chain management. Improving the operations involves reducing the operational wastes, simplifying, and improving the material handling techniques. Productivity, on the other hand, can be improved through investing in improving the labor standards. The CSDA laboratory has studied warehouse management and transportation optimization. Novel optimization heuristic techniques have been developed to further increase operational efficacies among various types of warehouses. By leveraging the power of discrete event simulation, potential optimized operating strategies have been validated and visualized via simulation software packages. Figure 7 shows an example of the warehouse simulation modeling and optimization results. Meta-heuristic solution approaches and discrete event simulation models are integrated to better mimic the real environments of various warehouses. This research optimized the order picking route and picker assignment by using genetic algorithm as shown in Figure 7.



(a) Order picking route optimization by GA



(b) Warehouse simulation model

Figure 7: An example of the warehouse simulation modeling and optimization results

In transportation research, the CSDA laboratory has focused on optimizing the truck-load assignment decision to match the best truck in a fleet to service a load. There are three main goals in the load planning decision, which are to service the load on time, minimize empty miles where the vehicle runs without a load, and satisfy the driver. In the literature, there is an extensive research optimizing the traveled distance and reducing the non-revenue generating empty miles, but there is less attention paid to the other two goals of load planning. Thus, this research includes driver satisfaction constraints in the traditional optimization models to produce a load plan that is not just focused on minimizing the empty miles, but also provides the driver with adequate conditions to retain.

### Future Research

This research effort has focused on warehouse process optimization and has significantly improved efficiency of various warehouses. To seek more warehouse operational improvement opportunities, future research would study perform physical utilization optimization including warehouse configuration, dock locations, racking configuration and orientation, and material transfer staging.

### Relevant Publication

- C. M. Mohr, “Optimization of warehouse order-picking routes using vehicle routing model and genetic algorithm,” 2014
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