Background

Bridging the gap between theory and practice to bring about economic and social impact has been the motif for my research. Working at the intersection of Artificial Intelligence and Operations Research, I am interested in the design of efficient computational methods and tools that either automate or provide decision support for resource management (planning, scheduling, and coordination) in a variety of domains, ranging from logistics, transportation, e-Commerce and health-care. In particular, I have chosen Logistics as the primary area of application for three reasons. First, logistics is one of the pillars of the Singapore’s economy, so business problems and benefits are prevalent. Second, the complexities of logistics operations warrant that we take an inter-disciplinary approach that draw richly from computing, industrial engineering, and management. Third, logistics at scale offers a key solution to address major emerging social concerns (such as environmental sustainability and disaster relief) in the world we live today.

My research is undergirded by real problems and challenges in industry, and my goal is to not only to contribute new knowledge and methods to tackle these problems, but embed them in software systems for field trials with real data and deployment in end-user organizations. To achieve this end-to-end research agenda, I seek external grants from both academic funding agencies and industry that enable me to pursue academic research and translate them into impactful applications. My research interests are in 3 broad areas:

- Planning and Scheduling
- Algorithm Engineering
- Multiagent Coordination

Here’s a sample of systems developed recently:

<table>
<thead>
<tr>
<th>System/Prototype Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaborative Urban Logistics System</td>
<td>A web-based auction system that enables shippers and carriers to bid for last-mile delivery resources in an Urban Consolidation Center</td>
</tr>
<tr>
<td>Adviser (Algorithm Portfolio Deviser)</td>
<td>An automated web-based system that combines the concepts of algorithm configuration, selection, and portfolio generation that enables end-users to finetune and select appropriate algorithms to solve optimization problems. <a href="http://research.larc.smu.edu.sg/adviser/">http://research.larc.smu.edu.sg/adviser/</a></td>
</tr>
</tbody>
</table>
Research Areas

In the following, I provide details of specific research areas and contributions.

1: Manpower Scheduling and Constraint Satisfaction

This research was done in early years – focusing on two related problems: Manpower Scheduling and Constraint Satisfaction. In [Lau96], I established the computational complexity of the Manpower Shift Scheduling problem, provided polynomial-time algorithms for special cases and showed how they can be embedded in complex real-world manpower scheduling settings. For the Constraint Satisfaction problem, we proposed heuristic algorithms with provable approximation bounds for Max-CSP [Halldorsson and Lau 1997], and using randomized rounding of semidefinite programs, I proved bounds for the weighted CSP problem and provided a uniquely new approach to solve it [Lau 1996, 2002].

Selected Publications:

2: Planning and Scheduling in Logistics

a: Dynamic Routing Problems

I worked mainly on two related logistics problems: Vehicle Routing Problem (VRP) and Pickup and Delivery Problem. [Lau, Sim and Teo 2003] introduced a new practical variant to the classical VRPTW (VRP with time windows) and provided a tight upper bound for this problem. Our metaheuristic approach is interesting not only in the sense of optimality (closeness to the upper bound), but from the stability standpoint, in that it degrades gracefully under constrainedness: when the number of vehicles is reduced, the customer packing density (average number of customers per vehicle in service) is monotonically non-decreasing. On PDPTW, [Lau and Liang 2002] proposed metaheuristics that beat the best-published results at that time, and proposed an algorithm to generate hard instances of PDPTW.

Selected Publications:

b: Defense Logistics Problems

Defense logistics differ from commercial logistics in that the availability of service is of primary importance (over cost/profit, etc). Furthermore, they are complicated by peace-to-war transitions (breaking assumptions of stationary probability distributions) and effects such as passivation and combat damage.

I tackled a variety of defense logistics problems that transcend standard problems and methods in the OR/OM literature. In recognition of my contributions on the new methods and systems that benefitted the defense technology community, I was nominated the 2007 Defense Technology Prize (individual category).
– the most prestigious award to recognize outstanding contributions in science and technology to enhance Singapore's defense capability.

As an example, we pioneered the work on Multi-echelon spares inventory allocation and reallocation problems under time-varying demand and limited resource capacities. Our novel solution approach combined stochastic optimization models, queuing theory and heuristic search [Lau et al 2006, Lau and Song 2008, Lau et al 2010]. The work won the 2006 National Innovation Convention Star Award (team category) in recognition of actual inventory cost reduction when the system was deployed in the Airforce.

As another example, we combined shortest path computation with constraint propagation to tackle the problem of dynamic Convoy movement planning through a high-fidelity urban city road network. This work is innovative in that it addresses a real problem that the Singapore military faces – having to move its forces during peace time across the city state without causing disruption to the civilian activities. This work was published in IAAI 2008 [Thangarajoo et al 2008] where we showed that our approach drastically improved run time efficiency compared with best known results. The resulting system has been field tested and deployed in the Singapore Army.

Another innovative work is [Lau, Agussurja and Thangarajoo 2008], which studied a resource coordination problem in logistics during a peace-to-war transition. Given that agent behaviors change over time as the tempo of war picks up, the plan that was previously consistent may be rendered inconsistent. Determining when and how agent behaviors should change adaptively is a computationally challenging problem. We studied the literature on agent adjustable autonomy and proposed a sense-and-respond approach that combines a centralized fuzzy controller and multi-agent negotiation for conflict resolution. I applied the idea to a similar problem in industry and develop a working prototype for dynamic management of resources in a large logistics complex [Chen and Lau 2011].

Selected Publications:

3: Algorithm Engineering – Hybridization, Visualization and Automation (2002-now)

My contributions are the following in chronological order:
- Metaheuristics Development Framework (MDF), a framework that allows designers to design new meta-heuristics through hybridization ([Lau et al, 2000, 2002, 2004])
- Viz, a visualization tool that allows designers to analyse a target local search algorithm while it traverses the problem’s fitness landscape. Understanding trajectory behavior enables the designer to
manually perform parameter tuning. It is the main idea behind the PhD thesis of my student Steven Halim. Presented in MIC 2005, UIST 2006 and CP 2007 [Halim et al 06, 07].

- **Adviser**, a web-based algorithm portfolio recommendation system. Presented in GECCO 2014, LION 2014, AAAI 2015 and LION 2015, and one paper was the best paper award runner up at LION 2015.

**Selected Publications:**


**Tools developed:**

4: Multi-Agent Coordination under Uncertainty (2006-now)

a. Robust Planning and Scheduling

This work is concerned with generating robust schedule policies that can be executed with high probability in uncertain environments. Stochastic Programming often assumes that uncertainty is modeled by known probability distributions – which is theoretically interesting but practically unrealistic. In contrast, Robust Optimization can deal with linear optimization under uncertainty with mild probability assumptions (see for example, [Bersimas and Sim 2004]).

My first work is in tackling the long-standing fundamental problem in AI of executing temporal constraint networks under uncertainty. Most papers on temporal networks with uncertainty deal with execution under 100% confidence. This may be too conservative, and in practice, it can lead to wasteful resource allocation or even infeasible networks. In [Lau, Ou and Sim 2005], we take a risk-based approach where we allow the decision maker to specify a level of risk, and our main contribution was to develop a computationally tractable technique for verifying and executing temporal constraint networks with a prescribed level of risk. This idea provided the seed for a larger (and main) effort on robust schedule execution under uncertainty. In [Lau, Ou and Xiao 2007], we proposed a method that augments a local search (or meta-heuristics) procedure to find robust solutions for NP-hard optimization problem under uncertainty. Our approach is distribution-free¹, and generic in the sense that given any local search algorithm for a deterministic problem, one may readily convert it so it could solve the corresponding chance-constrained variant. This idea was expanded subsequently in the PhD thesis of my student Na Fu ([Fu, Xiao and Lau 2008, Fu et al 2012]) for executing resource-constraint project networks. Our approach can be applied in decision support for service systems in general to produce solutions that require guarantee of quality of service. In [Liang, Wu and Lau 2009] for example, we applied the approach for web service composition in uncertain environments.

Selected Publications:

b. Multi-Agent Schedule Cooperation and Coordination

Real-world decision making often involves multiple decision-makers (agents) reaching agreement on a joint set of decisions.

In a cooperative setting, I developed a unified combinatorial auction framework for solving decentralized resource allocation and scheduling problems. In this framework, jobs are represented by agents, and

¹ There is no distributional assumption on the input data, but the means and variance must be known.
machine timeslots are treated as resources bidded by job agents through an auctioneer. Given the temporal dependency between tasks, resource bids are combinatorial. I developed different algorithms for achieving general equilibrium and winner determination. One such effort is the work with two Electrical Engineering professors at NUS. We developed price adjustment strategies based on adaptive PID-control theory that enable rapid convergence to general equilibrium in a combinatorial auction, thereby allowing large-scale decentralized job scheduling to be performed in real-time [Lau et al. 2011]. This stands in contrast with literature which typically works with benchmark jobshop problems. This work resulted in the PhD thesis of my student Z. Zhao. This framework was extended to handle problems under demand uncertainty [Cheng, Tajan and Lau 2012]. In terms of winner determination, our auction framework has been applied in e-procurement and humanitarian logistics contexts [Park et al 2008, Lau et al. 2012a].

Subsequently, PSA (the main container terminal port operator in Singapore that handles tens of thousands of container transshipments per day) took an interest in our work. We customized our auction framework, and our result was verified by them that is capable of producing a significant performance improvement over existing planning algorithms.

Another work on agents to cooperatively derive a schedule is through message exchange among themselves. This can be achieved through the Distributed Combinatorial Optimization Problem (DCOP) model. While DCOP in itself is academically interesting, what really motivated me to work on DCOP is its potential applications in distributed coordination and consolidation of multi-party logistics operations. [Nguyen, Yeoh and Lau 2012, 2013, Nguyen et al 2014] extends the Distributed Combinatorial Optimization Problem (DCOP) in different settings.

In a non-cooperative setting, I have been working on problems in urban transportation and leisure:

- In [Agussurja and Lau 2012], we analysed a large dataset of taxi GPS traces and passenger trips provided by the largest taxi company in Singapore, and based on taxi cruising behavior derived from this dataset, we developed a stochastic congestion game model that guides thousands of individual taxis’ cruising actions in real time to achieve improved utilization and hence revenue. This paper was chosen from among 8% of the submitted papers for oral presentation at UAI 2012. Currently, we are looking into the passenger aspect of the problem.

- Another work is concerned with maximizing visitor experience in theme parks (through minimizing wait times). In [Lau et al. 2012b], we proposed an algorithm for the Orienteering problem in a dynamic stochastic theme park environment where wait times at different attractions are time-varying and stochastic since other agents are also visiting the attractions. The time-varying and probability distributions of wait times are derived from a large dataset provided by a large theme park. Also, visitor behavior and preferences are modeled by data collected from actual field surveys conducted on tracking the GPS locations and activities of visitors using smart phone devices. Depending on the visitor “risk-appetite”, our approach will yield a route (sequence of visits) that maximizes his reward accordingly. More recently, this work is extended that allows park operators to minimize congestion on rides by coordinating the movement of visitor agents via real-time guidance and the use of incentives.

Selected Publications:


Future Directions

Broadly, my future research agenda will continue to be driven by real-world problems that have economic and social impacts. I will study new problems that entail dynamic large-scale resource planning and scheduling in environments involving one or more decision makers. They include:

Urban Computing: Mobile technology changes the way businesses engage with consumers. At the individual level, there is an increasing trend in using mobile apps to plan and manage activities. At the corporate level, customers’ digital traces can be aggregated and analysed to accurately predict demand patterns and congestion. This opens many opportunities for real-time crowd flow management and coordination, which is essentially the logistics of moving people (rather than freight). Unlike freight however, humans are self-interested and vary in behavior. The challenge is to coordinate people flows in an uncertain environment by providing customized information/incentives via mobile devices so people move towards some form of system optimality. I am interested in developing computationally efficient methods to solve these large-scale coordination problems where people are agents exhibiting different human behavior.

Early works have been presented in AAMAS 2013 and 2014.

Sustainable Planning, Scheduling and Coordination in Urban Networks: By 2050, more than 70% of the world population will live in urban cities. This introduces new challenges in sustainability and livability that entail proper resource optimization and coordination on large physical networks in operational settings. I already embarked on research in a few urban management projects:

1. Logistics networks (multi-party coordination of logistics operations for last-mile delivery in a city)
2. Transport networks (ride-sharing mechanisms for passengers’ last mile travel from an interchange/hub)
3. Environmental networks (randomized resource scheduling to enhance public security and safety).

Early works on these topics are in IJCAI 2013, IAAI 2013 and AAAI 2015 respectively.

Algorithm Engineering: As computational problems become increasingly large-scale and complex, the need for tools for algorithm (in particular, meta-heuristics) designers to rapidly design, configure and test their algorithms become more pressing. I have a sustaining interest to work on these automated tools and workbenches.

Early works have been presented in AAAI 2015 and LION 2015.