

Research Statement

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Background

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 targetted domains of logistics, transportation, travel planning and health-care. **Logistics** is 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 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.

Recently, I find myself tackling such operational problems in an urban shared economy context.

The common thread running through my research is a focus on going beyond papers to build usable novel tools and prototypes, a number of which have been testbedded and deployed in industry. 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 can be divided into 3 broad areas:

- a. Planning and Scheduling
- b. Algorithm Engineering
- c. Multi-agent Coordination

Here's a sample of systems developed recently:

System/Prototype Name	Purpose
Personalized Conference Scheduling Agent (web and mobile app)	Targetted at visitors in large conferences and conventions, the app provides a list of recommended papers/talks based on keywords entered, and generates a personalized itinerary tailored to user schedule and preferences. The web system for CIKM 2017 is available in: https://ucp.unicen.smu.edu.sg/press/page
Collaborative Urban Logistics platform (CLUE)	A web-based auction e-marketplace that enables carriers to collaborate on last-mile delivery through load consolidation via an Urban Consolidation Center http://research.larc.smu.edu.sg/CLUE/
Adviser (Algorithm Portfolio Deviser)	Web-based tool that enables algorithm designers to finetune and select appropriate algorithms to solve optimization problems http://research.larc.smu.edu.sg/adviserplus/ (Automated Algorithm Portfolio Deviser)

Recent Works (past three years)

Crowd Management and Crowdsourcing: 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 so people move towards some form of system optimality. I am interested in developing computationally efficient methods to solve these complex problems where people are agents exhibiting different human behavior.

Sustainable Planning, Scheduling and Coordination in Urban Networks: Urbanization and ageing economy introduce 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 freight consolidation and coordination for last-mile delivery)
2. Transport networks (ride-sharing mechanisms for passengers' last mile travel from an interchange/hub)
3. Physical networks (resource scheduling to enhance public security and safety).

Selected Publications (2016-2017)

Truc Viet Le, Richard Oentaryo, Siyuan Liu and Hoong Chuin Lau. Local Gaussian Processes for Efficient Fine-Grained Traffic Speed Prediction. *IEEE Transactions on Big Data*, 3(2), 2017.

Pradeep Varakantham, Akshat Kumar, Hoong Chuin Lau and William Yeoh. Risk-Sensitive Stochastic Orienteering Problems for Trip Optimization in Urban Environments. *ACM Transactions on Intelligent Systems and Technology*, 9(3), November 2017.

Shih-fen Cheng, Cen Chen, Thivya Kandappu, Hoong Chuin Lau, Archan Misra, Nikita Jaiman, Randy Tandriansyah, Desmond Koh. Scalable Urban Mobile Crowdsourcing: Handling Uncertainty in Worker Movement. *ACM Transactions on Intelligent Systems and Technology*, 9(3), November 2017.

Duc Thien Nguyen, Akshat Kumar and Hoong Chuin Lau. Collective Multiagent Sequential Decision Making Under Uncertainty. In Proc. *AAAI Conference on Artificial Intelligence (AAAI 2017)*, San Francisco, USA, February 2017.

A. Gunawan, H. C. Lau and P. Vansteenwegen. Orienteering Problem: A Survey of Recent Variants, Solution Approaches and Applications. *European Journal of Operational Research*, 225:2, 315-332, 2016.

D. Handoko, H. C. Lau and S. F. Cheng. Achieving Economic and Environmental Sustainability in Urban Consolidation Center with Bi-Criteria Auction. *IEEE Trans. Automation Science and Engineering*, 13:4, 2016.

In the following, I provide highlights of previous works and contributions.

1: Manpower Scheduling

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. More recently, I have worked with such problems in patrol scheduling as well as physician scheduling.

Selected Publications:

- H. C. Lau. On the Complexity of Manpower Shift Scheduling. *Computers and Operations Research*, 23:1, 93-102, 1996.
- H. C. Lau, Z. Yuan, and A. Gunawan. Patrol Scheduling in an Urban Rail Network. *Annals of Operations Research*, 1-26, June 2014.
- A. Gunawan and H. C. Lau. Master Physician Scheduling Problem. *Journal of the Operational Research Society*, 64 (3), 410-425, 2013.

2: Planning and Scheduling in Logistics

a. Large-Scale 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:

- H. C. Lau, Z. Liang. Pickup and Delivery Problem with Time Windows, Algorithms and Test Case Generation. *International J. on Artificial Intelligence Tools*, 11:3, 455-472, 2002.
- H. C. Lau, M. Sim and K. M. Teo. Vehicle Routing Problem with Time Windows and a Limited Number of Vehicles, *European J. Operational Research*, 148:3,559-569, 2003.

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.

Selected Publications:

- H. C. Lau, et al. Evaluation of Time-Varying Availability in Multi-Echelon Spare Parts Systems with Passivation. *European J. Operational Research*. 170:1, 91-105, 2006.

- H. C. Lau and H. Song. Optimization of Two-Echelon Repairable Inventory System with Limited Repair Facility under Non-Stationary Demands. *International J. Inventory Research*, 1:1, 67-92, 2008.
- R. Thangarajoo, L. Agussurja, H. C. Lau. A Hybrid Approach to Convoy Movement Planning in an Urban City. Proc. *Innovative Applications of Artificial Intelligence (IAAI)*, Chicago, USA, 2008.
- H. C. Lau, L. Agussurja and R. Thangarajoo, Real-Time Supply Chain Control via Multi-Agent Adjustable Autonomy. *Computers & Operations Research* (Special Issue on Real-time Supply Chain Management), 35, 3452–3464, 2008.
- H. C. Lau, J. Pan, and H. Song. Periodic Resource Reallocation in Two-Echelon Repairable Item Inventory Systems, *IEEE Trans. Automation Science & Engineering*, 7:3, 474–485, 2010.
- H. Chen and H. C. Lau. A math-heuristic approach for integrated resource scheduling in a maritime logistics facility. In Proc. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, Singapore, 2011. (**Best paper award runner up**)

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. See papers in UIST 2006 and CP 2007 [Halim et al 06, 07].
- **Autopartune**, a tool that allows designers to perform **automated tuning** of parameters. It forms the backbone of the PhD thesis of my student Lindawati. See papers in LION 2011 and 2013 [Lindawati et al 2011, 2013].
- **Adviser** and **Adviser Plus**, a web-based algorithm portfolio recommendation system. See papers in GECCO 2014, AAI 2015 and LION 2014-2016; and one paper was the best paper award runner up at LION 2015.

Selected Publications:

- H. C. Lau, A. Lim, and Q. Z. Liu. Solving a Supply Chain Optimization Problem Collaboratively. In Proc. *17th National Conf. on Artificial Intelligence (AAAI)*, Texas, USA, 2000.
- H. C. Lau, H. Ono, and Q. Z. Liu. Integrating Local Search and Network Flow to Solve the Inventory Routing Problem. Proc. *18th National Conf. on Artificial Intelligence (AAAI)*, Edmonton, Canada, 2002.
- H. C. Lau, K. M. Ng, and X. Wu. Transport Logistics Planning with Service-Level Constraints, In Proc. *19th National Conf. on Artificial Intelligence (AAAI)*, San Jose, USA, 2004.
- H. C. Lau, W. C. Wan, et al. A Software Framework for Rapid Hybridization of Meta-Heuristics. *Int’l Transactions on Operational Research* (IFORS 2005 Special issue edited by Stefan Voss), 14:2, 2007.
- S. Halim, R. Yap and H. C. Lau. Explaining Local Search Behavior Using Viz: The Local Search Visual Analysis Suite. Proc. *19th Annual ACM Symp. on User Interface Software and Technology (UIST)*. Montreux, Switzerland, 2006.
- S. Halim, R. Yap and H. C. Lau. An Integrated White+Black Box Approach for Designing and Tuning Stochastic Local Search. Proc. *13th International Conf. on Principles & Practice of Constraint Programming (CP)*, Rhode Island, USA, 2007.

- Lindawati, H. C. Lau and D. Lo. Clustering of Search Trajectory and its Application to Parameter Tuning. *Journal of Operational Research Society* (Special issue on *Systems to build Systems* edited by Burke, Ozcan and Thompson). (Conference version in LION 2011)
- Lindawati, Z. Yuan, H. C. Lau and F. Zhu. Automated Parameter Tuning Framework for Heterogeneous and Large Instances: Case study in Quadratic Assignment Problem. In Proc *7th Learning and Intelligent OptimizatioN Conference* (LION), Catania, Italy, 2013.
- A. Gunawan, H. C. Lau and E. Wong. Real-World Parameter Tuning using Factorial Design with Parameter Decomposition. In Springer Operations Research / Computer Science Interfaces Book Series (edited by Schaerf, Gaspero and Stuetzle), 37-59, 2013.
- Z. Yuan, D. Handoko, D. T. Nguyen and H. C. Lau. An Empirical Study of Off-line Configuration and On-line Adaptation in Operator Selection. In Proc *8th Learning and Intelligent OptimizatioN Conference* (LION) (LNCS), Gainesville, Florida, USA January 2014.
- R. Oentaryo, D. Handoko and H. C. Lau. Algorithm Selection via Ranking. In Proc. *Twenty-Ninth AAI Conference on Artificial Intelligence (AAAI-15)*, Austin, Texas, USA, January, 2015.
- M. Misir, D. Handoko and H. C. Lau. OSCAR: Online Selection of Algorithm Portfolios with Case Study on Memetic Algorithms. In Proc *9th Learning and Intelligent OptimizatioN Conference* (LION) (LNCS), Lille, France, January 2015. Best Paper Award Runner Up.
- M. Misir, D. Handoko and H. C. Lau. ADVISER: A Web-based Algorithm Portfolio Deviser. In Proc *9th Learning and Intelligent OptimizatioN Conference* (LION) (LNCS), Lille, France, January 2015.

Tools developed:

- MDF (2002-2006): http://www.mysmu.edu/faculty/hclau/JasonWan_MDF_Presentation.pdf
- Viz (2005-2009): <http://www.comp.nus.edu.sg/~stevenha/viz/index.html>
- Autopartune (2008-2013): <http://research.larc.smu.edu.sg/autopartune/index.aspx>
- Adviser (2014-2016): <http://research.larc.smu.edu.sg/adviserplus/>

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.

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 seeding 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, Lau and Varakantham 2015, 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. In [Chen, Cheng, Lau and Misra 2015], we applied the approach for crowdsourced task assignment.

Selected Publications:

- H. C. Lau, T. Ou and M. Sim. Robust Temporal Constraint Networks. *Proc. 17th IEEE Conf. on Tools with Artificial Intelligence (ICTAI)*, 82-88, Hong Kong, 2005.
- H. C. Lau, T. Ou and F. Xiao. Robust Local Search and Its Application to Generating Robust Schedules. In *Proc. International Conf. on Automated Planning and Scheduling (ICAPS)*, Rhode Island, USA, 2007.
- A. Liang, X. Wu, H. C. Lau. Optimizing Service Systems based on Application-Level QoS. *IEEE Trans. Service Computing*, 2:2, 108-121, 2009.
- N. Fu, H. C. Lau, P. Varakantham, and F. Xiao. Robust Local Search for Solving RCPSP/max with Durational Uncertainty. *Journal of Artificial Intelligence Research*, 43, 43-86, 2012.
- N. Fu, H. C. Lau and P. Varakantham. Robust Execution Strategies for Project Scheduling under Unreliable Resources and Stochastic Durations. *Journal of Scheduling*, 18:6, 607-622, 2015.
- S. Saisubramanian, P. Varakantham and H. C. Lau. Risk based Optimization for Improving Emergency Medical Systems. In *Proc. Twenty-Ninth AAAI Conference on Artificial Intelligence (AAAI-15)*, Austin, Texas, USA, January, 2015.
- C. Chen, S. F. Cheng, H. C. Lau and A. Misra. Towards City-scale Mobile Crowdsourcing: Task Recommendations under Trajectory Uncertainties. In *Proc. International Joint Conference on Artificial Intelligence (IJCAI-15)*, Buenos Aires, Argentina, 2015.

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 **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 machine timeslots are treated as resources bid 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, humanitarian logistics and last-mile logistics contexts.

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

¹ There is no distributional assumption on the input data, but the means and variance must be known.

(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 **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.
- In [Agussurja, Lau and Cheng 2016], we modeled the problem of getting multiple logistics providers to collaborate on urban last-mile deliveries as a cooperative game, and consider profit sharing schemes that are stable and fair, with minimal additional external subsidy.
- 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:

- H. C. Lau, Z. Zhao, S. Ge, T. H. Lee. Allocating resources in multi-agent flowshops with adaptive auctions. *IEEE Trans. Automation Science and Engineering*, 8:4, 732-743, 2011.
- S. F. Cheng, J. Tajan, H. C. Lau. Robust distributed scheduling via time period aggregation, *Web Intelligence and Agent Systems: An International Journal*, 10, 305-318, 2012.
- D. T. Nguyen, W. Yeoh, and H. C. Lau. Stochastic Dominance in Stochastic DCOPs for Risk Sensitive Applications. In Proc. *Int'l Conference on Autonomous Agents and Multiagent Systems (AAMAS)*, Valencia, Spain, 2012.
- D. T. Nguyen, W. Yeoh, and H. C. Lau. Distributed Gibbs: A Memory-Bounded Sampling-based DCOP Algorithm. In Proc. *Int'l Conference on Autonomous Agents and Multiagent Systems (AAMAS)*, St Paul, Minnesota, USA, 2013.
- D. T. Nguyen, W. Yeoh, H. C. Lau, S. Zilberstein, and C. Zhang. Decentralized Multi-Agent Reinforcement Learning in Average-Reward Dynamic DCOPs. In Proc. *Twenty-Eighth AAAI Conference on Artificial Intelligence (AAAI-14)*, Quebec City, Canada, July, 2014.
- L. Agussurja and H. C. Lau. Toward Large-Scale Agent Guidance in an Urban Taxi Service. In Proc. *Conference on Uncertainty in Artificial Intelligence (UAI)*, Catalina Island, USA, 2012.
- L. Agussurja, H. C. Lau and S. F. Cheng. Achieving Stable and Fair Profit Allocation with Minimum Subsidy in Collaborative Logistics. In Proc. *30th AAAI Conference on Artificial Intelligence (AAAI-16)*, Phoenix, Arizona, USA, February, 2016.
- H. C. Lau, et al. Dynamic Stochastic Orienteering Problems for Risk-Aware Applications. In Proc. *Conf. on Uncertainty in Artificial Intelligence (UAI)*, Catalina Island, USA, 2012.