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Challenges and Opportunities in Cluster Urban Logistics: The Jurong Gateway Precinct

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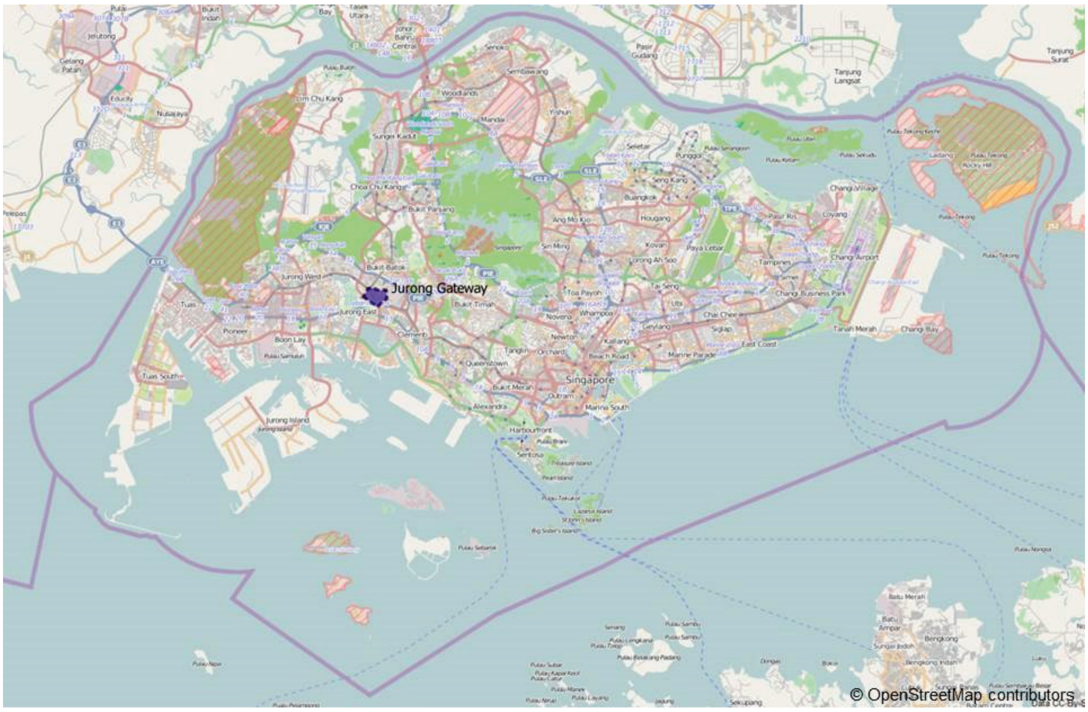

A Collaboration Between

The Logistics Institute Asia Pacific

NUS National University of Singapore

Georgia Institute of Technology

The Collaborative Urban Logistics (CUL) project is a joint research collaboration to address last-mile deliveries problems and challenges. CUL comprises four inter-related smaller projects: (1) Data Harmonization & Analytics, (2) Synchronization & Multi-Objective Planning, (3) Eco-Friendly Collaborative Delivery and (4) Multi-Party Coordination. The objective of the CUL project is for shippers, manufacturers, end-users, and logistics service providers to collectively improve their economies of scale/scope in terms of the value chain efficiency and overall system productivity and effectiveness while maintaining environmental sustainability. Doing so will then ensure a more liveable community and a vibrant future for all.

*This work is part of the Science and Engineering Research Council (SERC) Urban Systems (Logistics and Supply Chain Management) Initiative supported by the Agency for Science, Technology and Research (A*STAR) under Grants 1224200001, 1224200002, 1224200003, and 1224200004.*

COLLABORATING ORGANIZATIONS:

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CHALLENGES AND OPPORTUNITIES IN CLUSTER URBAN LOGISTICS: THE JURONG GATEWAY PRECINCT

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Networked Supply Chains: Robustness & Resilience

27th MARCH 2014

SINGAPORE

Challenges and Opportunities in Clustered Urban Logistics: The Jurong Gateway Precinct

Executive Summary

Jurong Gateway (JG) is considered as a cluster of urban logistics in The Jurong Lake District (JLD) which has been designated as a strategic piece in the decentralization of Singapore's commercial and leisure activities[1]. This is a bold move to better manage congestion, improve environmental sustainability, and optimize land use for a brighter urban future.

(Maps powered by streetdirectory.com)

Fig. 1: Dashed delineation of JG with main transport entry and exits points in purple, entry points from the street grid to mall loading bays in red and key intersections in blue

JG provides a rich mix of urban functions, with expansions planned for the near future. Malls such as JCube, Jem, Westgate and IMM already provide around 200,000 sqrm of retail footprint, housing over 800 shops. The upcoming Westgate Tower will supply a large increase in high-rise commercial space by end 2014, and the Ng Teng Fong General and Jurong Community Hospitals will collectively provide 1100 hospital beds, catering to over a million residents in JLD. Finally, JG also houses light business and warehousing facilities.

However, the high density of urban functions in JG is naturally prone and highly sensitive to traffic congestion, especially when both cargo and people are channeled into the area, causing negative externalities to all concerned. Put simply, the current approach to creating a more liveable community creates operational and tactical challenges for routing and resource scheduling. The large amount of urban logistics activity generated deserves better orchestration through resource and information sharing in collaborative and co-opetitive efforts between stakeholders in the precinct. Only then can this bold dream for JG be a well-executed reality.

This TLIAP White Paper discusses some of the attendant urban logistics problems and offer solutions to help shift behavior, workforce productivity, and alter transport habits. To logistically operate the precinct optimally, we consider:

1. **In-mall optimization.** Using 3-D simulation and a capacitated delivery routing problem with time windows and penalties, we model a consolidated mechanism for goods distribution inside the mall to optimize the efficiency (i.e. workforce, congestion, and emissions) and reliability improvements of the loading bay activities. We also structure a system dynamics approach to show how policy levers for managing traffic flow at a mall loading bay (e.g. charges) can be optimized for improved sustainability.

2. **Precinct consolidation**. Using performance based contracting mechanisms with environmental considerations, we show how 3PLs servicing the precinct can be "effectively integrated" to improve their operations with no cost increase to service level. We also propose a postponement delivery strategy to optimize the truck load for each delivery and reduce the number of trucks going in and out of the JG precinct.

[1] Malone-Lee, L.C., Sim, L.L. & L. Chin, "Planning for a more balanced home–work relationship: the case study of Singapore," *Cities* 18, no. 1 (2001): 51-55.

Business Challenges

Jurong Gateway (JG), as a key precinct in a logistics cluster, offers an attractive live-work-play environment with good housing estate, employment area, and recreational and leisure facilities. With a high density of urban activities, JG experiences multiple challenges in maintaining livability and self-sufficiency of the precinct and to satisfying the residents' need for a high-quality living environment.

This TLIAP White Paper focuses on the urban logistics activities in JG. At the heart of the challenges in urban logistics in JG are traffic congestion, workforce productivity, and future development of the JLD eco-system.

Jurong Lake District (JLD) Development Features[2]

- *Size: 360ha*
- *Office Space: 500,000 sqrm*
- *Retail space: 250,00 sqrm*
- *Resident: 1,000 homes*
- *Hotel: 2,800 hotel rooms*
- *Hospitals: Ng Teng Fong General Hospital and the Jurong Community Hospital*

Traffic Congestion

Traffic congestion is an inconvenience of urban living, one that increases travel and dwell time for logistics service providers and urban society.

In JG, traffic congestion occurs mostly during the "peak hours" of 6-9.30 am and 6-8 pm. One major highway (AYE) experiences heavy congestion during these peak hours on weekdays, reducing the traffic speed to below the desired range of 45-65 km/h for expressways, and dipping to as low as 35 km/h[3].

… traffic speeds are below the optimal speed and dipping to 35km/h …

Traffic congestion will ultimately increase the cost of last mile logistics to / from JG and cause disruptive delays in delivery.

Workforce Productivity

Like many industries, logistics and transportation depend on lower-skilled labour for last mile delivery. At the same time, this labour resource is in short supply in Singapore. As such, industries try and need to improve their workforce productivity and better utilize manpower.

Based on our observation and interviews in JG, the distribution of goods in the mall, as part of the loading/unloading activities is not executed optimally and underutilized workers are the result.

For instance, in most deliveries to the mall, one delivery requires a truck driver and a helper. The helper manually unloads the goods and delivers the goods physically to the shop(s). This last mile process requires about 15-60 minutes. During that time, the driver remains idle.

Future Development of JLD

The URA (Urban Redevelopment Authority) is developing and promoting JLD as a unique living, business and leisure destination. Comprising two complimentary precincts - JG and Lakeside, JLD will be the largest commercial hub outside of the CBD.

However, with the upcoming developments including a bus interchange, road network expansion, additional warehouse, retail, office, and hospital bed space[4], JG faces a new challenge: to balance the residents' desired economic and leisure activities with the congestion and environmental impact of this bold development.

More can and must be done to build an optimal eco-system, where a more liveable community is realizable wihout foregoing any compromise in operational efficiency.

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[2] Urban Redevelopment Authority, Singapore. http://www.ura.gov.sg/MS/DMP2013/regional-highlights/west-region/Economy.aspx. Accessed on 13 March 2014.

[3] Malone-Lee, L.C., Sim, L.L. & L. Chin, "Planning for a more balanced home–work relationship: the case study of Singapore," *Cities* 18, no. 1 (2001): 51-55.

[4] Ibid. Note 2.

Urban Logistics Solutions

Cities like Singapore, in the objective to reduce the congestion and improve the productivity of the labour force, have put forward the concept of decentralization of development so that residents can 'live, work and play' in new urban areas such as JLD. In practice, however, this decentralization attempt presents business with operational challenges of traffic congestion near key amenities such as shopping malls, hospitals, and office towers due to the limited capacity of the transport network, inadequate information on usage and space availability, and the integrated design of the facilities.

To reduce the traffic congestion as well as to improve workforce productivity and prepare the JG precinct to support the continued development of JLD, we propose some innovative urban logistics solutions which focus on synchronizing the last mile logistics activities in key facilities such as the malls. We classify our solutions into two segments (see Fig. 2): 1) optimization inside the mall via in-mall optimization; and 2) truck flow optimization through precinct consolidation.

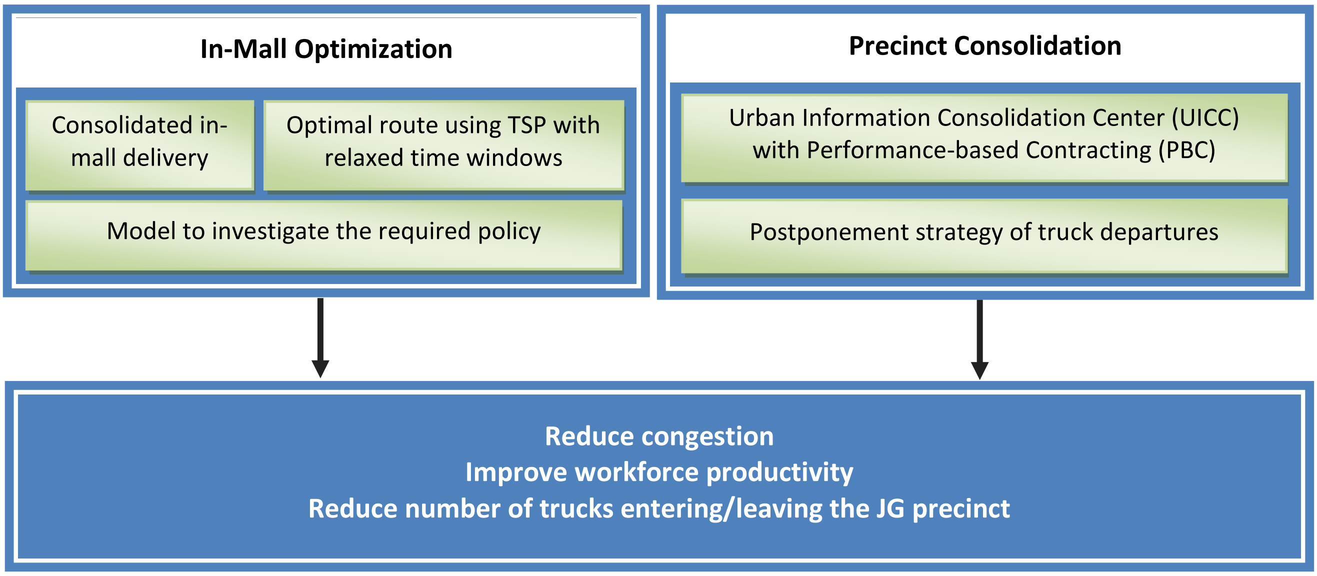

Fig. 2: Urban logistics solutions

1. In-Mall Optimization

In a typical goods distribution in a mall (we refer to this as the non-consolidated scenario), a truck, operated by a driver and a helper from a carrier, arrives at the mall and the helper unloads the goods and delivers them to the stores on a specific floor using the goods elevator. The truck then waits until the helper returns and then departs the mall. The arrival time of the trucks is often random, and the routing and delivery sequence is made based on driver experience and preferences of the delivery personnel. A simulation model for this goods distribution in a mall is built using Simio version 6.97 and shown in Fig. 3 (Please scan QR code to see the short video).

In this setting, goods distribution in the mall is not executed optimally. The helpers may need to wait for available elevators which may lead to late deliveries. In addition, the helpers and elevator related delays impose additional waiting time for the truck in the loading bays. Other delivery trucks are then denied this space. As a result, we are left with sub optimal space and time utility of critical logistics resources (drivers, helpers, elevators, and loading bays), retail delivery delays, and unintended queues of other vehicles waiting to enter the mall basement carpark.

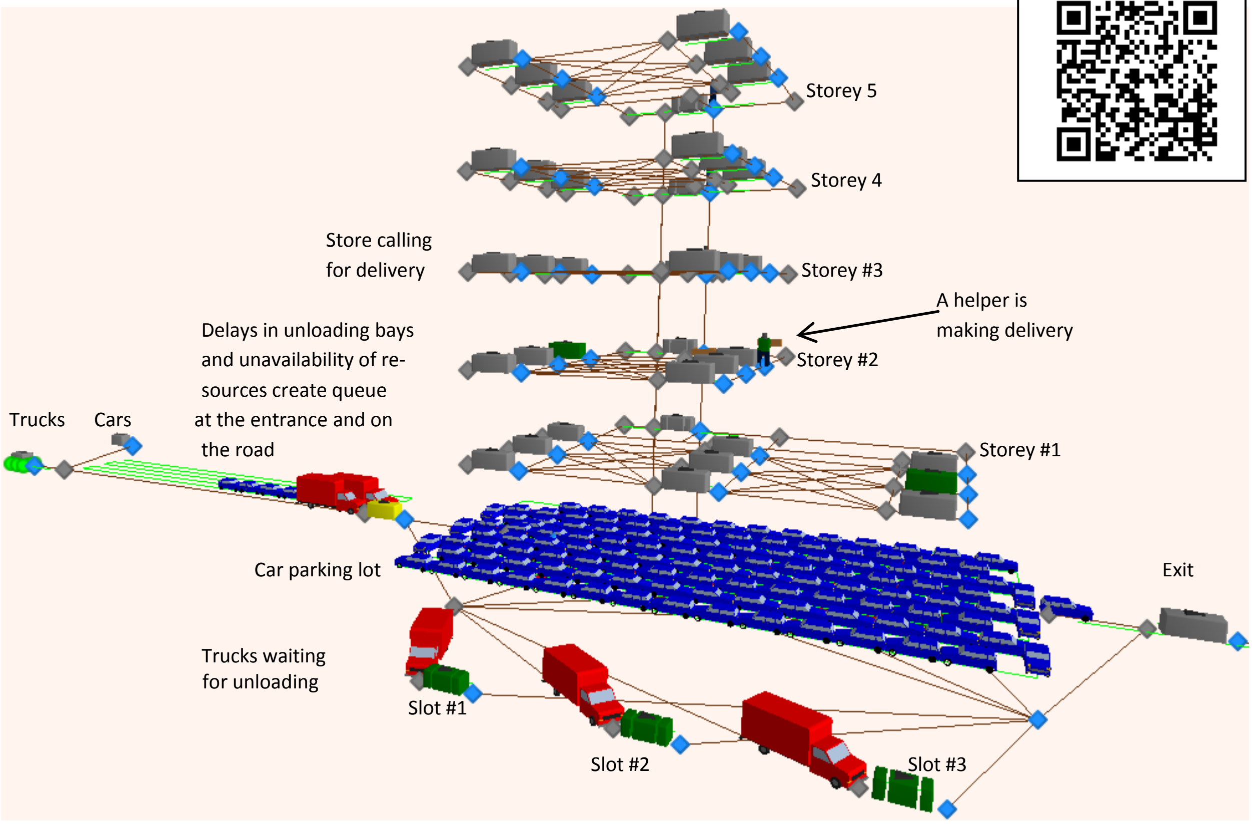

Fig. 3: Simio model for goods distribution within a specific mall in JG

As a consequence of the inefficiency of such goods distribution within the mall, we propose a novel solution: **consolidated in-mall delivery** using a Simio 3D simulator. In consolidated in-mall delivery, after different orders of different stores from different delivery transporters (and perhaps at different times) are unloaded at the loading points (bays), these orders are collected, sorted, and consolidated at the basement of the mall. All orders that have the same destinations (i.e. floors or shop clusters) are sent out together while considering capacity (elevator or worker) and time window (preferred delivery time) constraints.

To efficiently perform the final delivery operation, **optimally designed delivery routes,** based on the capacitated Traveling Salesman Problem (TSP) with relaxed time windows, are introduced. The time window is the time interval in which each store requests to be serviced at their location. However, a delivery worker could possibly violate the time windows and still make the drop. Using a capacitated TSP with relaxed time windows, we optimize the delivery routes by penalizing any delivery outside of the time windows.

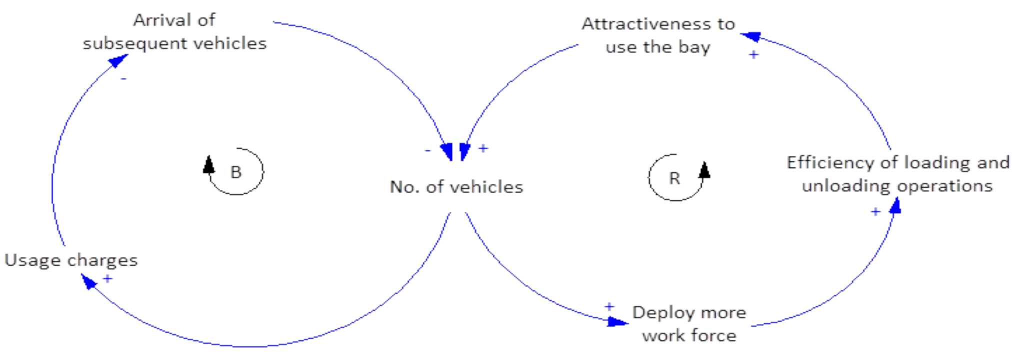

Fig. 4: Causal loop diagram for the loading bay, including the reinforcement of diverting vehicles

We then combine this consolidated in-mall delivery that improves the efficiency of the Loading / Unloading Efficiency (LUE) policy with a range-bound congestion pricing (parking pricing policy or Bay Usage Charges (BUC)) mechanism, and build **a model to investigate the required policy using the system dynamics methodology** to better manage the queue length at the mall's entrance gate. These two policies create two feedback (balancing) loops to control the queue length as shown in Fig. 4. The first loop is developed to measure the impact of congestion pricing (BUC) on the queue length, while the second loop measures the impact of loading and unloading (LUE) efficiency on the queue length. Thus, this model is developed to investigate its balance in order to achieve an acceptable queue size and time. The '+' sign denotes direct proportionality in that if the value of the preceding variable increases, then the value of the succeeding variable increases as well and the '-' sign denotes otherwise.

Charging existing vehicles more leads to a reduced arrival rate of subsequent vehicles. This then stabilises the demand rate due to the vehicles now diverting their route in order to avoid the long queue at the gate. As the number of trucks in the queue increases, deploying more resources for loading and unloading activities at the bay will increase the efficiency and that inherently improves the attractiveness for the trucks and thus realising fewer vehicles in the queue. This loop reinforces diverted vehicle movement towards the mall for loading and unloading operations and hence satisfies the retail demand rate at the shops.

Using this model, the mall operator can analyze the impact of multiple policies and can decide the appropriate mix of policies to implement.

Using this model, the mall operator can analyze the impact of multiple policies and can decide on the appropriate mix of policies to implement to better manage the traffic flow of the trucks and hence reduce congestion to and from the basement car park gate and on the main road.

2. Precinct Consolidation

Besides the four large shopping malls, JG has many small retail shops (SMEs) that are serviced by transporters carrying small to average sized loads. These SME retailers demand a high number of small-volume deliveries that increases the flow of trucks to the area, thus contributing to traffic congestion around the vicinity of the malls.

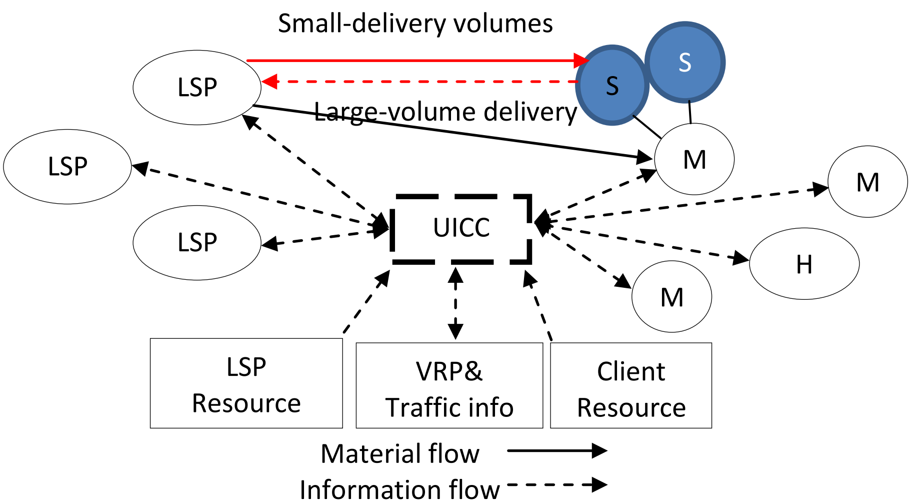

Fig. 5: Urban Information Consolidation Center (UICC) mechanism

In this case, a joint distribution concept can be applied to improve the situation through reducing the Less-than-Truck-Load (LTL) shipping significantly. Due to the deliberate retail mix, the goods delivered to the retail shops have very different characteristics, so developing a *k-means* clustering mechanism can help to effectively consolidate smaller delivery loads based on delivery service characteristics such as volume, timing, and type of goods to reduce the number of trucks going into the precinct. This should then minimize the within-cluster travel time.

Notwithstanding the above, the lack of space, especially around JG, can make it challenging to find a desirable location as a temporary consolidation point to consolidate the orders. Also, creating a separate central consolidation infrastructure and keeping inventory is not cost effective, given the premium on space. To overcome the above problems, we propose an **Urban Information Consolidation Center (UICC)** that consolidates and mines information instead of the physical items as illustrated in Fig. 5. The UICC concept may also consolidate the LTL deliveries to the mall, using a time-triggered algorithm. As a strategy to encourage information sharing from all stakeholders, a **Performance-Based Contract (PBC)** will be applied from economic welfare and incentive theory to combine the stakeholder's social objectives (e.g. reduce the noise pollution in JG and increase the quality of life for residents) and the retail players' commercial goals (e.g. distribution cost reduction and on-time delivery) in a centralized framework.

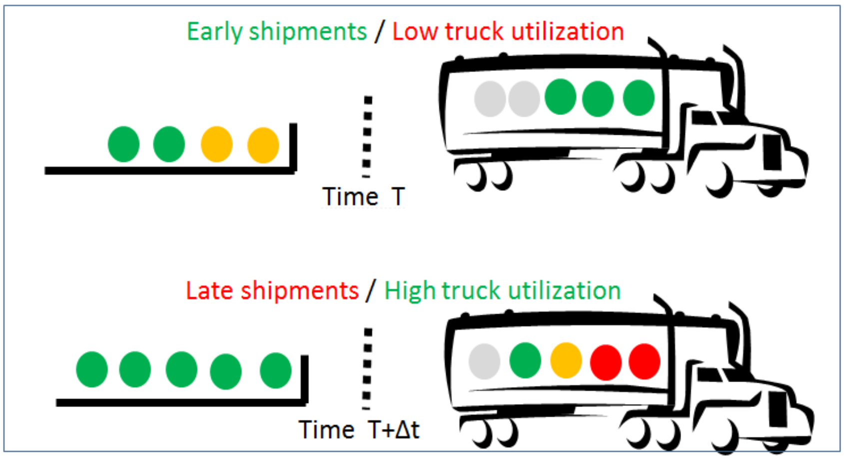

Fig. 6: Uncertain departure time affects truck utilization and delivery success

The UICC receives the retail shop's demand data, including point of sale, order quantity, pick-up and delivery location. The UICC then evaluates the demand data considering the mall and shop orders (e.g. loading dock size), optimal delivery route using a Vehicle Routing Problem (VRP) based schedule, anticipated traffic information and other capacity constraints (e.g. truck availability) to determine the best possible joint-distribution, and assigns the tasks to the nearest available delivery service provider.

To balance efficiency and time windows, we develop analytic models to determine the latest possible time to send delivery trucks.

To optimize the truckload and the number of trucks needed for the trip deliveries, we determine the latest possible time to send each delivery using a **postponement strategy of truck departures** by temporarily holding the incoming orders for a specific duration. Using such a strategy ensures that more demands (belonging to the same customer cluster) can be combined in the same truck to improve the truckload efficiency, lessen mileage, and decrease the excessive use of vehicles. However, deliveries may not be completed within the required time windows. To balance efficiency and time windows, we develop analytic models to determine **the latest possible time** to send the delivery trucks by investigating the risk associated with late deliveries and its impact on operating costs and delays in deliveries as illustrated in Fig. 6.

Results and Impacts

To investigate the performance of our proposed solutions, we generated a set of demand and traffic data (truck arrival times) based on the distribution in Fig. 7. The distribution is derived from: 1) our observation of the traffic entering/leaving the JG precinct during weekdays (see Fig. 8) which is crowded during certain times in the morning and afternoon; and 2) our semi-structured interviews with the mall and delivery truck workers.

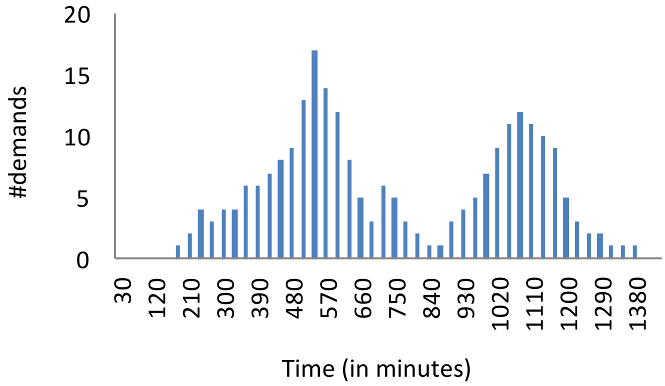

Fig. 7: Demand distribution of the generated data

(Taken from http://www.onemotoring.com.sg)

Fig. 8: Traffic camera views from AYE to Tuas

1. In-Mall Optimization Results

Under in-mall optimization, we first investigate the impact of the **consolidated in-mall delivery** on the congestion level and the number of workers as shown in Fig. 9. In a typical goods distribution in a mall (non-consolidated scenario), each truck / store requires an additional helper to pick the delivery orders from the unloading bay and deliver them to the retail store. In Fig. 9, the blue data points show the congestion for the non-consolidated system. When there is no consolidation, the number of required workers on each floor must be at least five to avoid loading bay congestion. When shop orders are consolidated using a consolidated in-mall delivery solution, loading bay congestion could be avoided by employing fewer workers (in our example, four instead of five), which points to a potential saving on

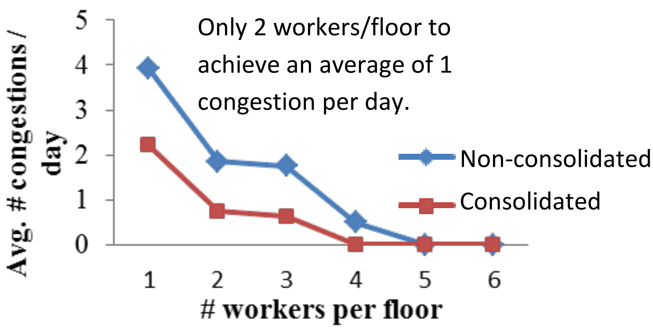

Fig. 9: Consolidation results in less workforce required and reduced congestion

manpower. We have a similar result for the number of trucks in the queue and bay usage efficiency, which validates the efficiency improvement of a consolidated in-mall delivery.

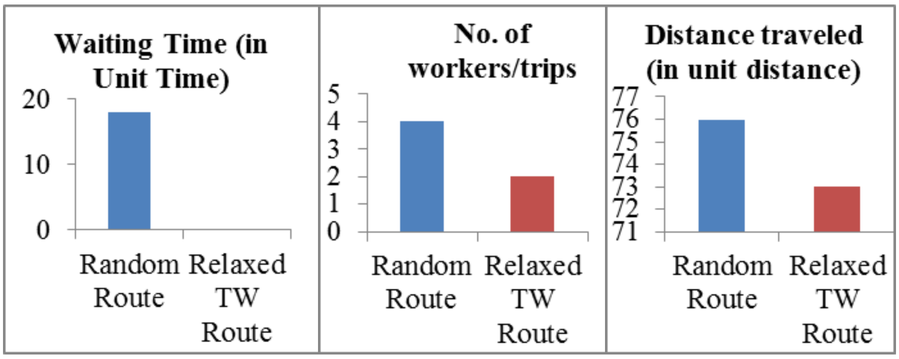

Fig. 10: Comparisons of delivery routes

Using the minimum number of workers with no congestion from the above result, we then investigate the impact of an **optimal delivery route using the capacitated TSP with relaxed time windows**. We assume that each floor has one worker to handle the goods which are to be delivered to six retail stores located in the same cluster on the floor. The TSP with capacity constraint and two different time window settings are performed using the exact-based column generation algorithm to provide the optimum routing and scheduling solution. Along with the assumed distance matrix and customer time windows, the comparisons of a random route and optimal delivery route using a capacitated TSP with relaxed time windows (TW) are shown in Fig. 10. Clearly, our proposed solution yields a reduction in total waiting time, number of workers/trips and total distance travelled by a worker, which is very important in practice to increase the loading/unloading bay efficiency.

Based on the loading/unloading bay efficiency result, we then investigate the balance between congestion pricing and loading/unloading bay efficiency by constructing our **model using a system dynamics methodology** with several parameters as summarized in Table 1.

Table 1: Input for parameters

Parameter	Range	Description
Desired workforce	10-100	Number of workers required for loading / unloading activity
Idle time	15-60 min	Time between two subsequent deployments of manpower
Avg. holding time	15-60 min	Time required to hold the workers for the loading and unloading operations
Usage charges	$ 0.50-$1.50	Amount or parking fee paid by the users of the loading bay

Table 2. Policy investigation in loading bay operations

Parameters	Chaotic	Non-chaotic
Desired workforce	10	30
Idle time	30	20
Avg. holding time	5	15
Usage charges	0.75	1.25

Using the above input ranges for the system dynamics model developed, two policies are analyzed to appreciate the impact of the policy parameters on the queue length under chaotic and non-chaotic situations (see Table 2). A chaotic situation refers to the case when the queue is unacceptable, while a non-chaotic situation refers to an acceptable queue length occurrence.

Fig. 11 presents the results of the system dynamics simulation. The desired non-chaotic situation is achieved through adjusting policy based parameters without assigning any weights on a particular factor. In reality, the mall operators can define the weights and values of the parameters based on their perception about the acceptable range of values of the parameters. Doing so can successfully strengthen operational decision making using reliable analytics.

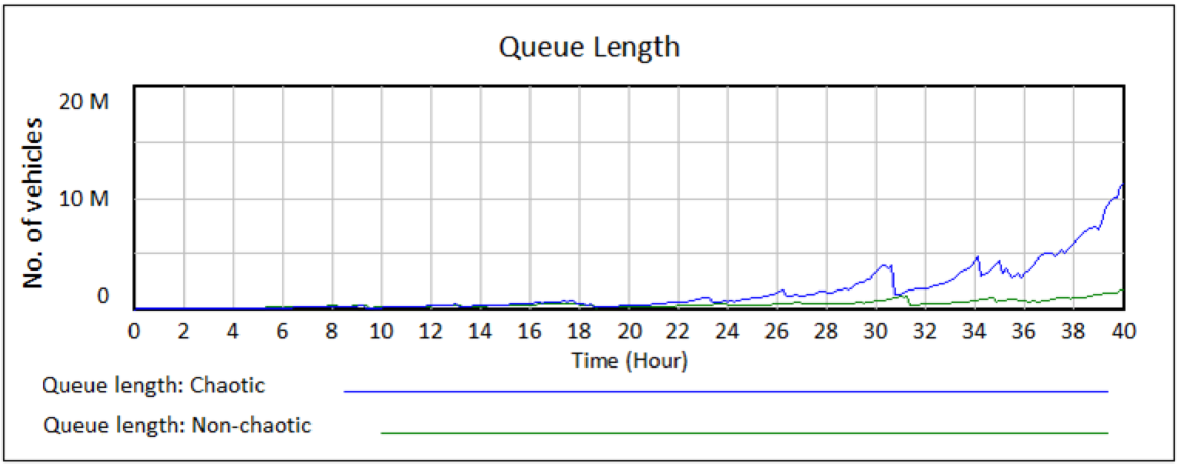

Fig. 11: Simulation results of the loading bay

2. Precinct Consolidation Results

Under precinct consolidation, a simulation model has been developed with the purpose of evaluating the UICC. The scenario of the simulation is as follows. The UICC receives random orders and clusters them based on their pick-up points (e.g. West, East). Each order may include different quantities. Then a separate module is used to specify the quantity of each order. The orders are held in the consolidation center until receiving one of the following signals:

1. Number of orders in the consolidation center reaches truckload capacity.
2. The waiting time of the orders in the center exceeds the maximum acceptable delivery delay.

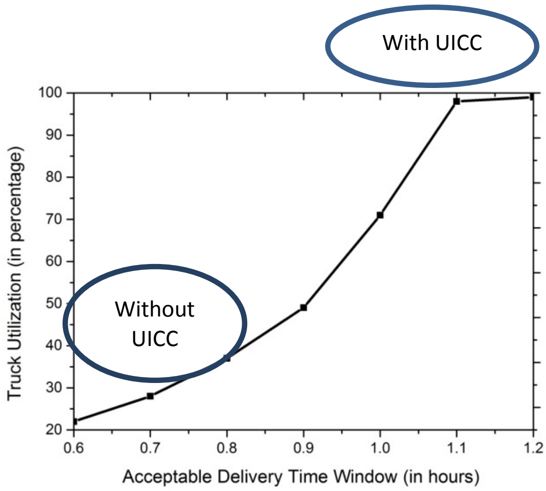

Fig. 12. Increasing truck utilization under UICC

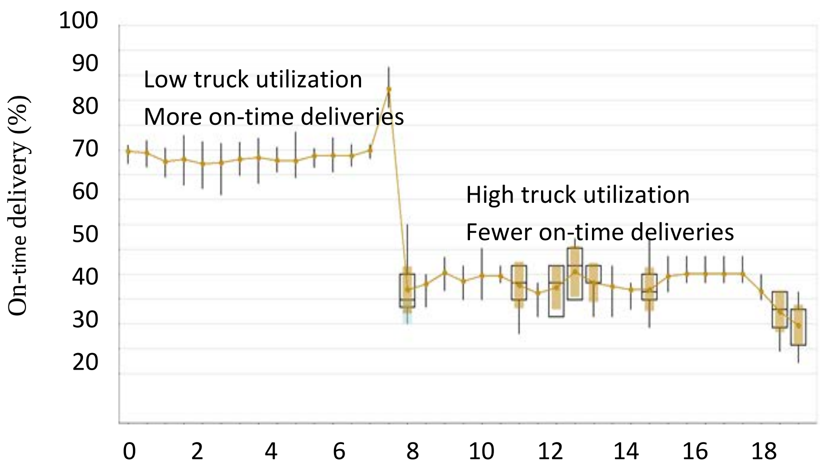

Fig. 13: Postponement strategy impact on delivery performance (in hours)

The comparison result between the scenario without and with a UICC supplemented by a PBC is shown in Fig. 12. Truck utilization denotes the percentage of a truck's capacity that is filled with product. Freight vehicle capacity in JG is highly under-utilized and that presents an opportunity for companies to reduce unnecessary traffic congestion and their carbon footprint through using the UICC. As shown in Fig. 12, accepting a longer delivery time window increases truck utilization and reduces vehicular traffic.

To maintain all orders to be delivered according to the retail shops' preferred time windows, a postponement strategy is needed. We test different postponement strategies for a fixed number of trucks and their capacities. In Fig. 13, the horizontal axis represents different departure times (between 0 and the deadline) used in the simulation model and the vertical axes show the average percentage of on-time-deliveries, respectively.

The simulation model using Simio suggests that postponing the delivery as late as possible to achieve a 100 percent truck utilization will diminish the benefit as orders are delayed longer (e.g. postponing more than 8.5 hours only improves on-time-delivery by 5 percent).

The on-time-deliveries percentage significantly drops when the UICC waits for more than 7.5 hours to consolidate orders after their arrival. The optimal postponement strategy can improve the degree of on-time-deliveries by at least 40 percent and at the same time improve truck utilization. We are also able to determine the minimum number of vehicles required to maintain desired service levels and maximize truck utilization. We plan to extend our existing models to capture other situations such as multiple UCCs with a centrally controlled UICC in which the vehicle routes can be adjusted to match the delivery times under some required time windows.

The optimal postponement strategy can improve the degree of on-time-deliveries by at least 40 percent and at the same time improve truck utilization.

3. Impact on Stakeholders

We have shown using generated data that our proposed solutions can improve the efficiency of logistics activities based on JG's characteristics. Our solutions offer cutting edge methods to reduce the congestion, better use of manpower and assets, and improve workforce productivity in preparation of the future development of the JG precinct for better liveability.

These solutions have different consequences for different stakeholders, both in the roles expected from them and in the effects these will have on their operational performance. Fig. 14 summarizes the impacts on the stakeholders.

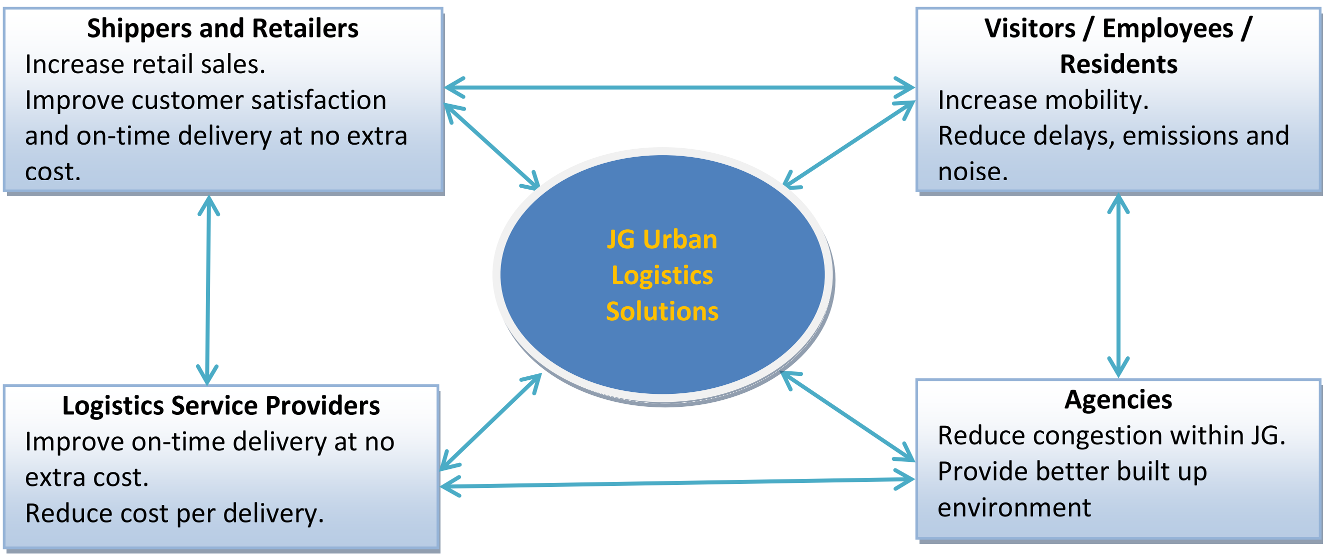

Fig. 14: Impact on stakeholders

Next Steps

JG is already experiencing the negative effects of uncoordinated and inefficient urban logistics operations, and it will suffer more of such consequences with the upcoming expansion of urban functions in the densely built precinct. Our preliminary research shows the potential for a mix of urban logistics solution for in-mall optimization and precinct consolidation.

Moving forward, we, together with our research partners, aim to develop a deeper understanding of the practical urban logistics problems in JG by involving the key stakeholders in the JG precinct through focus group discussions, validation, and industry research collaboration. We will seek to validate our solutions using actual data from the various stakeholders, which includes, but not exclusively, data on **parking charges, parking congestion periods, retail traffic flows in the malls, demand at the retail stores, loading bay operations, workforce engaged in the mall, truck volumes delivered to the malls, and current service contracts.** We invite the JG stakeholders to join us in helping to decongest the JG last mile urban logistics network, so that the expansion of operations can allow the precinct and the entire JLD to flourish as the Jewel of the West as it is intended to be.

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