On the evaluation of autonomous delivery robots in the food industry

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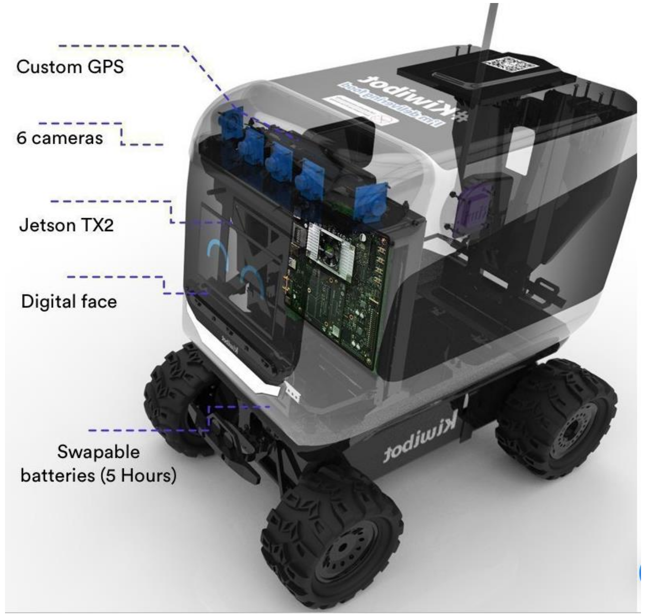
First of all: Why should we evaluate the operation of ADRs?

Answer: *To better understand the capabilities, benefits, and unintended consequences of these systems as an alternative to mitigate the externalities of freight transportation*

Background:

- ADRs are an environmentally-friendly alternative since they do not produce tail-pipe emissions. They are considered as a replacement for ICE vans in the delivery of parcels
- ADRs have proven to be a cost-efficient alternative to transport cargo in indoors environments.
- In theory, new technological developments have made ADRs a versatile and cost-efficient alternative for outdoor last-mile deliveries.
- More than 60% of merchants' customers live within 3 miles of the store location. (FedEx research).
- Traffic incidents involving ADRs have been more common in recent years.



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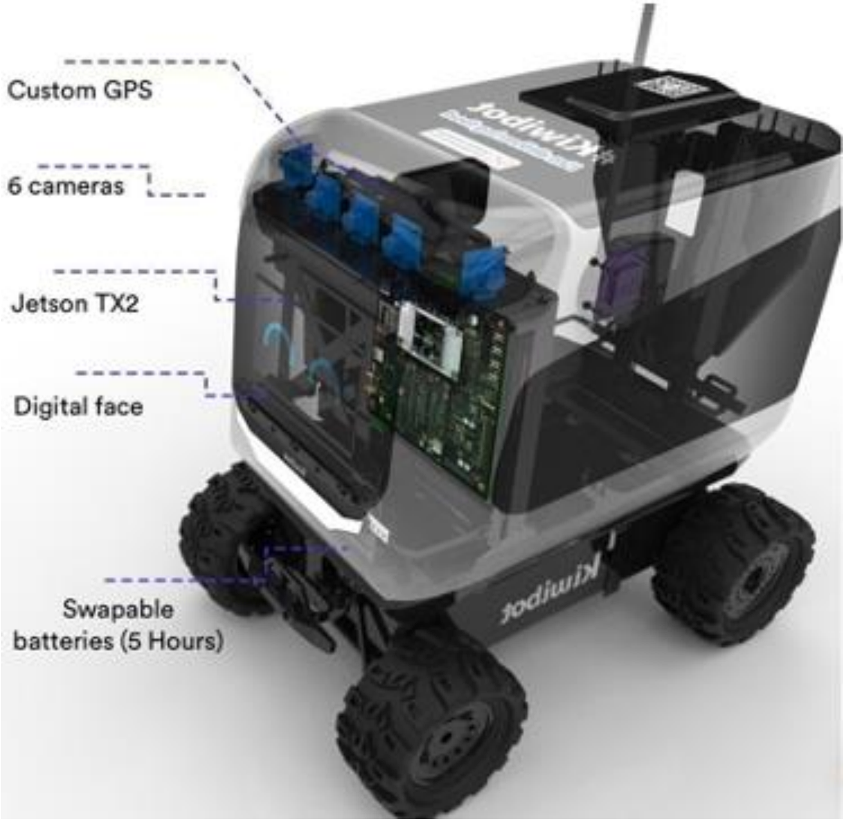
Our ADR: bot! by KiwiCampus



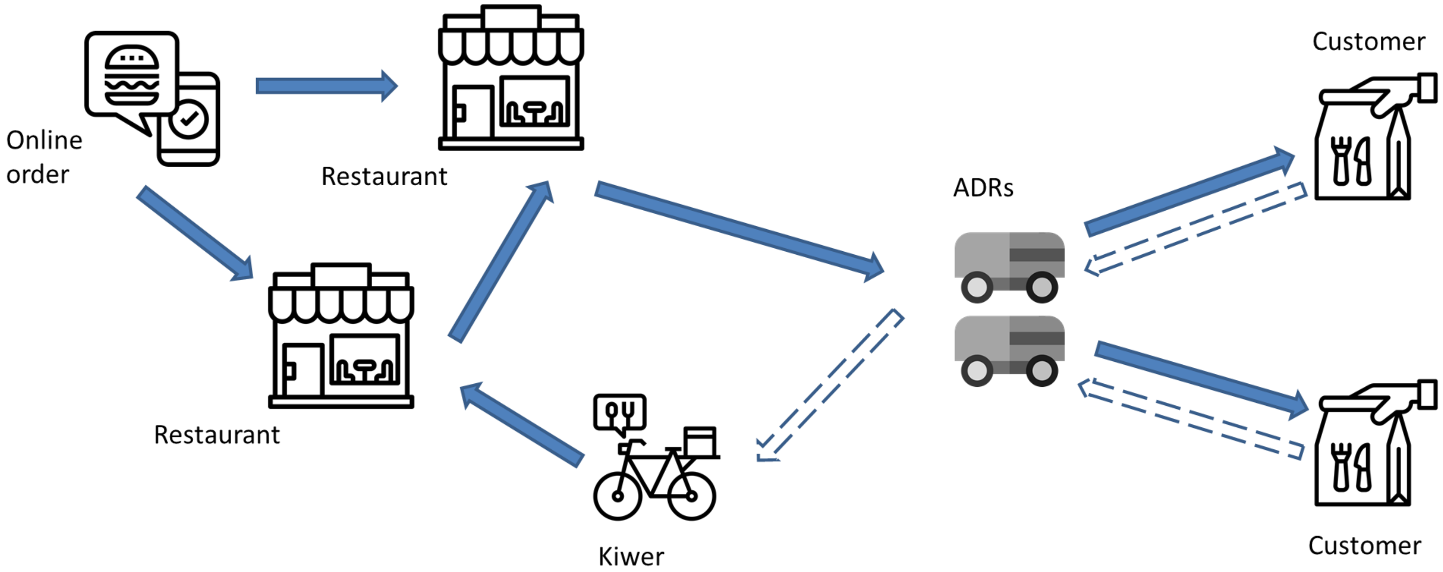
Bot 3.0 series features:

- Dual 4G LTE integrated GPS (communication system)
- 6 FOV 120° Cameras 1920*1080P: 3 frontals, 2 laterals, and 1 rear.
- 7 Benewakes (LIDAR): 5 frontals, 2 rear
- 1 AI computing module Jetson TX2
- Digital face: 9’’ LCD Screen
- Spot-lights UV 200
- Swappable lithium-ion batteries
- Payload capacity: one order
- Top speed: 10 mph.
- Pneumatic cargo compartment with remote opening/closing function.

The hybrid delivery system: bicycle + ADR

System description:

1. Customers order online
2. Restaurants have agreements with operator, facilitating the logistic process
3. Kiwers (biker) pick-up orders from restaurants
4. ADRs wait in strategic clusters to reduce the distance travelled
5. Kiwers load food to ADRs
6. ADRs deliver food to customers
7. ADRs & Kiwers reposition



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Methodology

1. Field observation: descriptive analysis
2. Operation data analysis
3. Simulation and sensitivity analysis
4. Design of strategies to improve the system

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Safety, mobility, and potential road conflicts

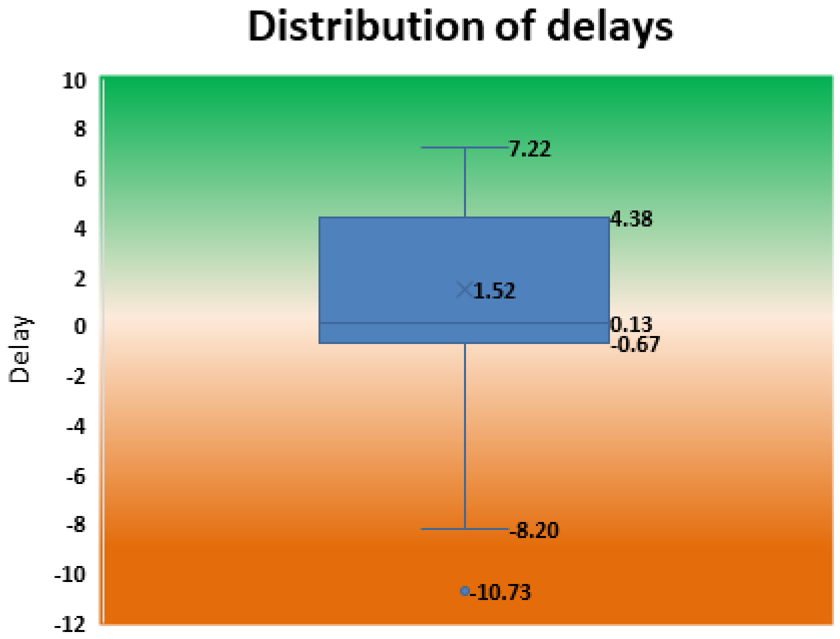
Safe sidewalk operation and crossing intersections; a big challenge

***Relevant factors**:*

- Technological limitations,
  e.g., limited object recognition
- High network latency,
  i.e., delays in data reception
- Long reaction time by supervisors
- People's curiosity
- Required human intervention,
  i.e., offline devices, stuck wheels
- Sidewalk topology and geometry
- Traffic conditions

Analysis of intersection delays

Pole Line and 5th Street: A complex intersection



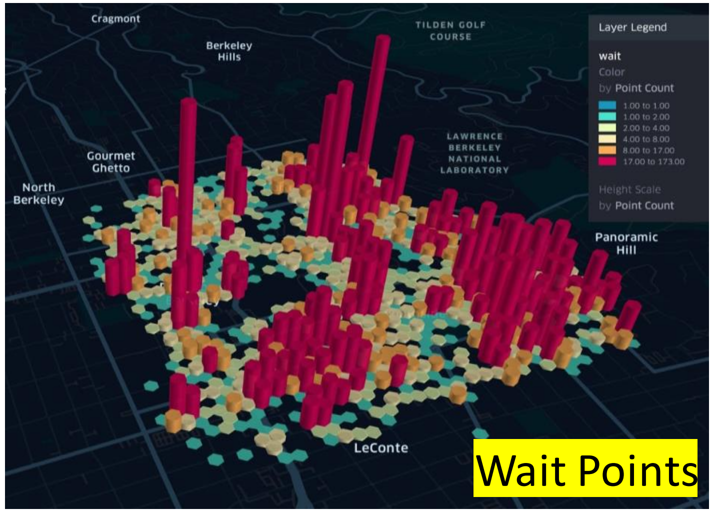
- There were delays in 43% of the trials
- 10% of the delays range between 5 and 10.7 seconds
- 43% of the delays range between 1 and 5 seconds
- 47% of the delays range between 0 and 1 seconds

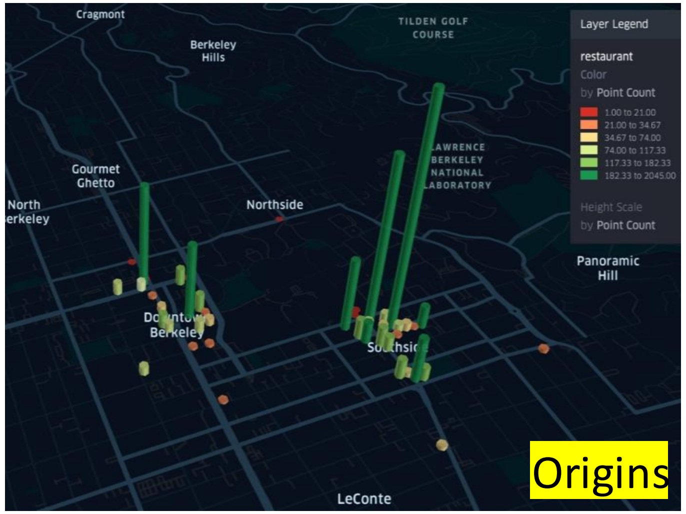
Operation data analysis

Semi-autonomous food delivery

How can we deliver on-time using kiwers and bots?

- Distribution network design
- Bikers schedule and bots' fleet size
- Resource allocation to time-slots
- Queuing & repositioning
- Automation limitations





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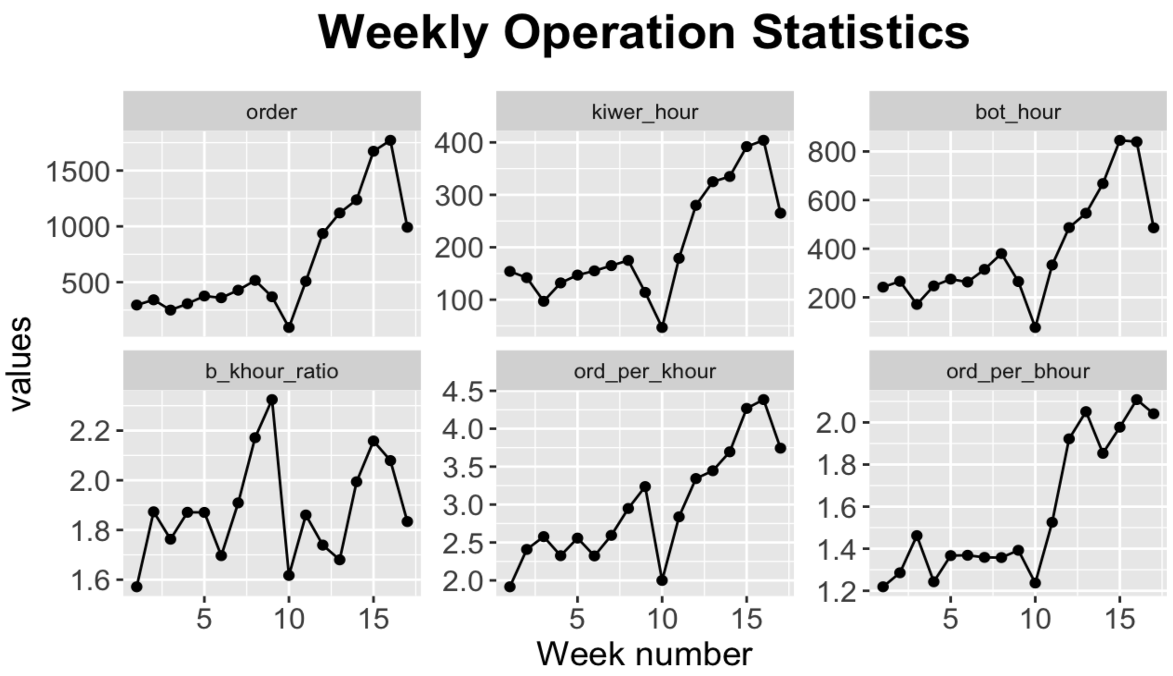
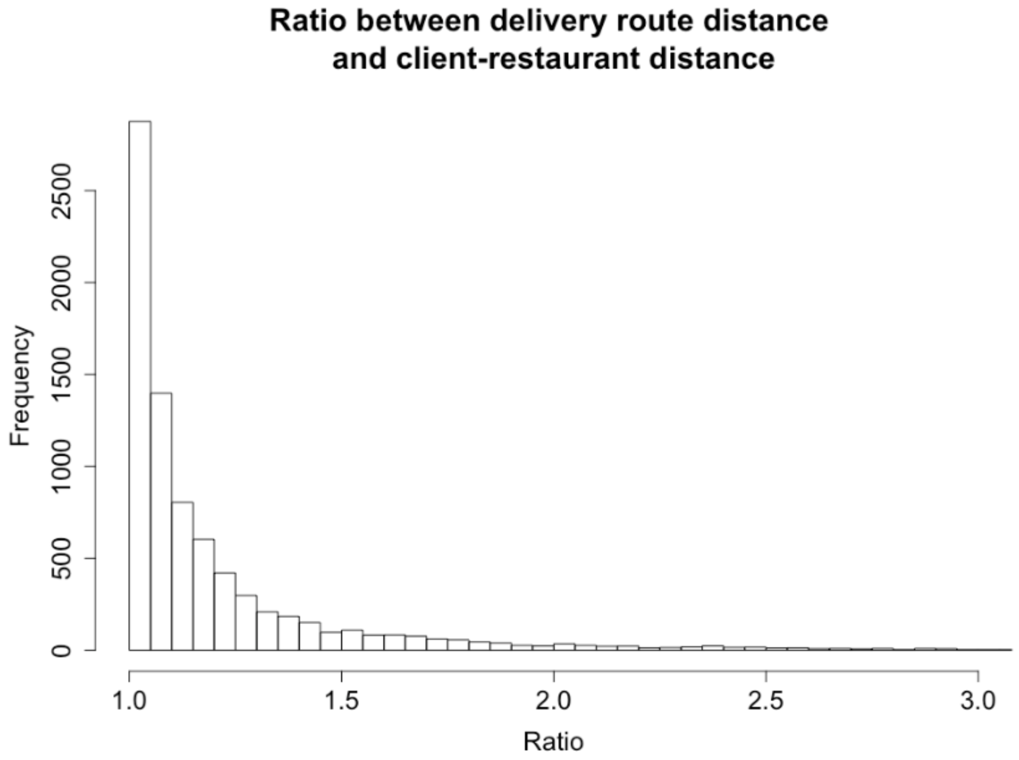
Data analysis





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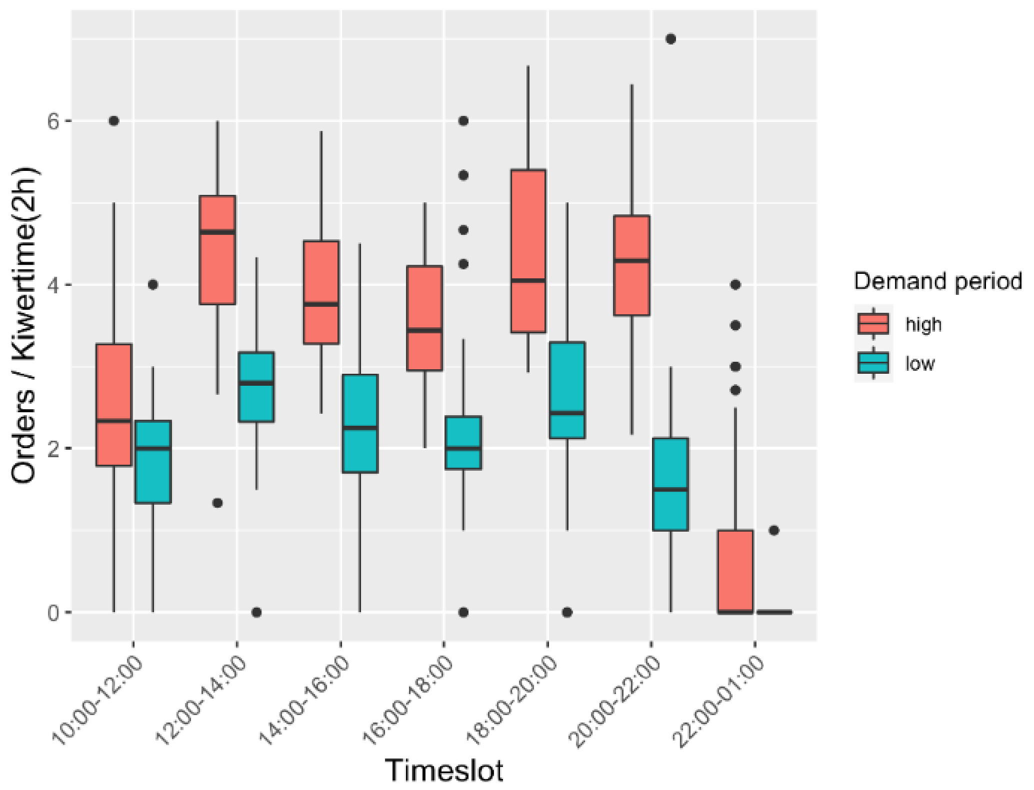
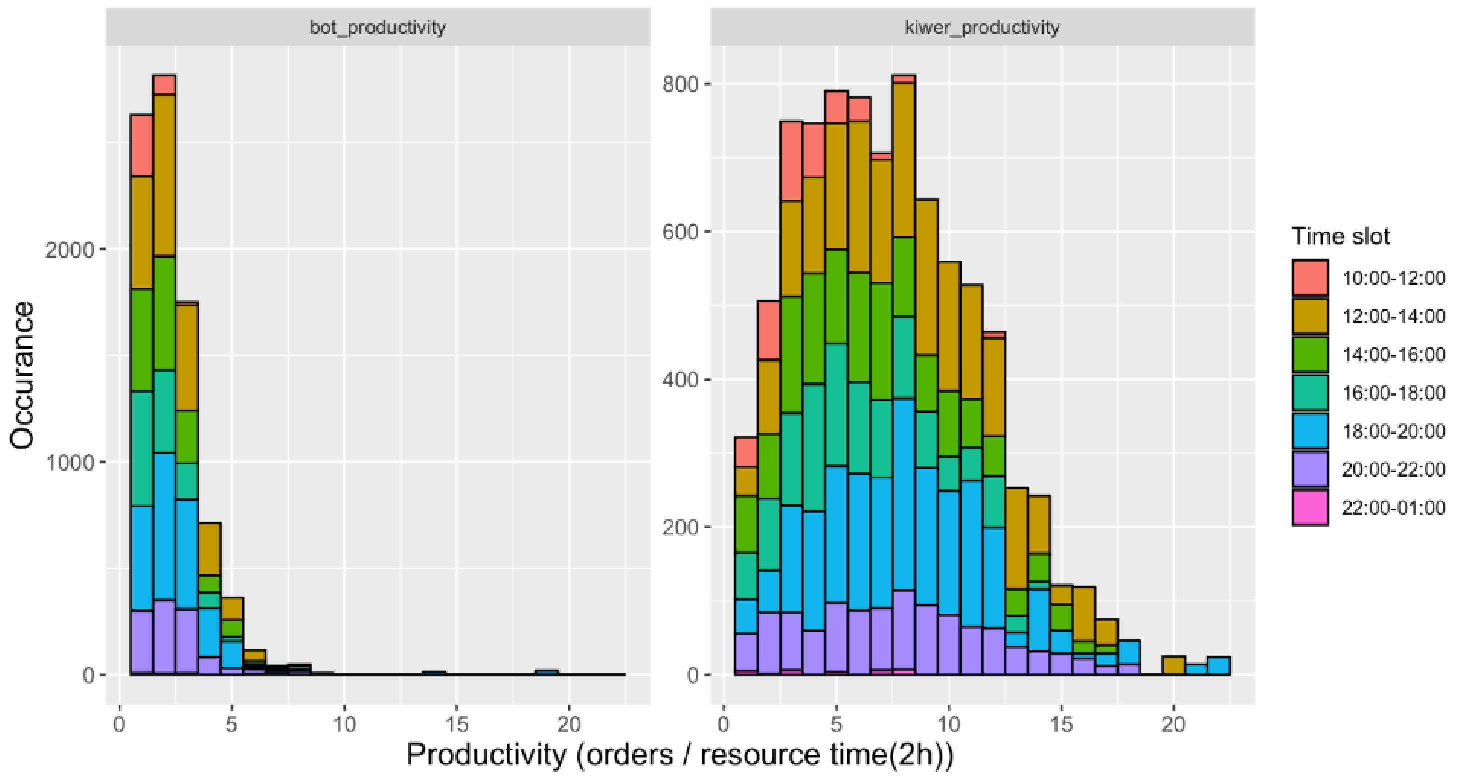
Data analysis





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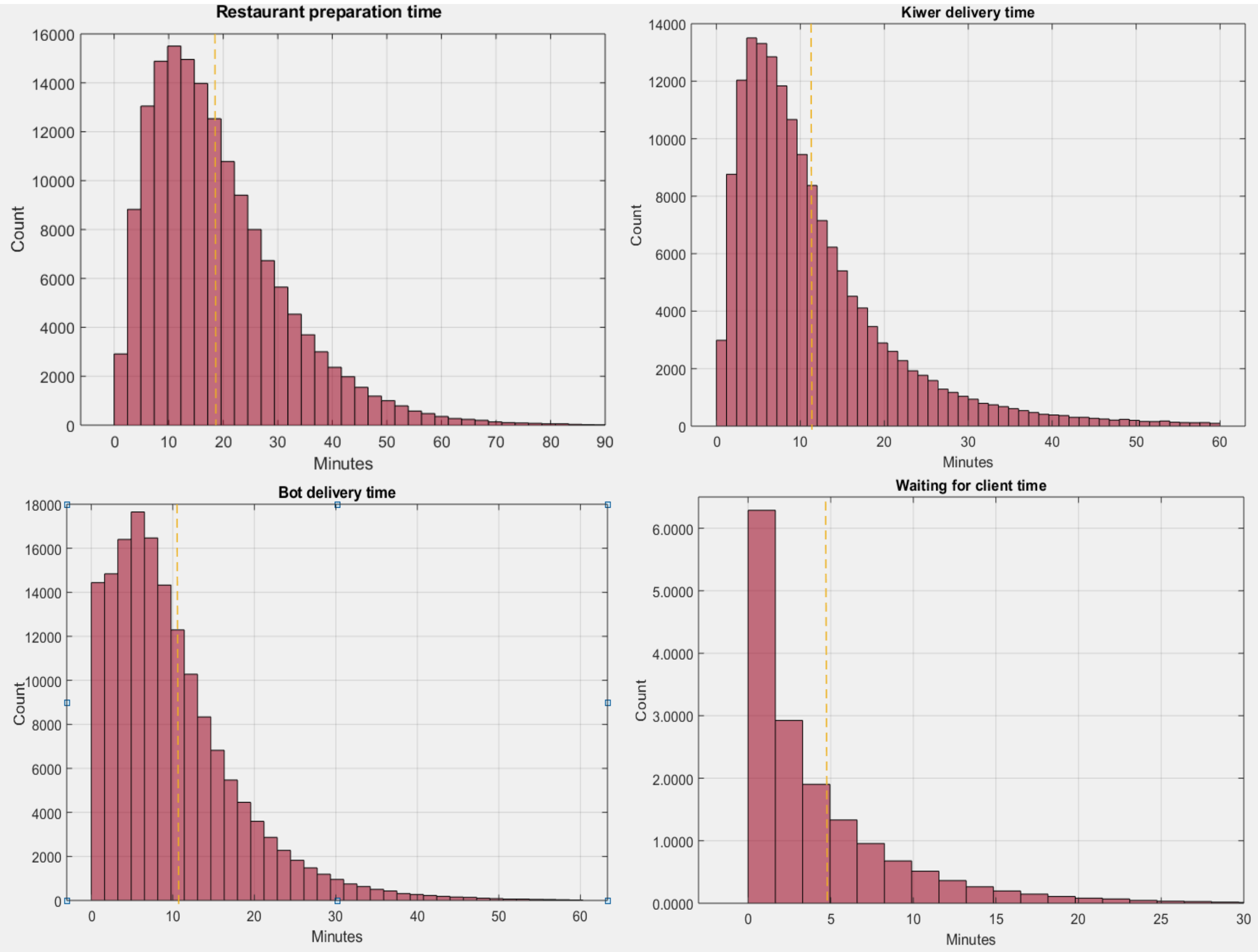
Semi-autonomous food delivery

- Raw data: ~ 16,000 orders
- Total delivery
  - Avg. time ~45 mins
- Restaurant preparation
  - Avg. time ~19 mins (42%)
  - From when an order is placed in the app until the kiwer receives the order
- Kiwer delivery
  - Avg. time ~11 mins (24%)
- ADR delivery
  - Avg. time ~10 mins (22%)
- ADR waiting for the client
  - Avg. time ~5 mins (11%)



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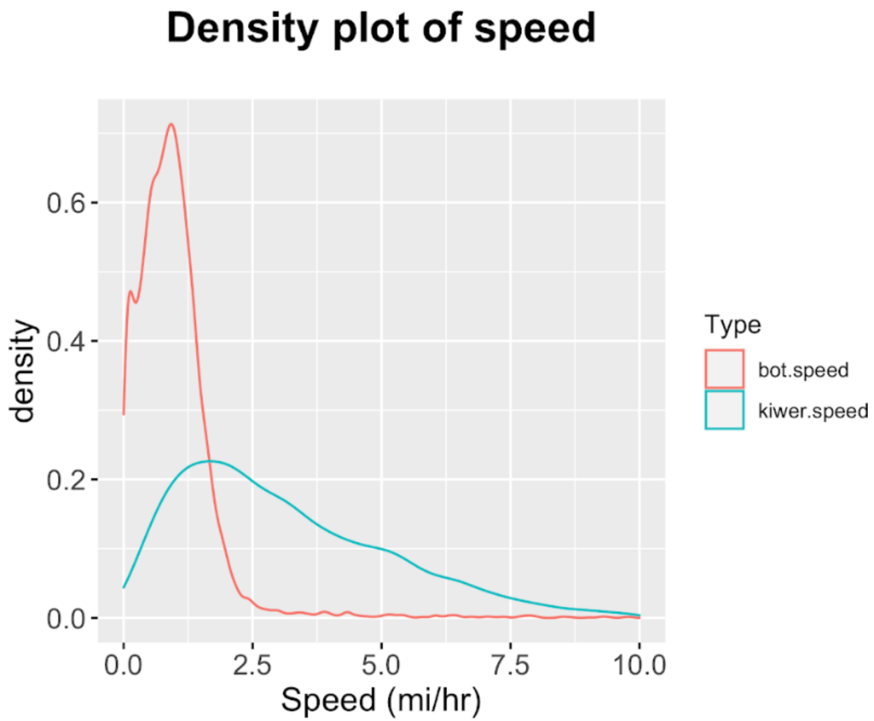
Scalability & Operations



- Delivery distance has an important effect on the system

- ADRs can travel faster but speeds are limited to avoid incidents and for better control

Simulation Model

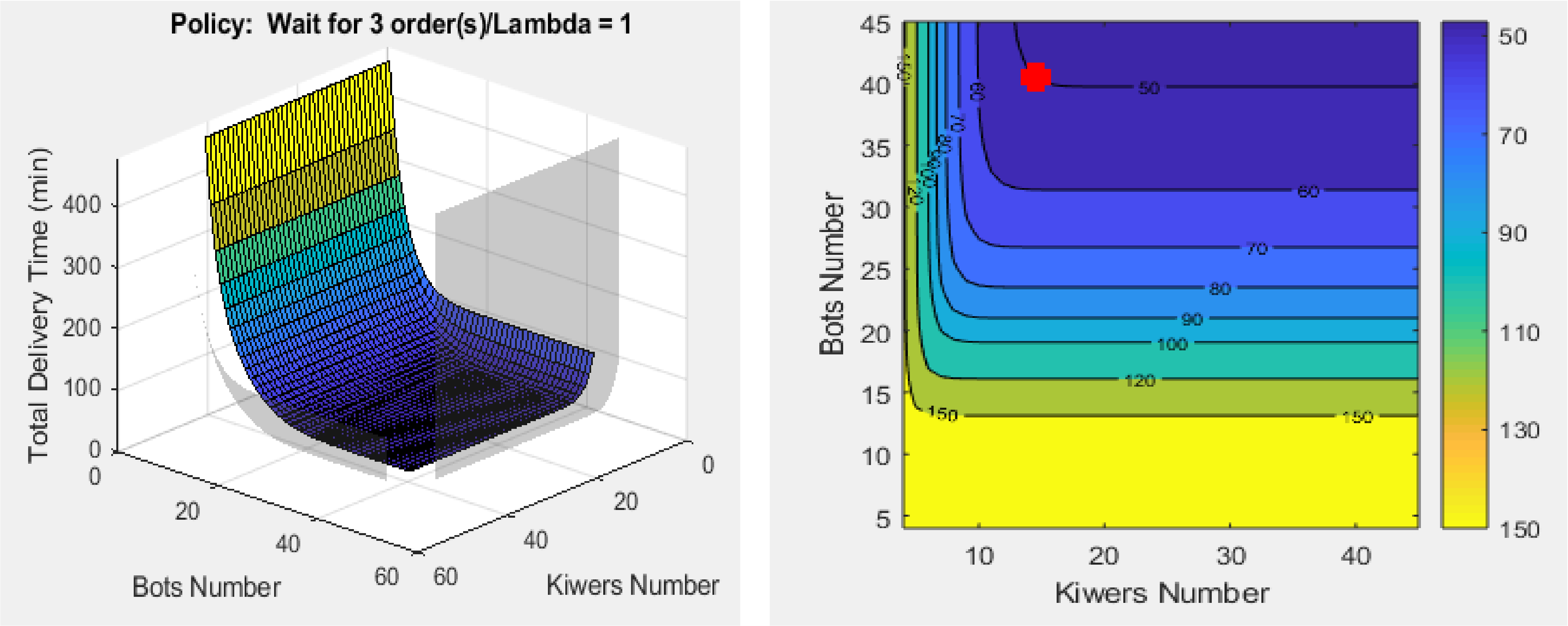
Results of Monte-Carlo Simulation

- Validation of simulation results for key parameters

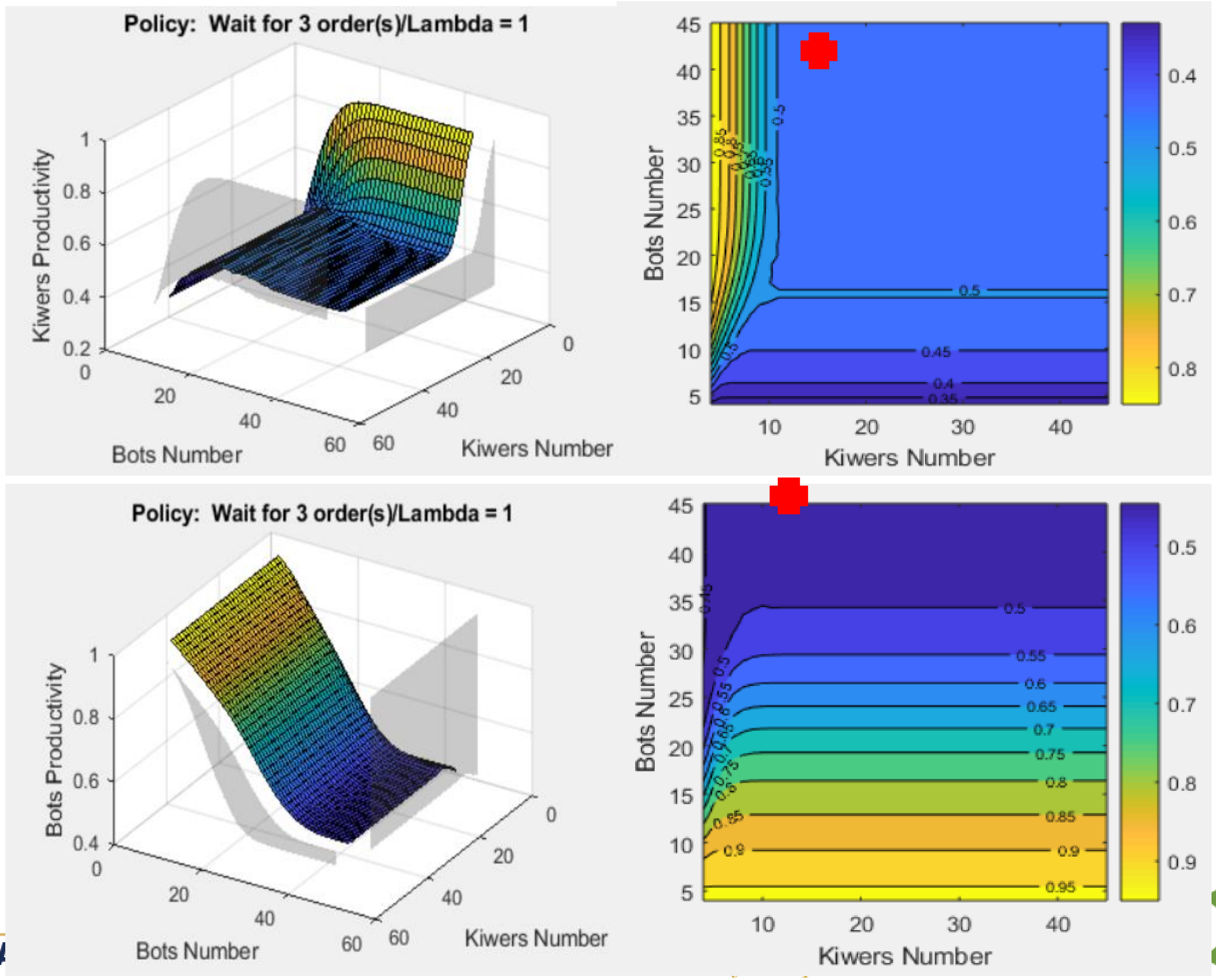
Variable	$\frac{1}{n}\sum x_n$	μ	Rel. Error	P-Value*	Dist. Fit	Parameters	Log-Likelihood
Avg Biker Speed	3.416	3.420	-0.132%	0.471	*Gamma*	K=2.352, θ=1.453	-6.686E+05
Avg Bot Speed	0.985	1.020	-3.431%	1.22E-08	*Triangular*	a=0.052, c=0.821, d=0.239	-6.146E+05
Avg Bot Proportion	0.306	0.307	-0.520%	NA	NA	NA	NA
Avg Bot Delivery Time	10.202	10.221	-0.188%	0.408	*Gamma*	K=1.514, θ=6.749	-1.048E+06
Avg Biker Delivery Time	10.815	10.807	0.077%	0.741	*Gamma*	K=1.501, θ=7.196	-1.066E+06
Avg Restaurant Prep. Time	19.142	19.079	0.329%	0.071	*Gamma*	K=2.338, θ=8.157	-1.210E+06
Avg Waiting for client Time	4.317	4.330	-0.300%	0.375	*Gamma*	K=0.700, θ=6.180	-7.728E+05
Avg Delivery Time	44.476	44.438	0.086%	0.446	*Gamma*	K=6.218, θ=7.146	-1.356E+06

** Z-test P-Value; k: Shape; ϑ: Scale; a=lower bound; c=mode; d=upper bound.*

Impact of demand levels on delivery times



Impact of demand levels on productivity



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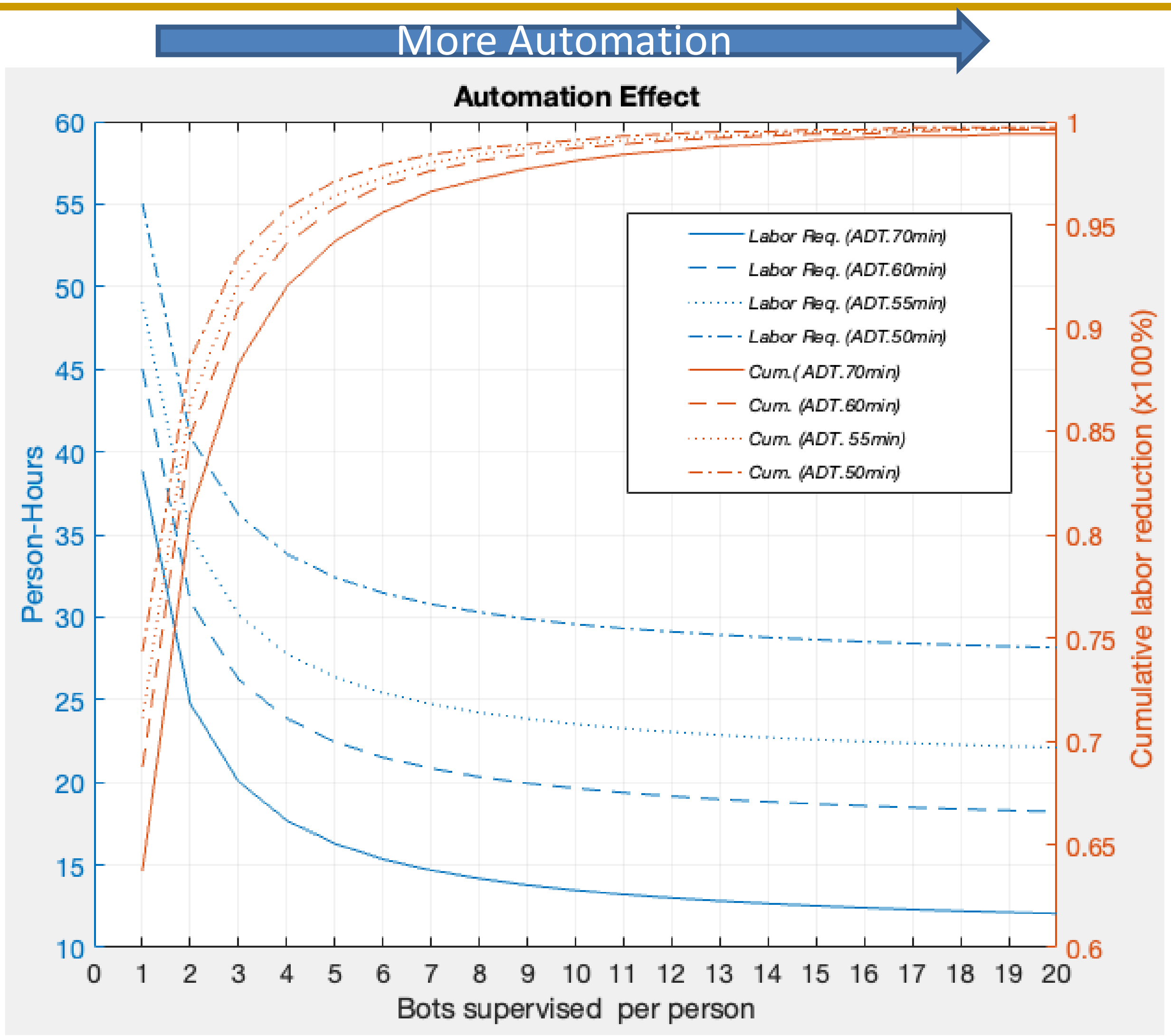
Impact of automation on the system performance

- Required Person-Hours includes labor of Kiwers (bikers) + supervisors
- Robots capable of making a greater number of correct decisions require a higher level of automation
- Supervisors must reason decisions in situations that are unknown to the ADRs.
- Full automation may not be cost-efficient; supervise more than 6 robots reduce less than 6% of labor



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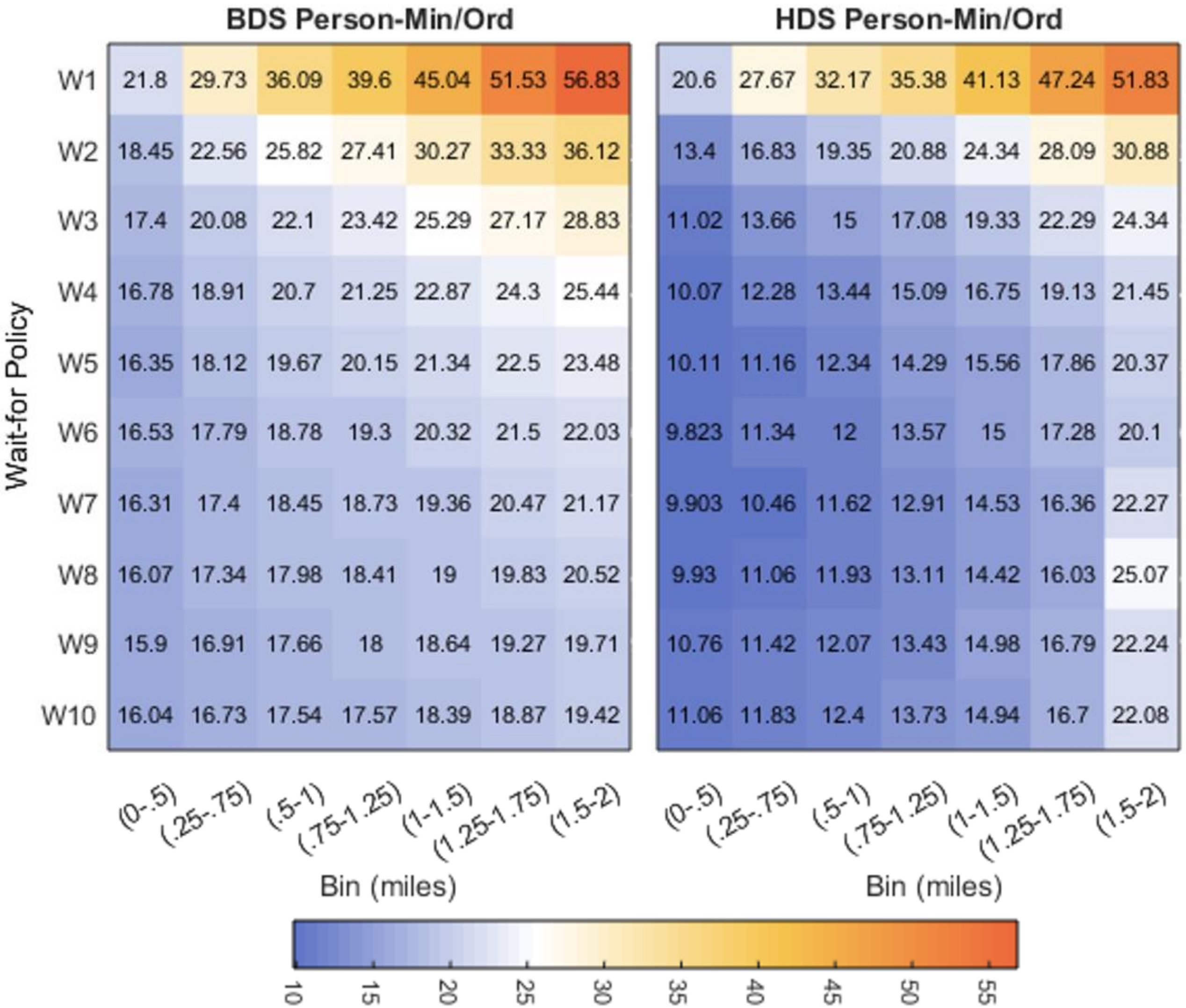
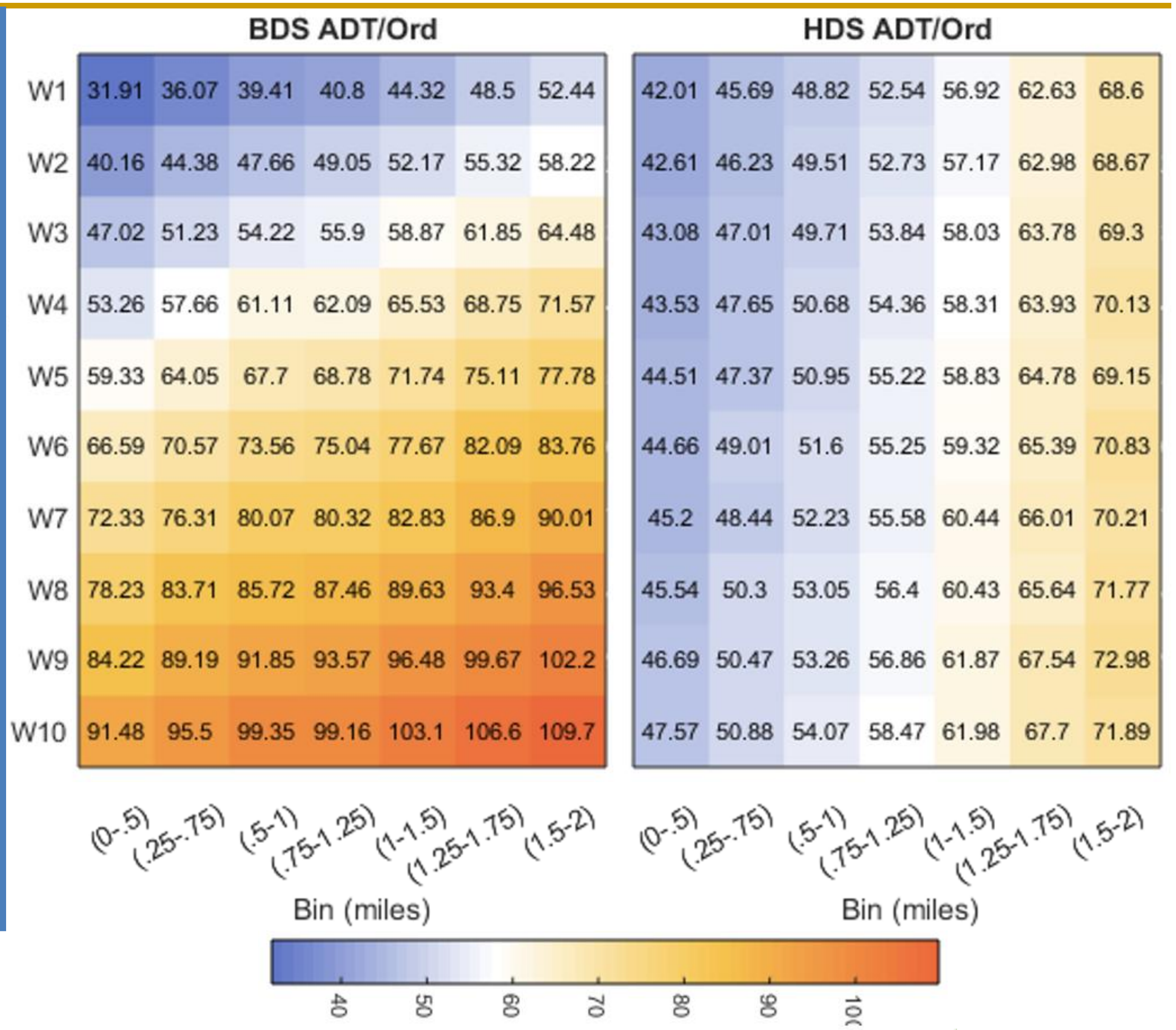
Strategies to improve the system: Dispatch policies

Decision support plots for different Wait-for policies





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Summary of Wait-for policies impacts on the HDS

	10% time/35% labor red.		*5% time/30% labor red.*		*Max. labor red.*		*Max. time red.*	
	ADT	Avg. Labor	ADT	Avg. Labor	ADT	Avg. Labor	ADT	Avg. Labor
Net Value	39.84	11.48	42.17	12.46	45.72	10.32	38.63	27.05
*% Change**	-10.33%	-36.04%	-5.09%	-30.58%	2.90%	-42.51%	-13.05%	50.70%

* Relative change with respect to the base case

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Summary of Findings

Findings: efficiencies/inefficiencies

- **Times:**
  - Restaurant preparation time + Client picking/collection time ~53 % of delivery time;
  - Delivery time ~45 minutes within 1.25 miles and 56.29 miles within 2 miles
  - When service time and labor requirements are equally valuated, the BDS is 5% faster than the HDS, but the latter requires 42% less labor
- **Market coverage:**
  - About a 1 – 1.5 mile radius (times are significantly larger after the 1.5 mile distance)
  - Spatial (dis) aggregation of demand affects resource requirements in 3-4x
  - Kiwers traveling ~2/3 of distances (about double the speed)
- **Human-hours of hybrid model:**
  - Fully ADRs vs. No automation of “DRs” can reduce human-hours requirements by 45-65%
  - Even in low to mid automation levels, remote supervision can bring significant reductions in costs

Any questions? Please contact:

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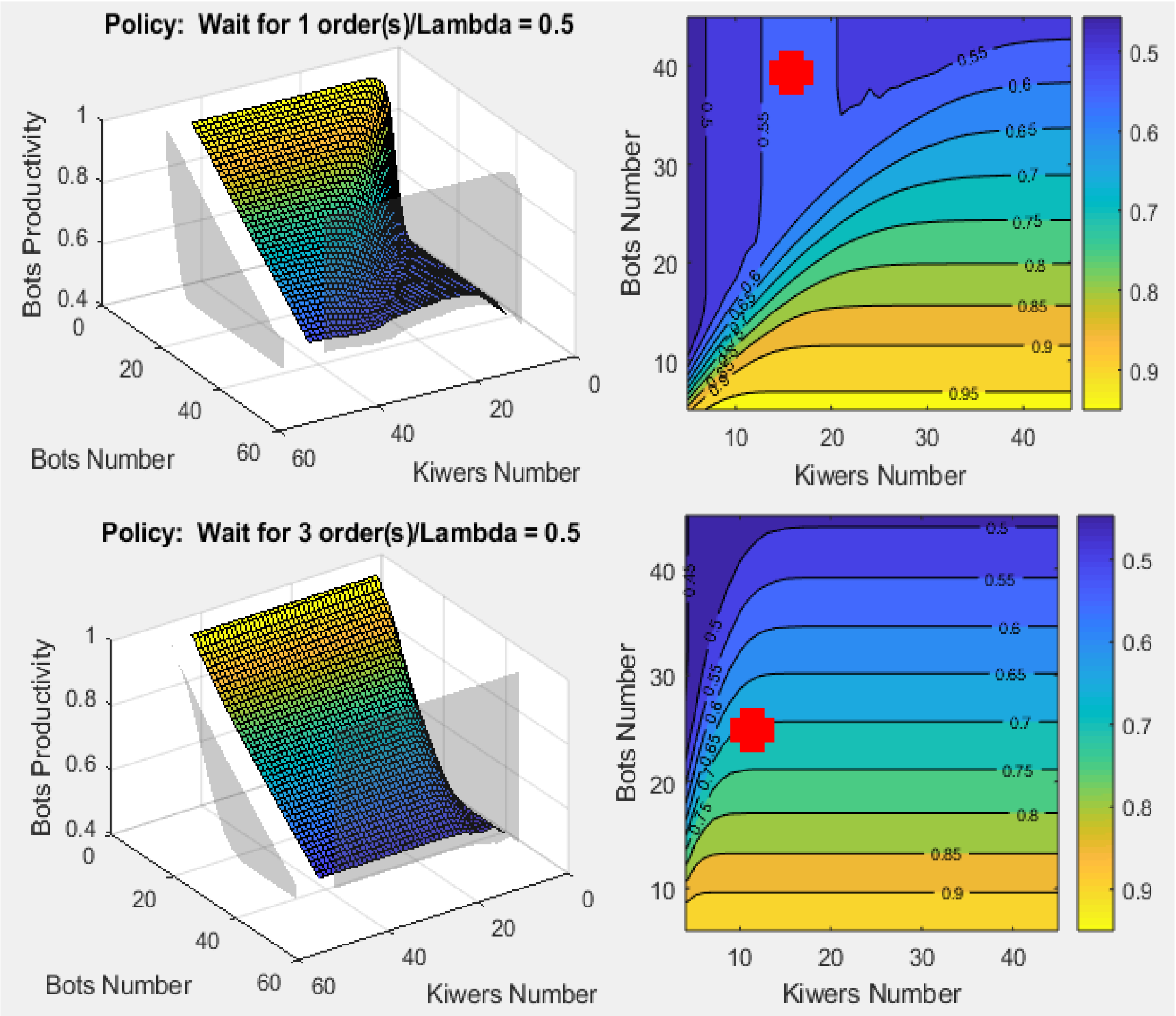
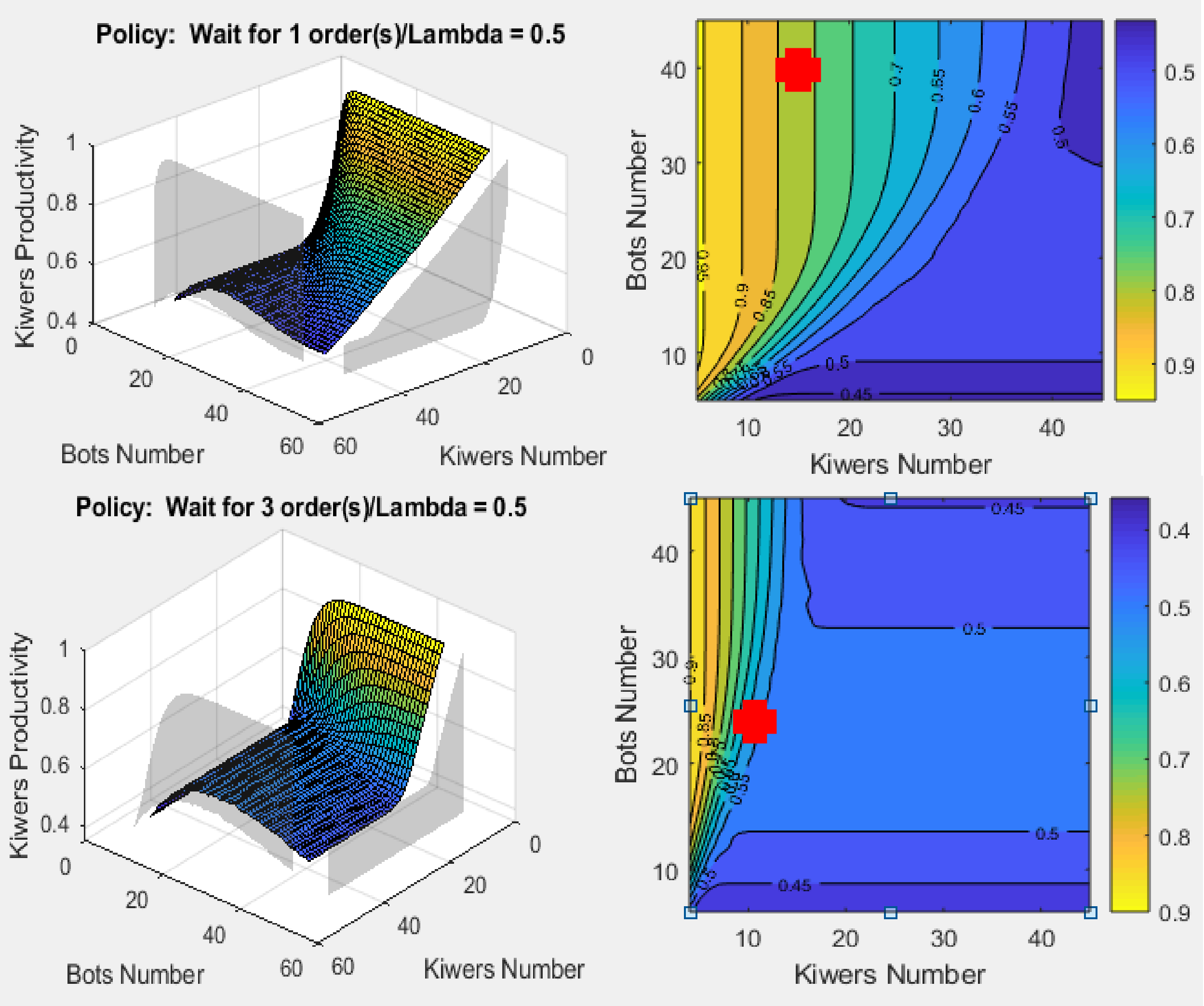
Impact of dispatching policy on productivity





Potential improvements

- Improvements:
  - Network design (multimodal, hubs)
  - Waiting/dispatch policies
  - Repositioning
  - Cluster evaluation (staging and transfer areas)
  - Decisions on Kiwer/ADR delivery split
- Impacts:
  - Potential traffic delays/conflicts with other curb users
  - Jobs
  - Requires transfer locations

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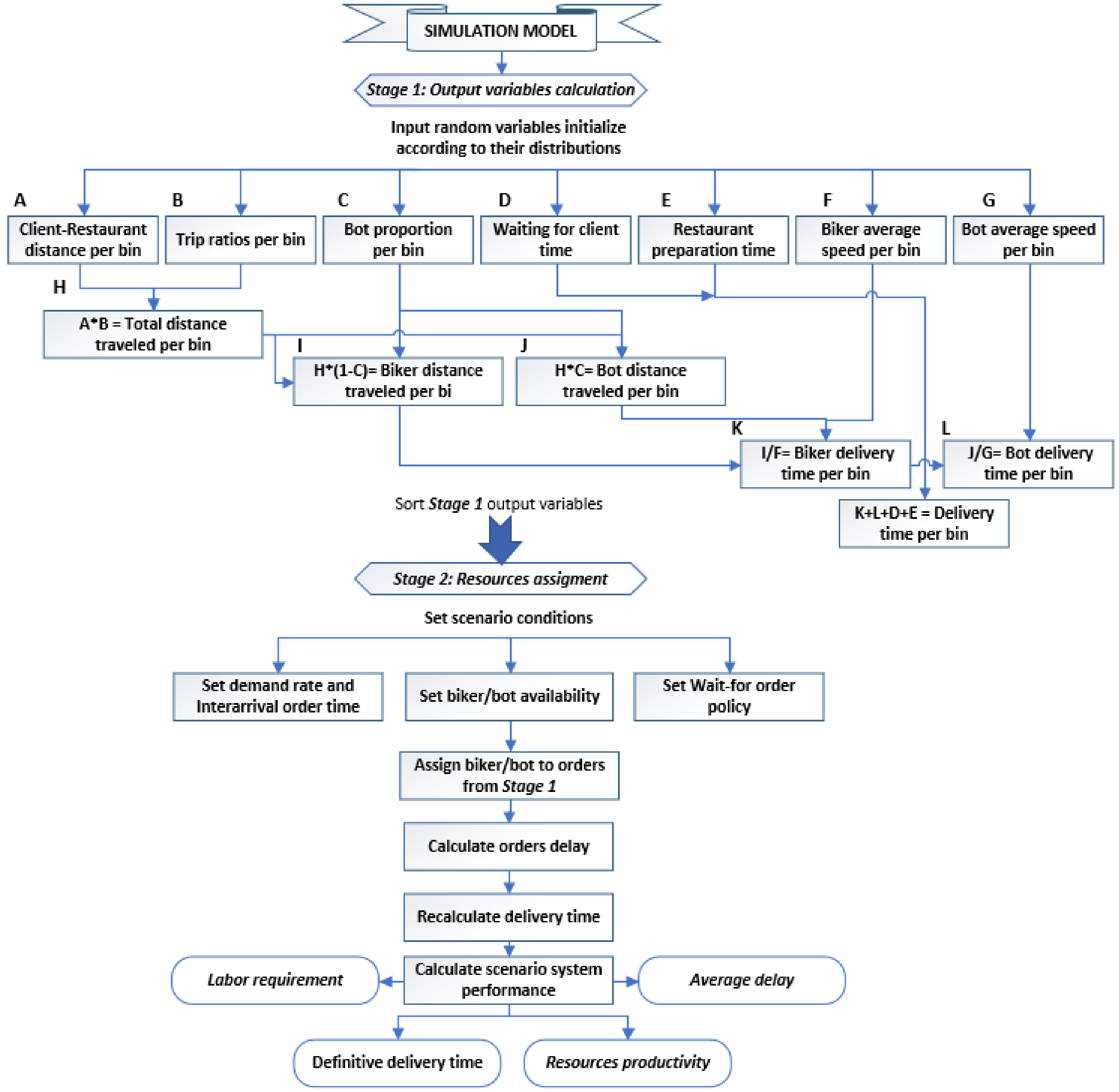
SIMULATION MODEL
Stage 1: Output variables calculation
Input random variables initialize according to their distributions
A
Client-Restaurant distance per bin
B
Trip ratios per bin
C
Bot proportion per bin
D
Waiting for client time
E
Restaurant preparation time
F
Biker average speed per bin
G
Bot average speed per bin
H
A*B = Total distance traveled per bin
I
H*(1-C)= Biker distance traveled per bi
J
H*C= Bot distance traveled per bin
K
I/F= Biker delivery time per bin
L
J/G= Bot delivery time per bin
K+L+D+E = Delivery time per bin
Sort Stage 1 output variables
Stage 2: Resources assigment
Set scenario conditions
Set demand rate and Interarrival order time
Set biker/bot availability
Set Wait-for order policy
Assign biker/bot to orders from Stage 1
Calculate orders delay
Recalculate delivery time
Calculate scenario system performance
Labor requirement
Average delay
Definitive delivery time
Resources productivity

Next Steps

Potential next steps

- Spatial and network modeling
- Multi-objective: Costs, labor, time, emissions, energy consumption, etc.
  – Time windows
  – Cluster locations
  – Backbone design (modes)
  – Dynamic demand/dispatching

- Efficient system deployment and operation methodology

- Traffic and sidewalk operation/policies
  – Intersection and sidewalk conflicts