日本航海学会
第131回講演会

Research on energy-saving performance analysis for cargo handling operation of Hybrid Straddle Carrier

ハイブリット型ストラドルキャリアのコンテナ荷役時の省エネ性能分析法に関する研究

正会員　篠田　岳思　（九州大学大学院）
学生会員　ハンガ　プトゥ　（九州大学大学院工学府)

国立大学法人 北海道大学, 平成26年10月31日

Background

- ✓ Kyoto Protocol 2005 – Reduce GHG Emission – Eco-Terminal – Pressure to container terminals to improve its facility for energy-saving
- ✓ Hybrid handling machineries is one of innovation expected to tackle the issue of reducing dependency to fossil fuel (In this case: Hybrid Straddle Carrier)

Problem Faced

- ✓ Implication of the effort by container terminals is hardly to seen
- ✓ Operational performance of hybrid container handling machineries need to be improved considering high investment cost
- ✓ Energy analysis is normally performed from the aggregate data for whole facility or region
- ✓ Lack of detail analysis to provide better input to Container Terminals
- ✓ Necessity to extract more useful information from operational data

Objective

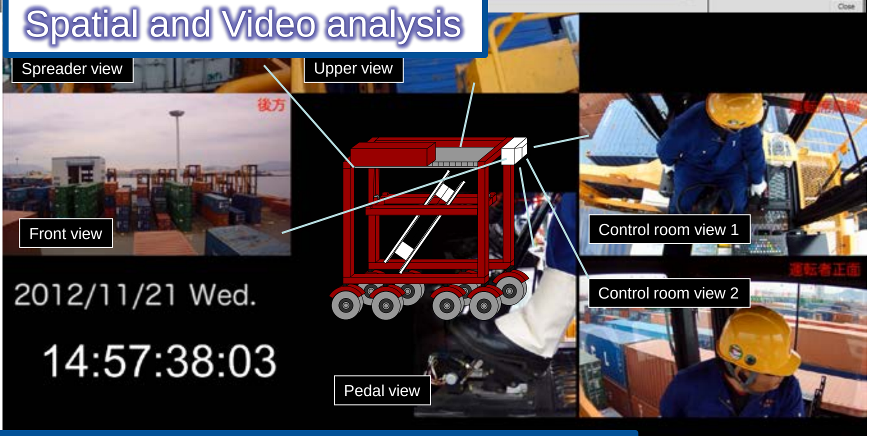
- ✓ Create visual energy analysis from operational database and model the operation of HSC to shows energy-saving impact of each kind of its operation.
- ✓ Improve the environmental footprint of Hybrid Straddle Carrier by efficient operation

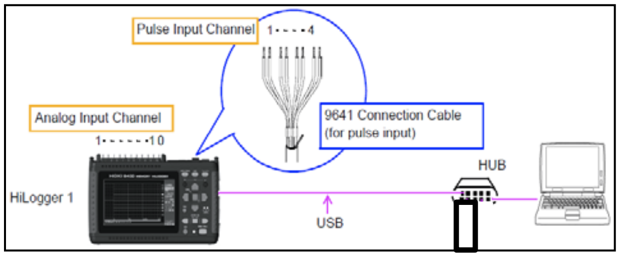
What have we done previously

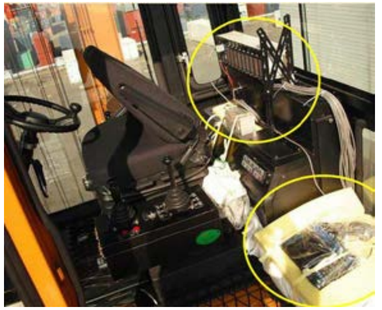
Performance measurement by data logging system

No.	Measurement item	Measuring Range	Output Voltage
1	Output current of battery	±500 A	±10 V
2	Output current of converter	±500 A	±10 V
3	Lifting motor speed	±2000 RPM	±10 V
4	Lifting motor torque	±200 %	±10 V
5	Traveling motor speed (L/R)	±4000 RPM	±10 V
6	Traveling motor torque L/R)	±300 %	±10 V
7	Throttle opening angle	0 - 100 %	0 - 10 V
8	Brake pedal angle	0 - 100 %	0 - 10 V
9	Hoist operating lever angle	0 - 100 %	0 - 10 V
10	Steering reverser direction	forward/reverse/neutral	10V/0V/5V
11	Engine speed	0 - 2000 RPM	0 - 10 V
12	Bus voltage (DC)	0 - 2000 V	0 - 10 V
13	State of Charge	0 - 100 %	0 - 10 V
14	Twist lock	lock/unlock/neutral	10V/0V/5V
15	Weight	0 - 40 Ton	0 - 10 V
16	Fuel Consumption	0 - 70 L/h	0 - 10 V

Spatial and Video analysis







Analytical Model for Energy analysis
-Motion analysis
-Operation work code

					Measurement by Logger				ACV (Converted) speed	battery (A)	fuel cons (L/h)	Weight (Ton)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-15.740	4.17	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-11.737	3.28	27
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- 6.964	1.70	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- 8.387	5.19	24
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- 4.777	1.73	0
6	14:52:40.0	14:52:46	00:06.4	32	23.35	-9.79	12.92	17	145.92	-15.292	2.83	21
7	14:54:07.6	14:54:14	00:06.4	32	32.93	-8.60	14.59		205.82	-13.438	3.19	0
8	14:55:25.8	14:55:41	00:15.0	75	[illegible]	[illegible]	[illegible]	[illegible]	238.12	- 8.251	4.63	28
9	14:56:28.6	14:56:35	00:06.8	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
10	14:57:21.6	14:57:44	00:22.2	111	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
11	14:59:01.0	14:59:07	00:06.4	32	[illegible]	[illegible]	[illegible]		190.39	- 9.779	3.13	0
12	15:00:01.2	15:00:07	00:05.8	29	16.91	-7.45	11.61	10	116.62	-12.842	2.80	14
13	15:00:21.0	15:00:26	00:05.0	25	25.60	-5.18	7.77		204.81	-10.355	2.18	0
14	15:00:42.0	15:00:50	00:07.6	38	30.35	-12.91	16.93	24	159.76	-16.983	3.12	25
15	15:01:56.8	15:02:03	00:06.6	33	36.39	-8.51	15.71		220.56	-12.892	3.33	0

Measurement by Logger

Conversion by ACV

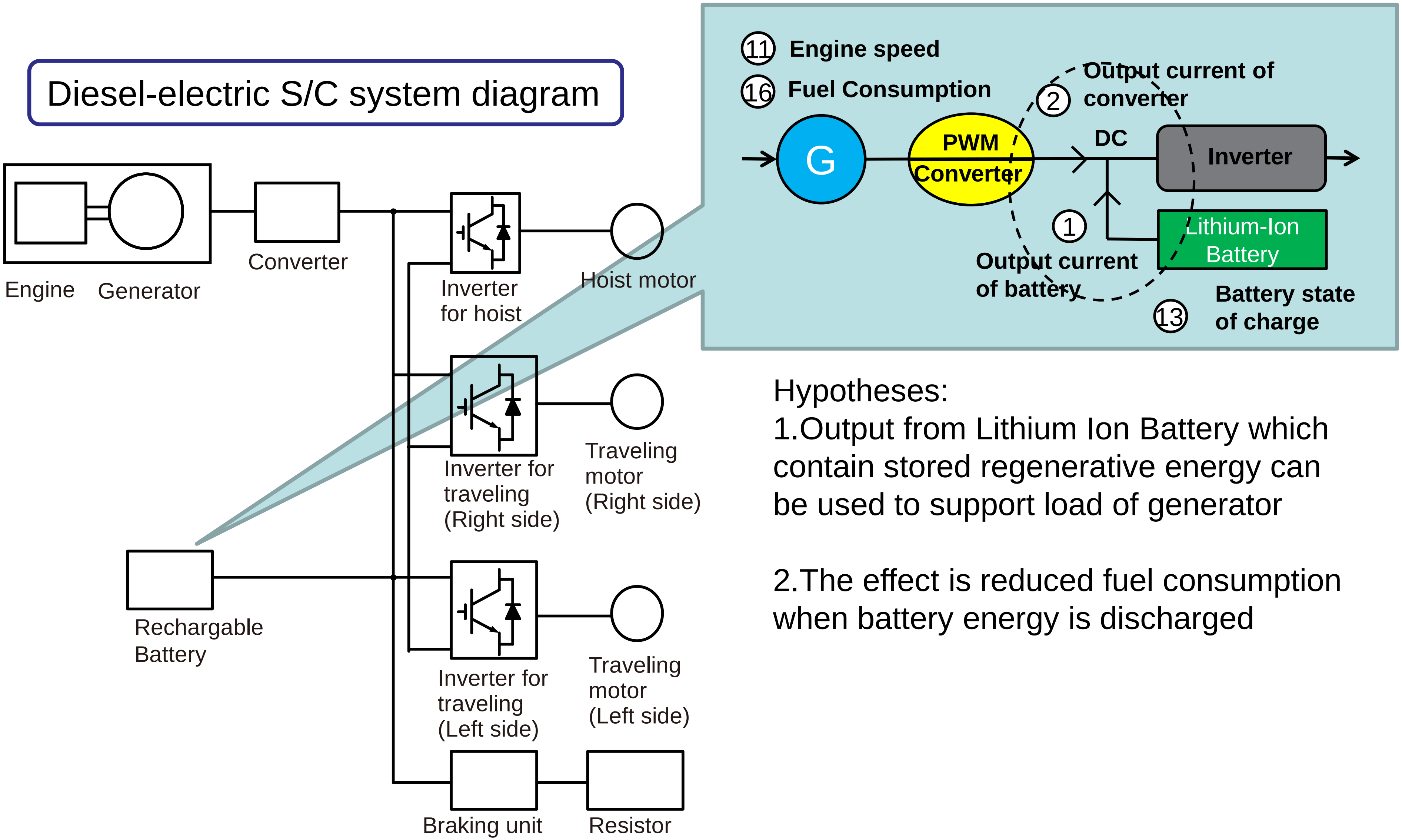
$$ACV = \left(\left(\sum_{i}^{n} di \times \Delta t \right) \div n \right) \times \left(\frac{M}{O} \right)$$

Converting value

Averaging value

Integration of shaded portions

Benefit of Regenerative Energy Stored in HSC's LITHIUM-ION Battery



Hypotheses:

1.Output from Lithium Ion Battery which contain stored regenerative energy can be used to support load of generator

2.The effect is reduced fuel consumption when battery energy is discharged

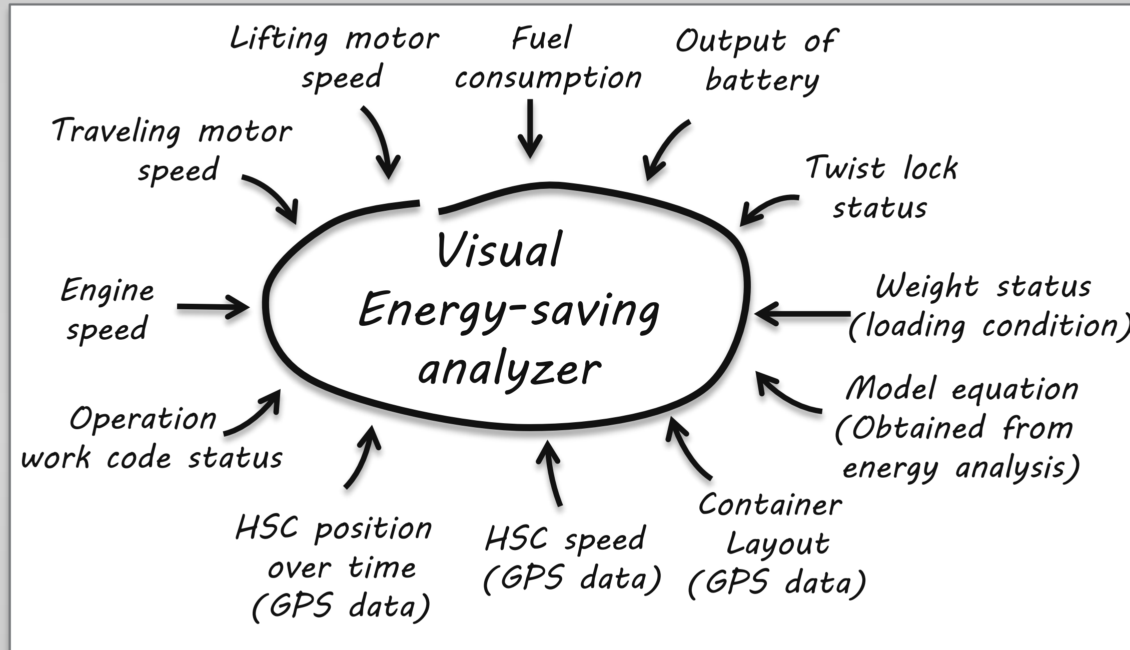
Visualizing energy analysis

Visualization of energy analysis able to extract various information from operation which were not able to be shown by previous method

Establish performance measurement system

Perform energy analysis

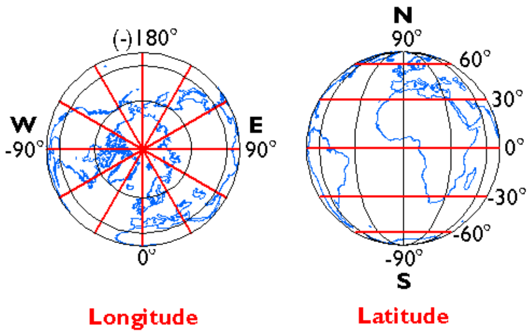
Conduct spatial analysis

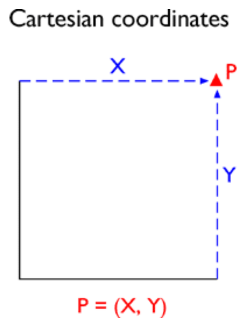


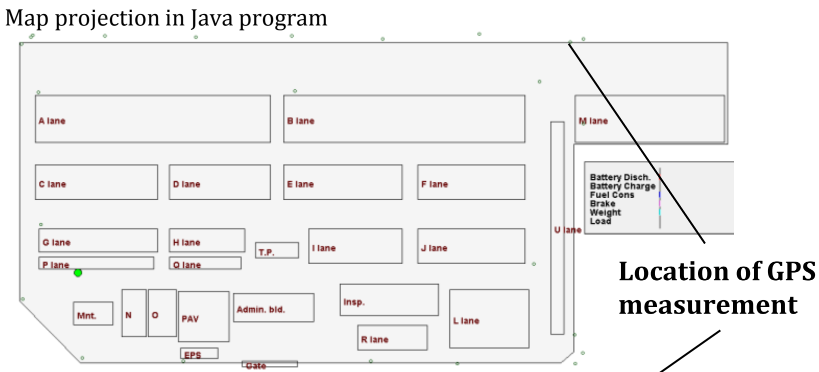
Visualization of the time elapsed energy consumption based on reconstructed operation database by means of object oriented programming

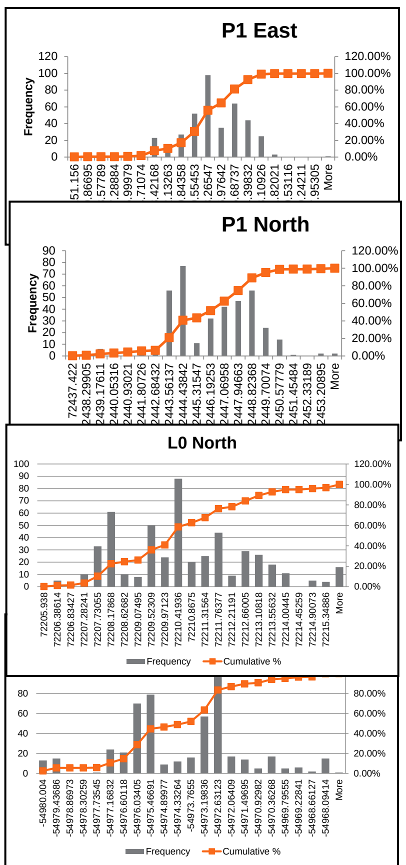
Visualizing Container Layout in Plain Coordinate

Map projection : Transform geographic coordinate of container terminal to plane cartesian coordinate system (use of JGD 2000 Japan Zone 2 (Fukuoka)

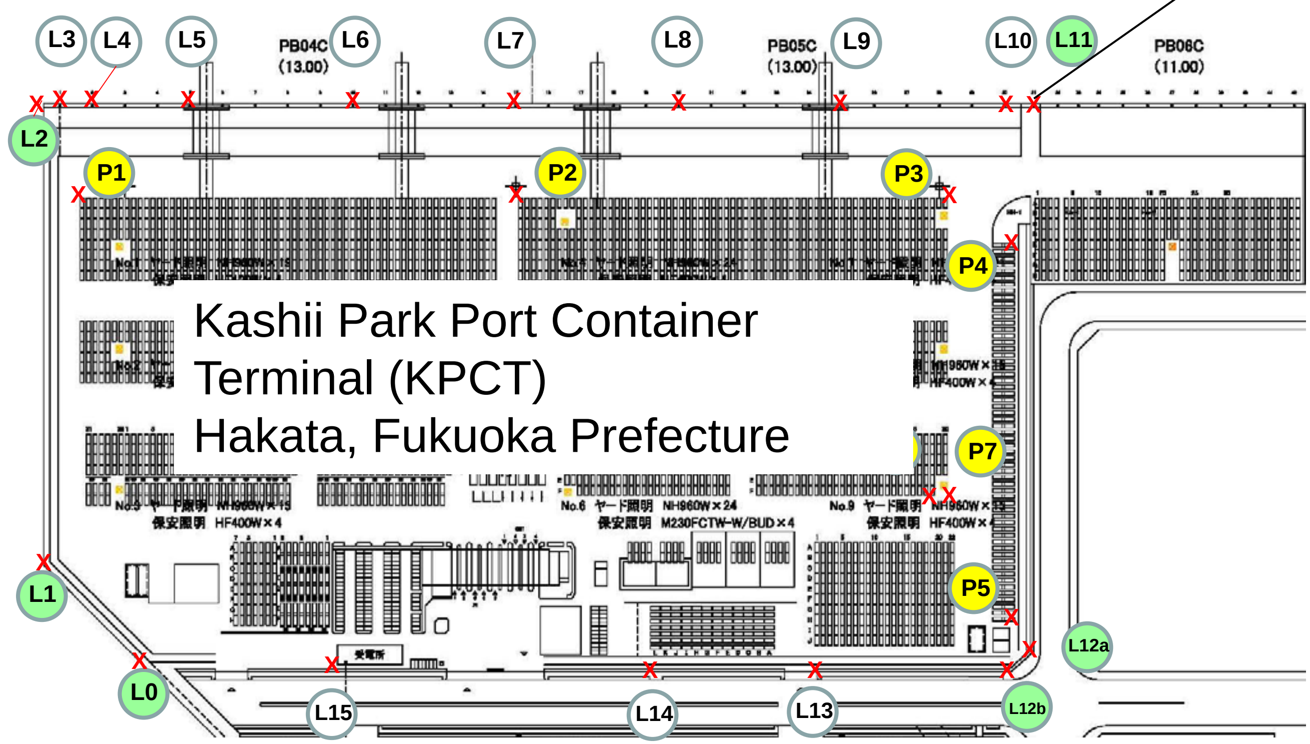








Location of GPS measurement



Visualizing HSC movement in Plain Coordinate

Database Reconstruction

HSC movement measurement by GPS

Data logger output

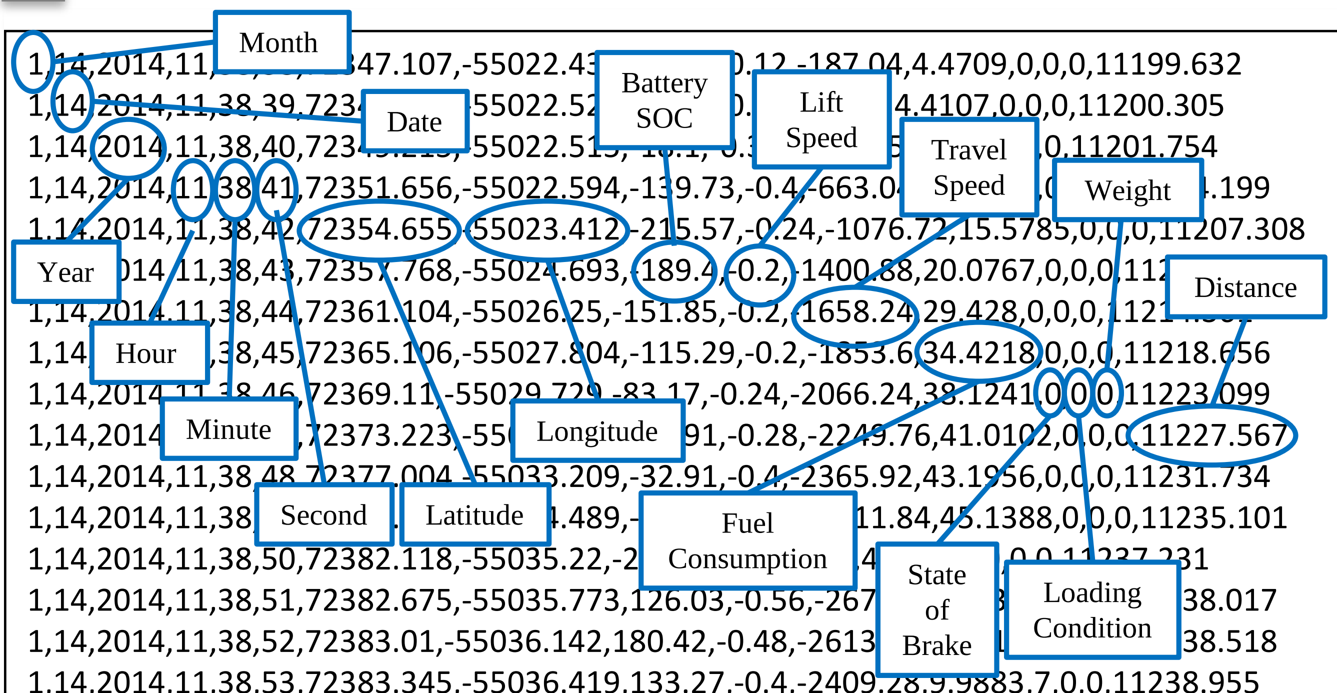
Input for java program

1 Operation Work Code

Code	Denomination	Type of Operation
1	Delivery	Deliver container from CY to Outside Chassis (OC)
2	Receipt	Receive container from Outside Chassis (OC) and stack it in CY
3	Export	Deliver container from CY to Apron (QC)
4	Import	Receive container from Apron (QC) and stack it in CY
5	Shifting	Stack and unstack of a container in CY (including rehandling, shift-in, shift-out)

Remark: CY: Container yard, QC : Quay crane, OC: Chassis from outside

2 Reconstructed Database

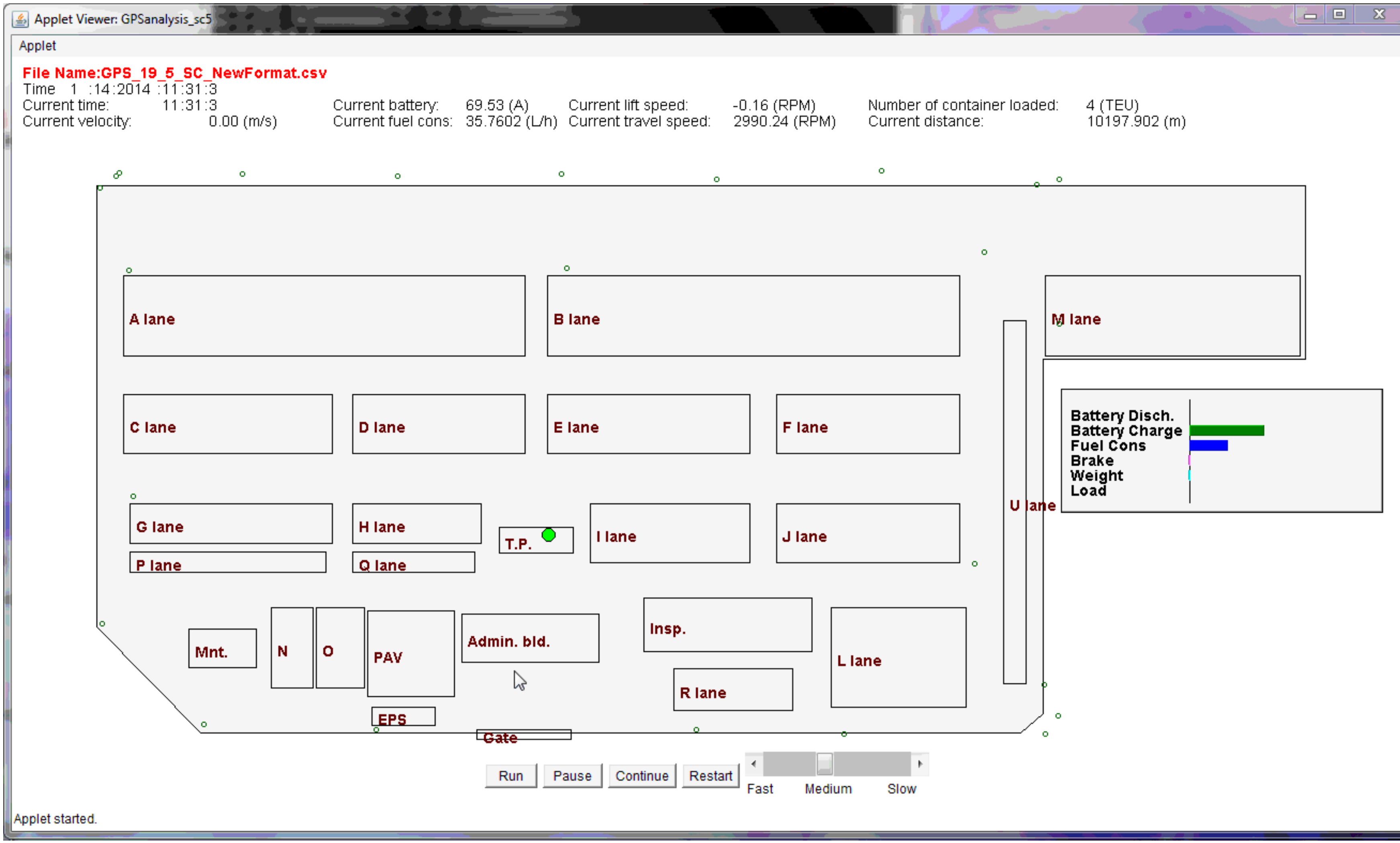


Energy-Saving Analyzer Output

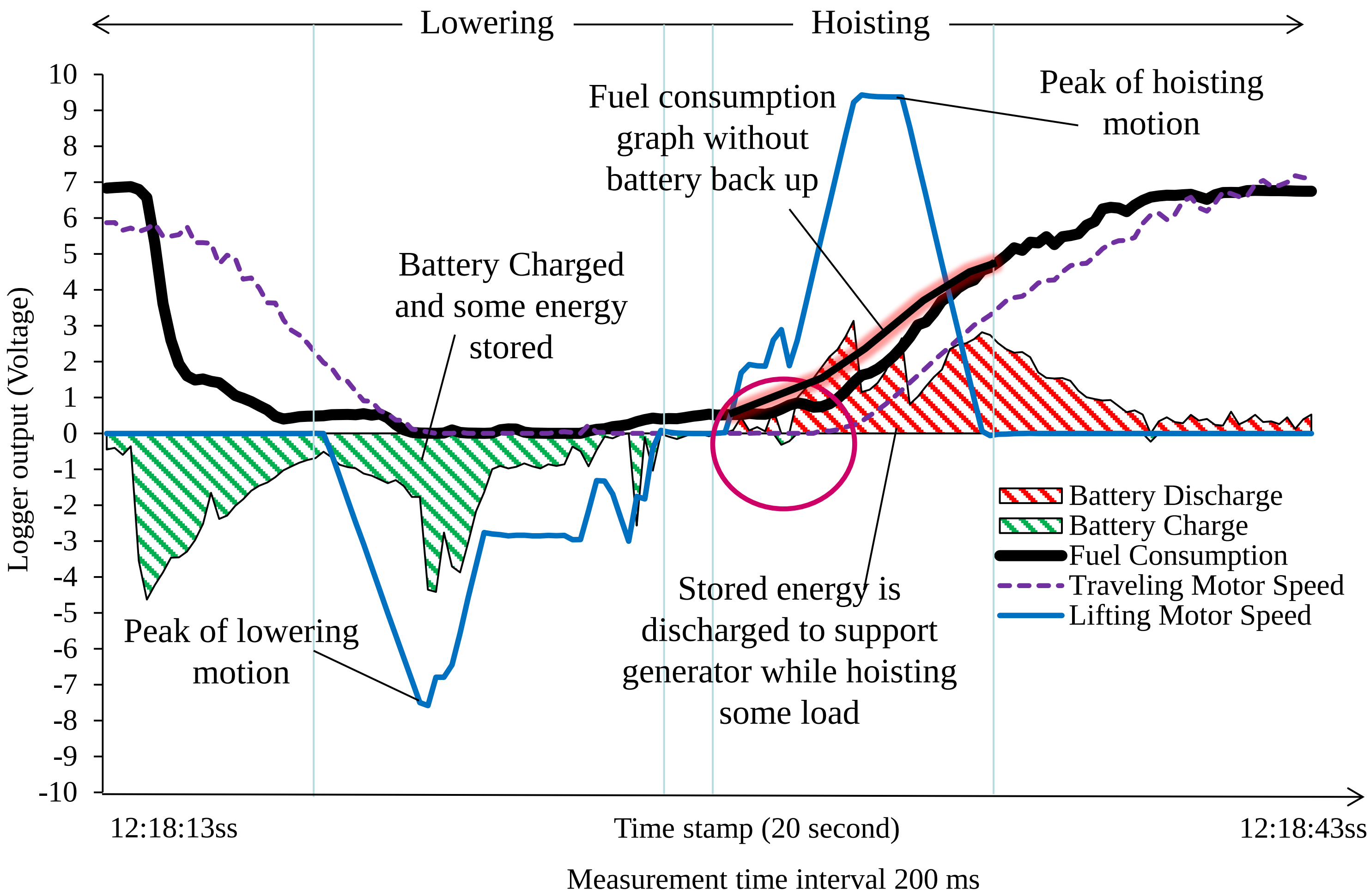
Battery utilization map

- Battery state of charge (green)
- Battery state of discharge (red)

Performance status will show exact amount of performance parameter when time elapsed as well as HSC's productivity



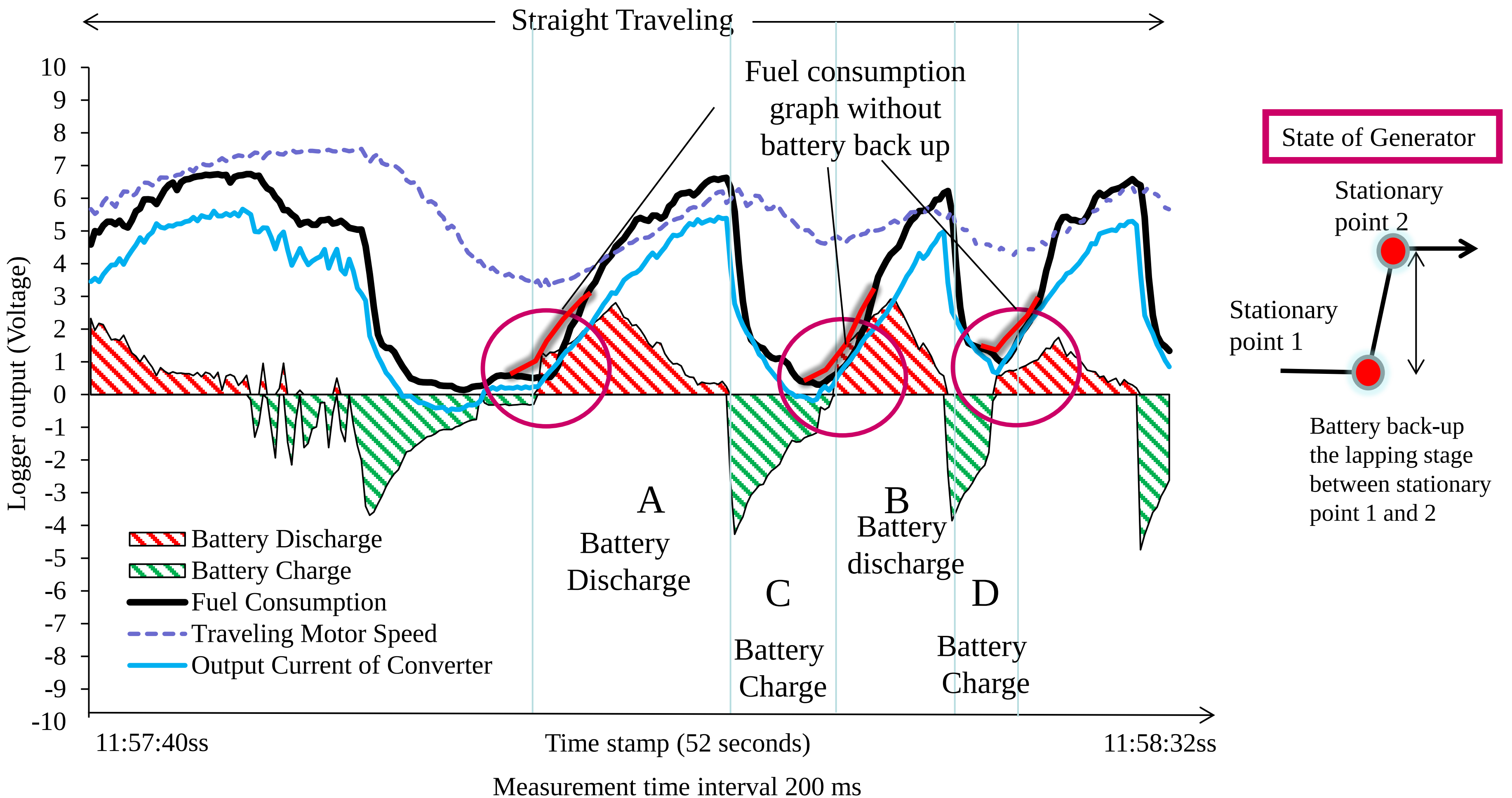
Benefit during vertical motion



Lowering the spreader generate some energy that will be stored in the battery.

The stored energy can be use to support generator when hoisting the spreader. The benefit of this process is reduced fuel consumption while hoisting.

Benefit during horizontal motion

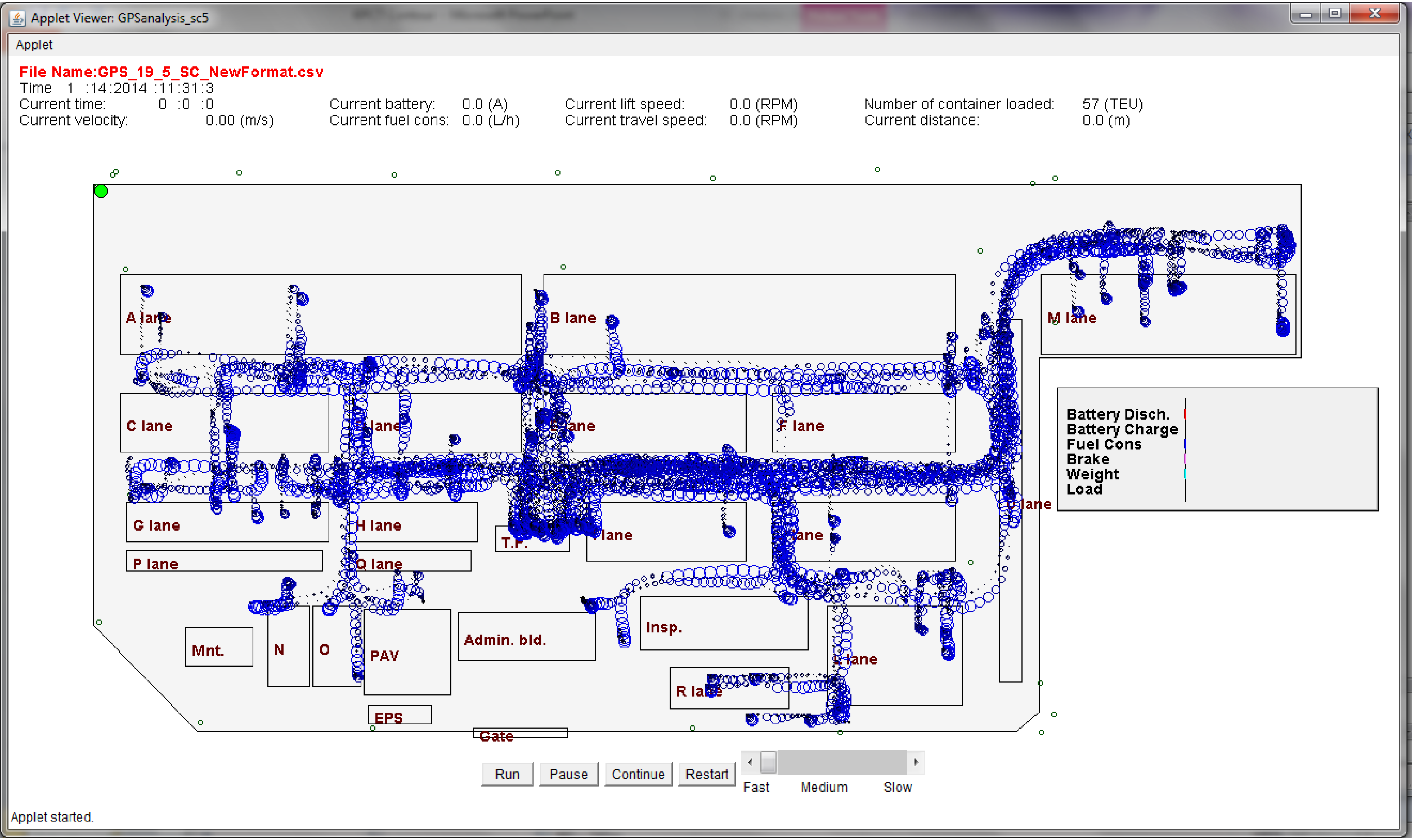


Discharging energy from battery to support the generator and reduce fuel consumption (Area A and B)

When lowering the speed and deaccelerate, vehicle can gain some energy charge from wheel rotation (Area C and D)

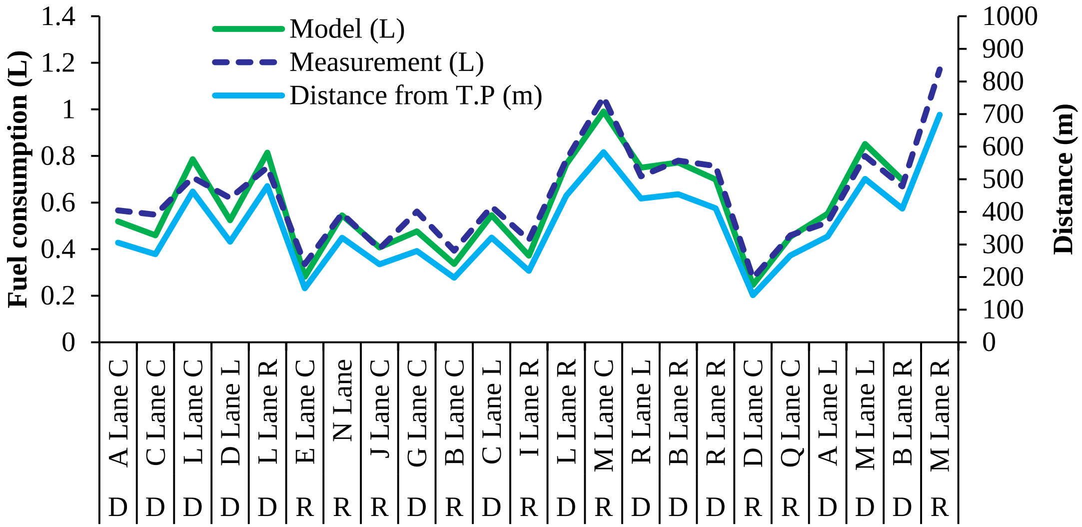
Energy-Saving Analyzer Output

Fuel consumption map



Result from modeling operation performance of HSC (half day)

All route is start from transfer point (T.P) to various stack position and simulated routes were compared to actual operation in database



$$\text{Total } F = F_{vertical} + F_{horizontal}$$

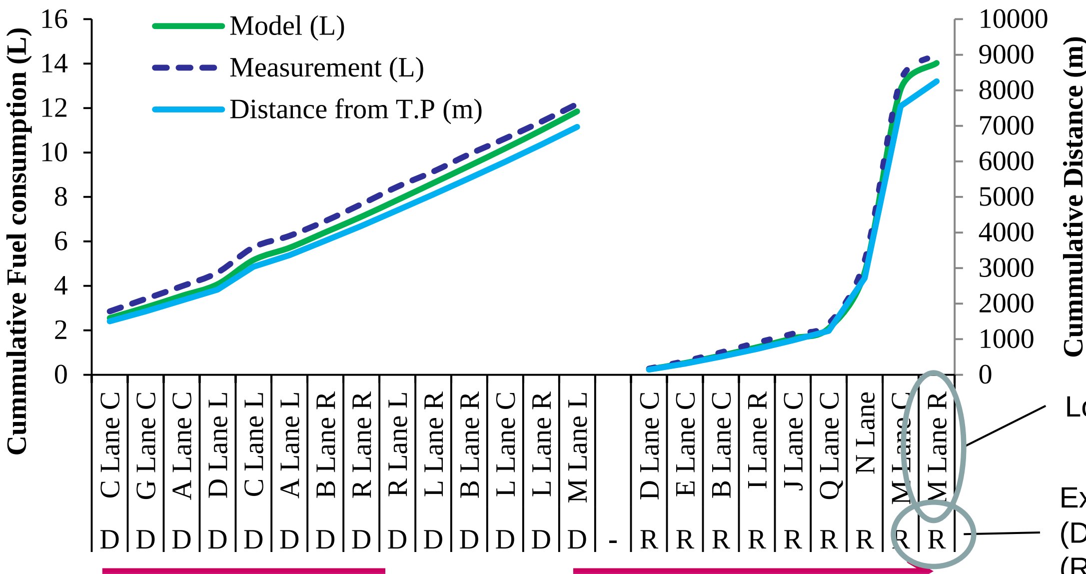
- Total fuel consumption for a specific route
- Total fuel consumption for vertical motion
- Total fuel consumption for horizontal motion

$$F_{vertical} = F_h + F_l$$

- fuel consumption from **hoisting**
- fuel consumption from **lowering**

$$F_{horizontal} = F_t + F_c + F_m$$

- fuel consumption for **straight traveling**
- fuel consumption for **cornering**
- fuel consumption from **maneuvering**



Putting together the measurement result, we attempted to model the movement of HSC by calculating point-to-point distance and compare it to measurement result.

Location (Lane and Position) in Yard

Explain operation work code status
(D): Delivery
(R): Receipt

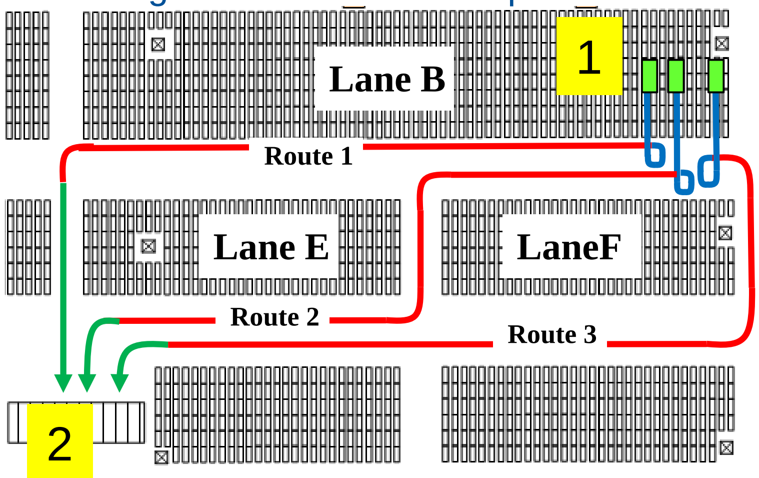
3:43:22 ss

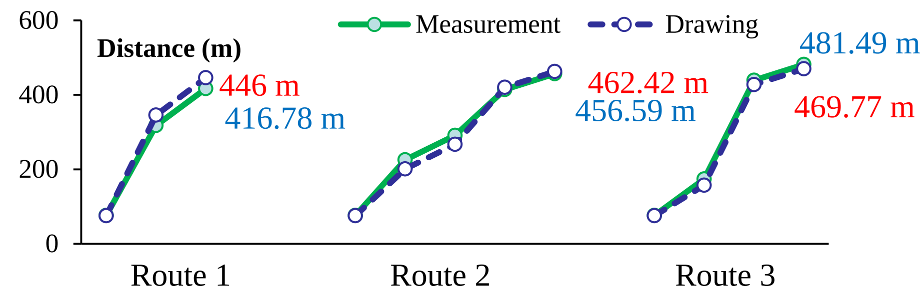
11:32:38 AM

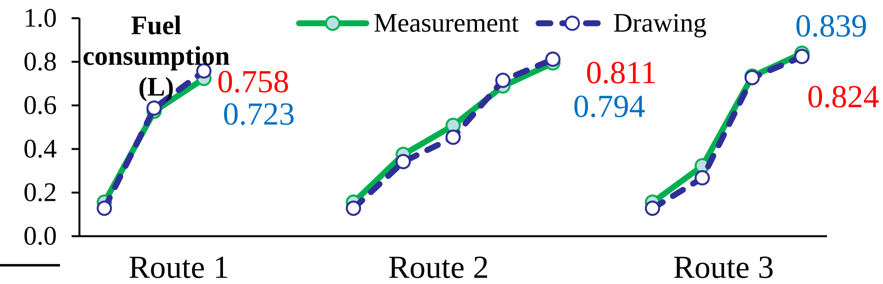
3:16:00 PM

Calculating best route for specific task

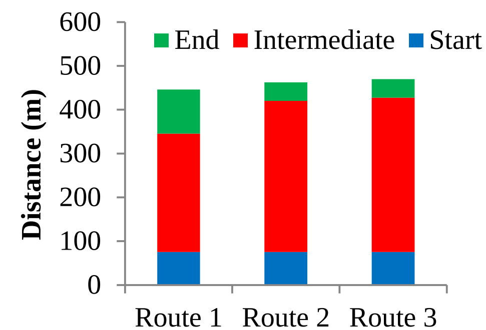
There might be several route option for each task

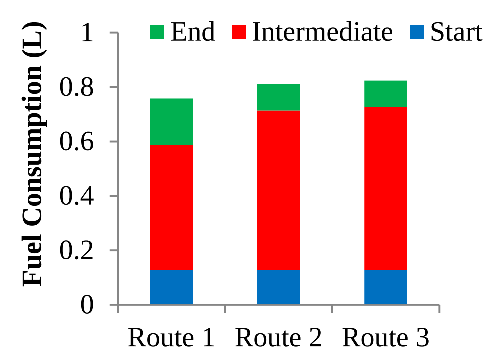






COMPARISON	Num of data	Distance (m)		FC (L)	
		Measurement	Model	Measurement	Model
Route 1					
B Lane RB - B Lane RR	8	75.93	75.25	0.16	0.13
B Lane RR - B Lane LR	2	241.63	270.28	0.42	0.46
B Lane LR - TP	3	99.22	100.48	0.15	0.17
Total	13	416.78	446.00	0.72	0.76
Route 2					
B Lane RB - B Lane RR	8	75.93	75.25	0.16	0.13
B Lane RR - B Lane CR	1	149.61	125.65	0.22	0.21
B Lane CR - E Lane RR/F Lane LR	1	65.59	65.95	0.13	0.11
E Lane RR/F Lane LR - E Lane LR	7	123.07	153.27	0.18	0.26
E Lane LR - TP	9	42.39	42.30	0.11	0.10
Total	26	456.60	462.42	0.79	0.81
Route 3					
B Lane RB - B Lane RR	8	75.93	75.25	0.16	0.13
B Lane RR - F Lane RR	2	98.14	81.95	0.17	0.14
F Lane RR - E Lane LR	8	265.03	270.28	0.41	0.46
E Lane LR - TP	9	42.39	42.30	0.11	0.10
Total	27	481.50	469.78	0.84	0.82

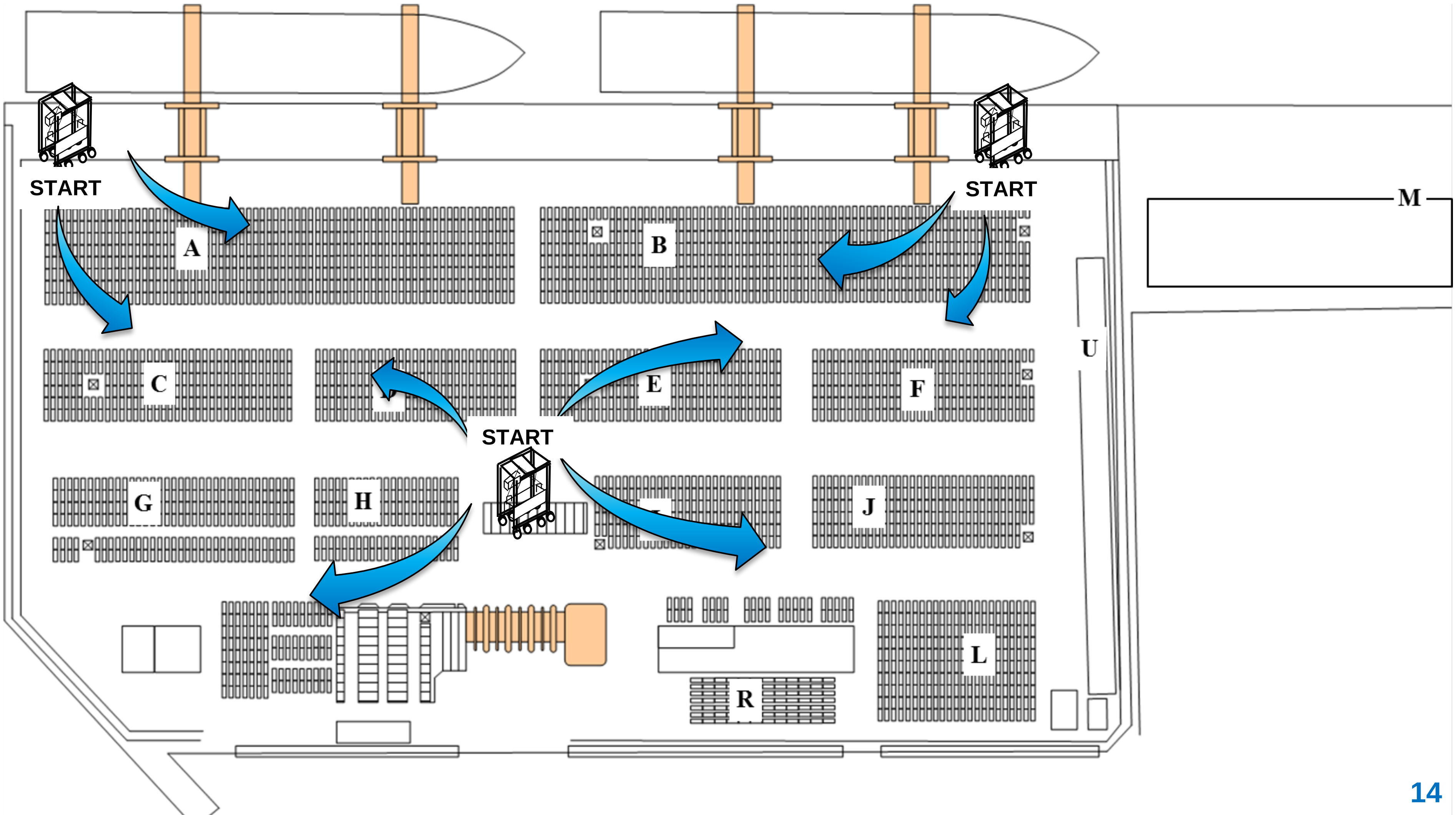




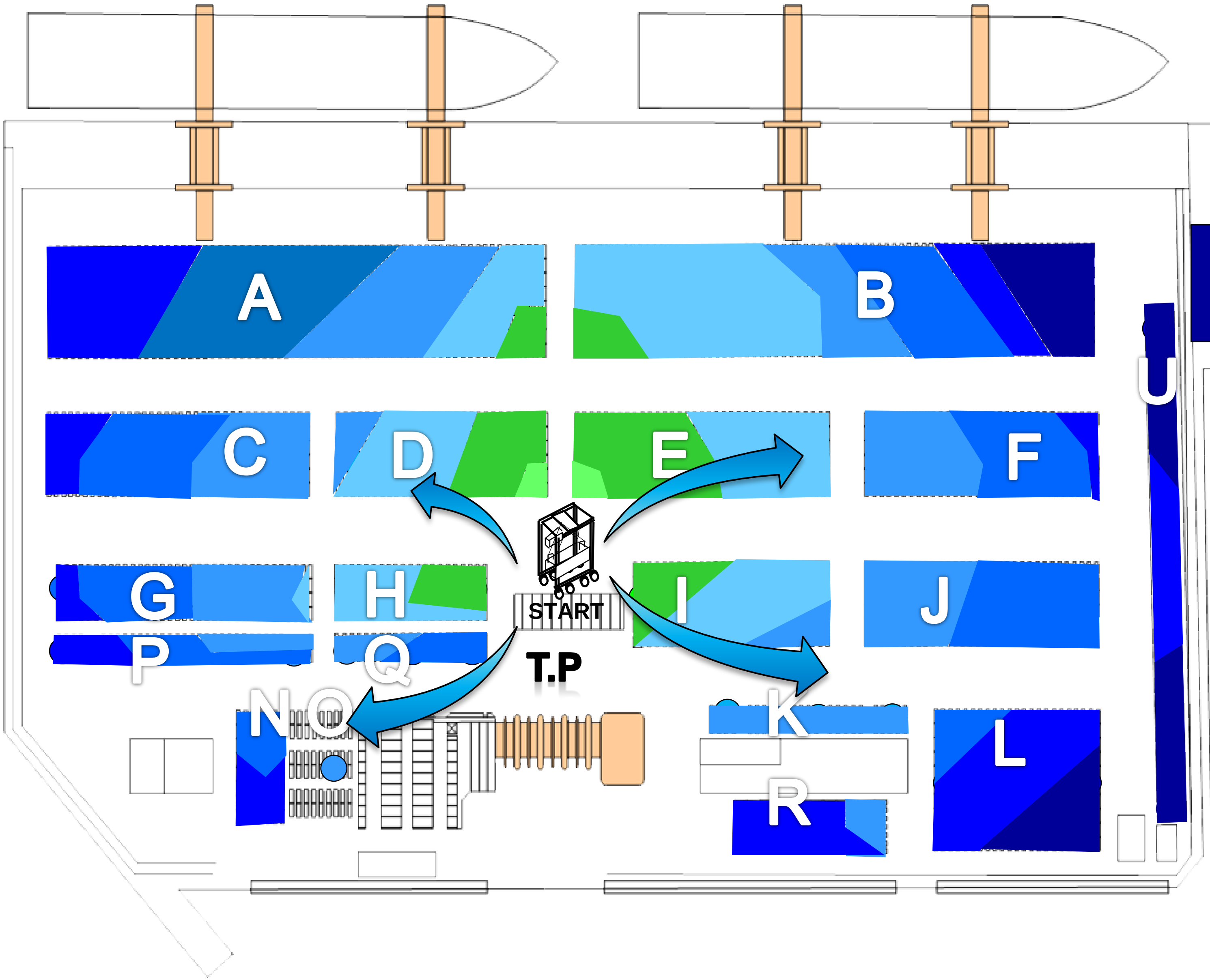
Difference is in number of cornering movement

Simulating HSC Movement

After knowing the best route for each point-to-point task, we can help to simulate HSC movement to all the position in the yard to create fuel consumption map

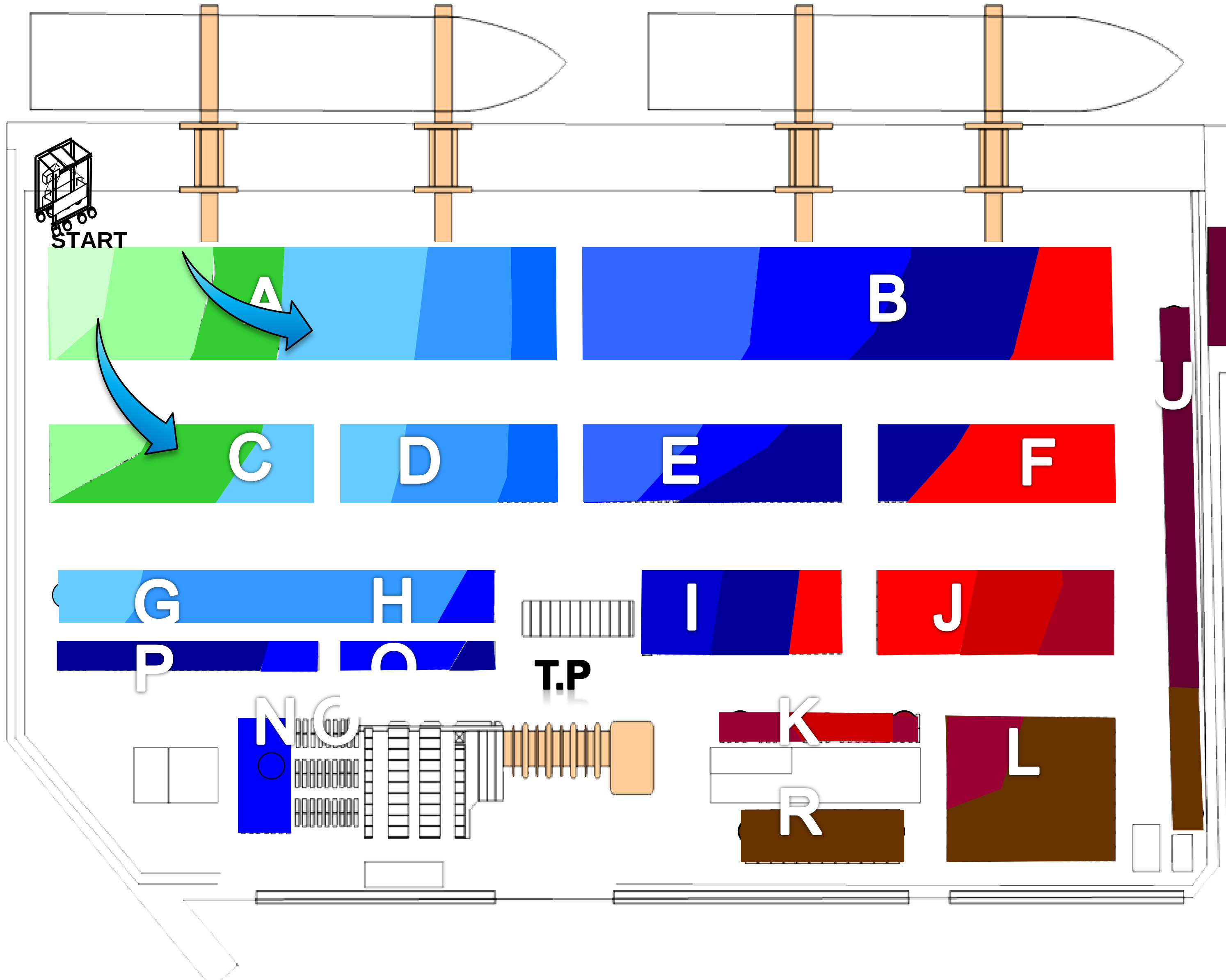


Example of Fuel Consumption Map (1)



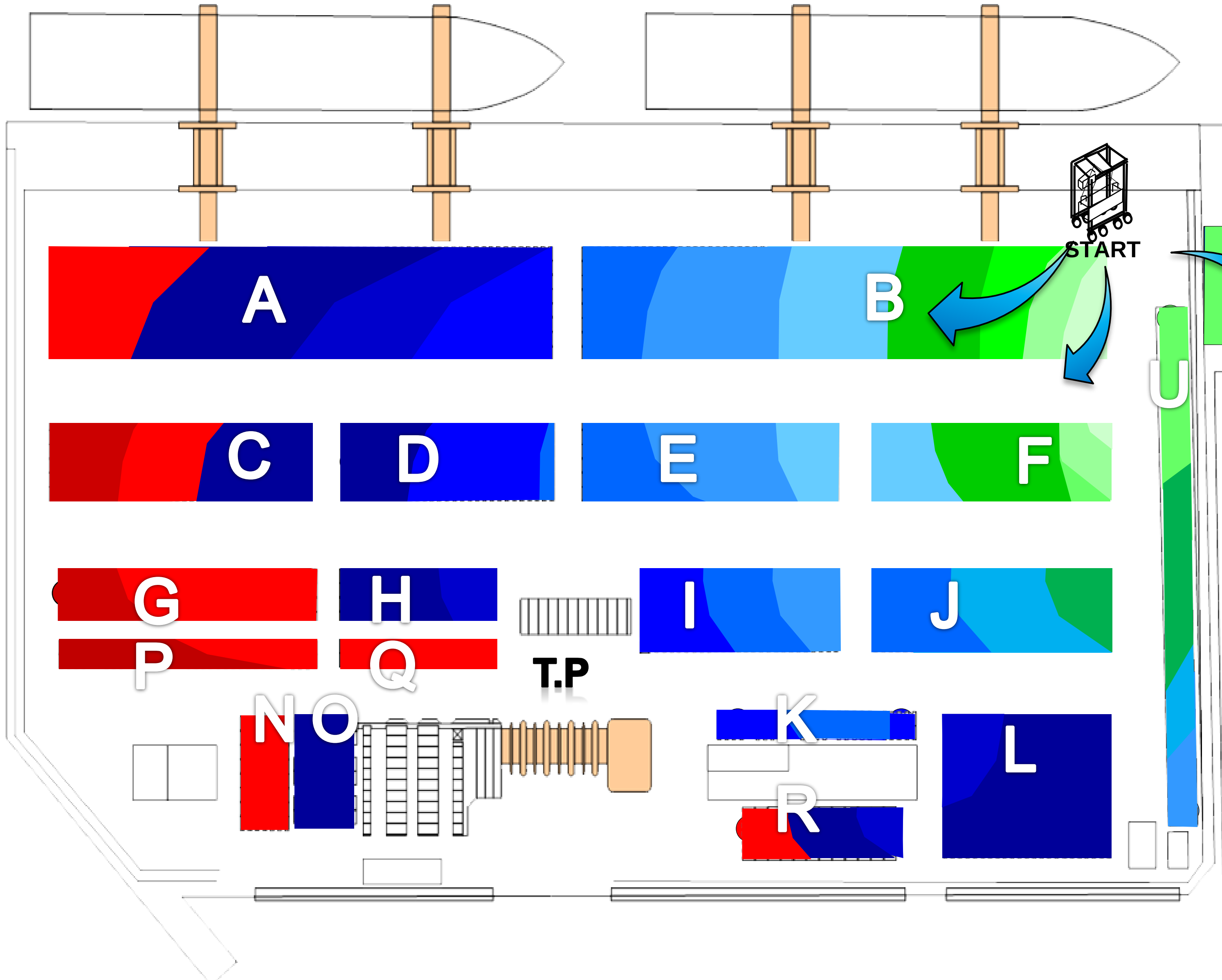
Fuel Consumption (L)	Color
0 - 0.1	
0.1 - 0.2	
0.2 - 0.3	
0.3 - 0.4	
0.4 - 0.5	
0.5 - 0.6	
0.6 - 0.7	
0.7 - 0.8	
0.8 - 0.9	
0.9 - 1.0	
1.0 - 1.1	
1.0 - 1.2	
1.0 - 1.3	
1.0 - 1.4	
1.0 - 1.5	

Example of Fuel Consumption Map (2)



Fuel Consumption (L)	Color
0 - 0.1	
0.1 - 0.2	
0.2 - 0.3	
0.3 - 0.4	
0.4 - 0.5	
0.5 - 0.6	
0.6 - 0.7	
0.7 - 0.8	
0.8 - 0.9	
0.9 - 1.0	
1.0 - 1.1	
1.0 - 1.2	
1.0 - 1.3	
1.0 - 1.4	
1.0 - 1.5	

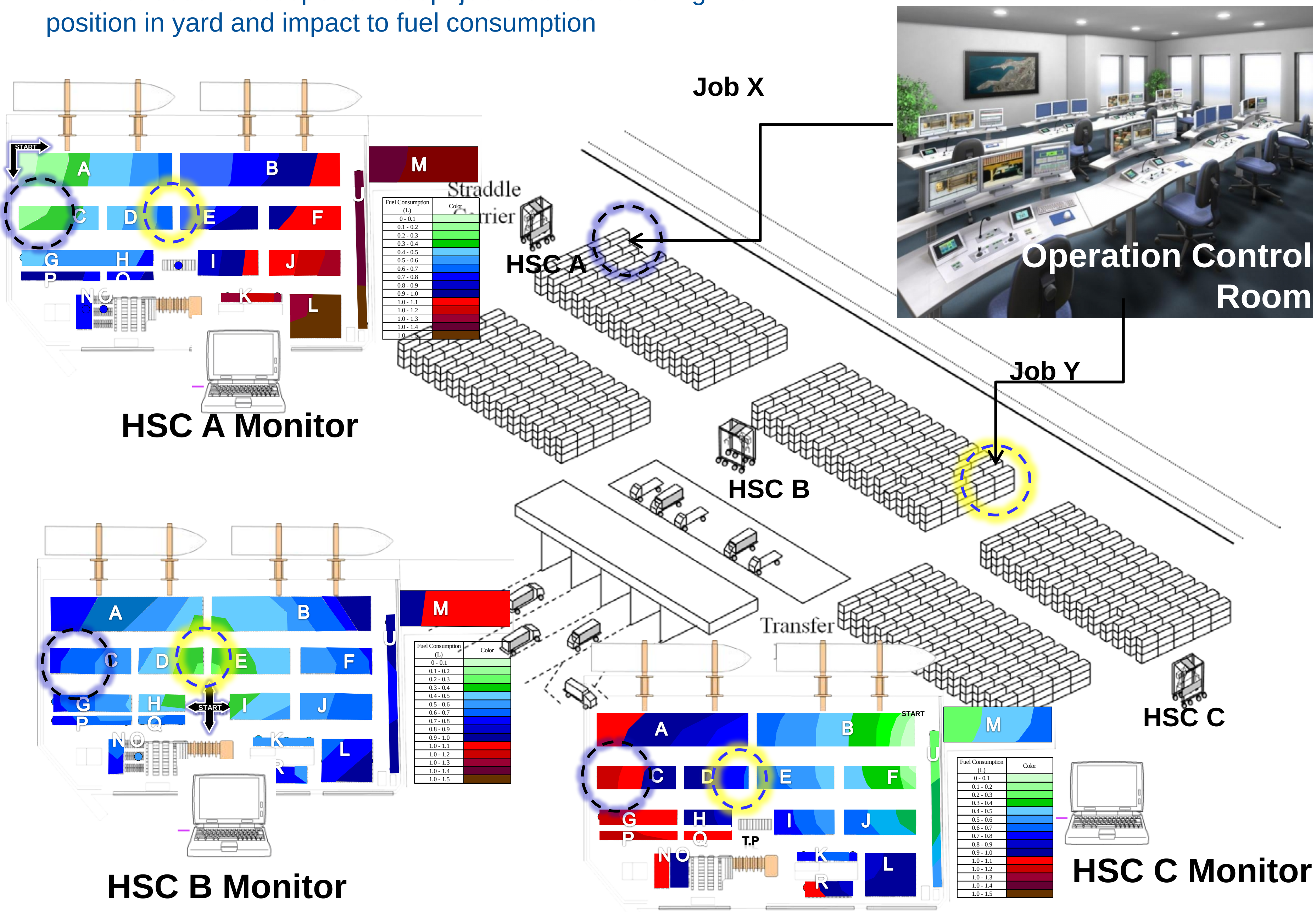
Example of Fuel Consumption Map (3)



Fuel Consumption (L)	Color
0 - 0.1	
0.1 - 0.2	
0.2 - 0.3	
0.3 - 0.4	
0.4 - 0.5	
0.5 - 0.6	
0.6 - 0.7	
0.7 - 0.8	
0.8 - 0.9	
0.9 - 1.0	
1.0 - 1.1	
1.0 - 1.2	
1.0 - 1.3	
1.0 - 1.4	
1.0 - 1.5	

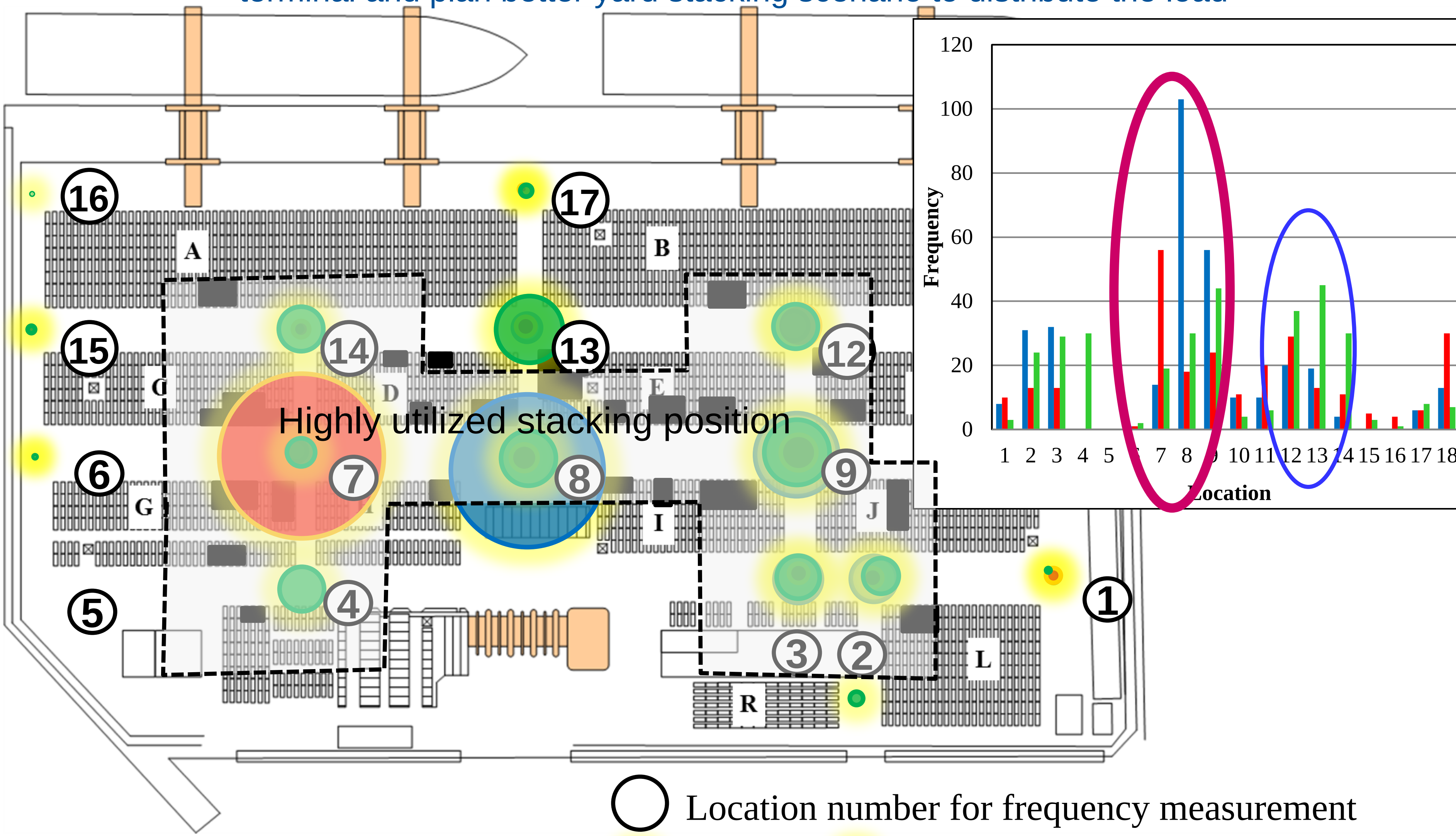
How fuel consumption map help efficient utilization of HSC

Driver choose to accept/not accept job order considering their position in yard and impact to fuel consumption



Density Map at intersections

By knowing the density at intersection, we can predict the operation pattern in the container terminal and plan better yard stacking scenario to distribute the load



Location number for frequency measurement

Day 1

Day 2

Day 3

Scale of frequency :

1 frequency ≡ 0.1” of circle diameter

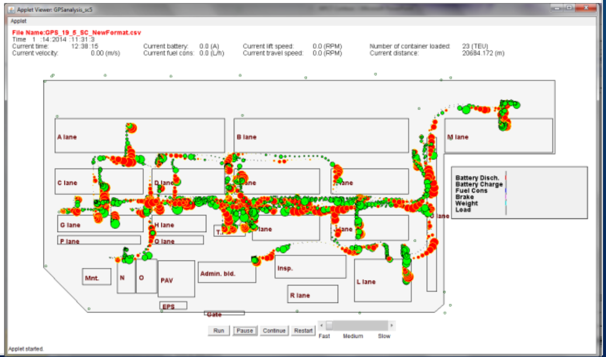
Conclusion

Support tools for environmental initiative

1

Visualization of energy analysis able to extract valuable information which were not able to be shown with aggregate calculation such as Battery utilization map and Fuel consumption map

Output from the analyzer can be used to model the movement all over the yard.



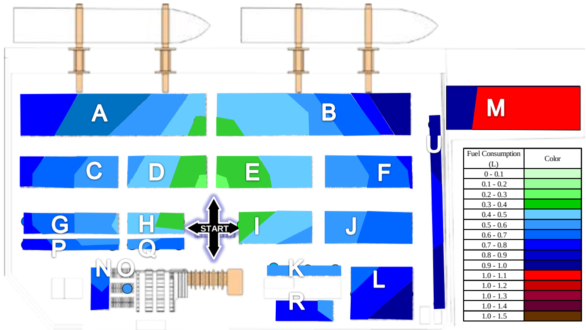
Visualizing energy analysis

2

Fuel map can be of help to organize efficient routing of straddle carrier

By knowing the density map, we can help to plan better yard utilization to reduce Yard Occupancy and reduce double handling

This method can be applied generally to any kind of handling equipment

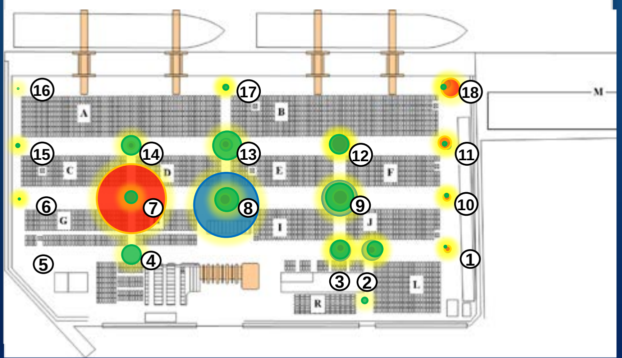


Final Target: Energy-Saving

3

The final target is to use dynamic simulation to investigate energy-saving performance for all handling equipment

We will consider also various operation constraint to improve the accuracy of the model



THANK YOU FOR YOUR ATTENTION