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Design, Analysis, Simulation, and Evaluation of Advanced Container Terminals

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Problem Motivation

- Worldwide container trade is growing at a 9.5% annual rate, and the U.S. rate is around 6%.
- By 2010, it is expected that 90 percent of all liner freight would be shipped in containers.
- Over the next 20 years, the volume of cargo is expected to more than double and possibly triple at major ports.
- It is almost impossible to gain the desired capacity through expanding the current facilities. (e.g. Scarcity of land)
- Therefore, the “operation-as-usual” in container terminals is unlikely to be able to cope with the complexity of tomorrow’s mobility requirements in a sustainable manner.

Possible Solution: Automation

- Replace manual operations with automated ones
- Synchronize and optimize operations
- Improve scheduling, dispatching
- Just_in time operations

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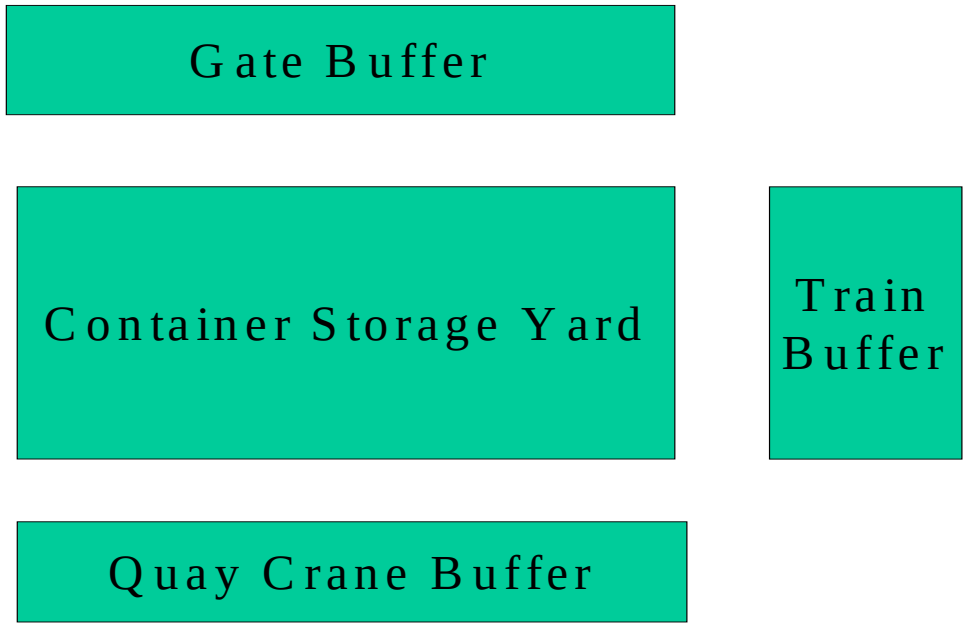
Automated Container Terminal System



ACT Design Considerations

- One vessel per day, vessel capacity 8000 TEUs, 85% loaded (carrying 6800 TEUs), operation hours is limited to 24 hours.
- 60% of cargo (4,080 TEUs) arrives by trucks, and 40% of cargo (2,720) by rail.
- Export containers start arriving within 2 days before the vessel is scheduled to arrive, with the arrival rates 0.2 (2 days in advance), 0.5 (one day in advance), and 0.3 (the same day the vessel arrives).
- Import containers are retrieved during three days, with retrieval rates 0.5, 0.3 and 0.2, respectively.
- Gates: 24-hour operation, average service time 3 min/truck for inbound trucks, and 2 min/truck for outbound trucks.
- Yard Cranes move 5 mph laterally, need 15 sec to line up with the container, and average time 50 sec for loading/unloading a container.
- Quay Cranes have the maximal physical capacity of 50 moves per hour.
- Yard vehicles move 5 mph when they are loaded, and 10 mph when empty.

ACT Specifications

- Number of Gates

  Gate operation is modeled by M/M/n queue

  $$\lambda/\mu < n$$

  where λ is the constant arrival rate

  μ is the service rate and n is the number of gates

  - 9 gates for inbound trucks.
  - 6 gates for outbound trucks.

ACT Specifications (Continued)

- Number of Cranes used for gate buffer and train buffer

  N = Q/V

  Where Q is the number of containers needs to be processed

  V is the speed of the cranes

- 2 cranes for train buffer
- 6 cranes for gate buffer

ACT Specifications (Continued)

- Number of Quay Cranes

$$ST = \frac{3{,}400}{42} \cdot \frac{1}{NC}$$

Where ST denotes the ship turnaround time

NC is the number of Quay Cranes

- 5 quay cranes are required
- 1 single berth is sufficient

ACT Specifications (Continued)

- Capacity of the storage yard

  - about 22,000 TEUs

- Number of vehicles for serving buffers

  -- depends on concept

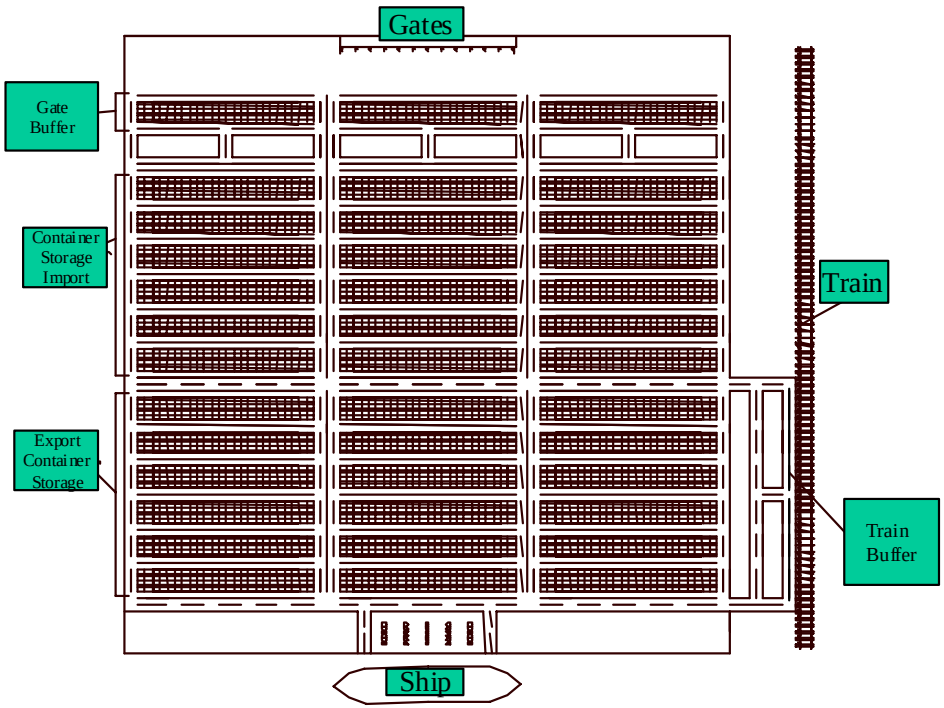
- Size of yard

  -- depends on concept

ACT Concept

- Concept: AGV-ACT Similar configuration as in today's terminals, except that free path AGVs and automated cranes are used

AGV-ACT Concept



Proposed layout for AGV-ACT

AGVs in Port of Rotterdam

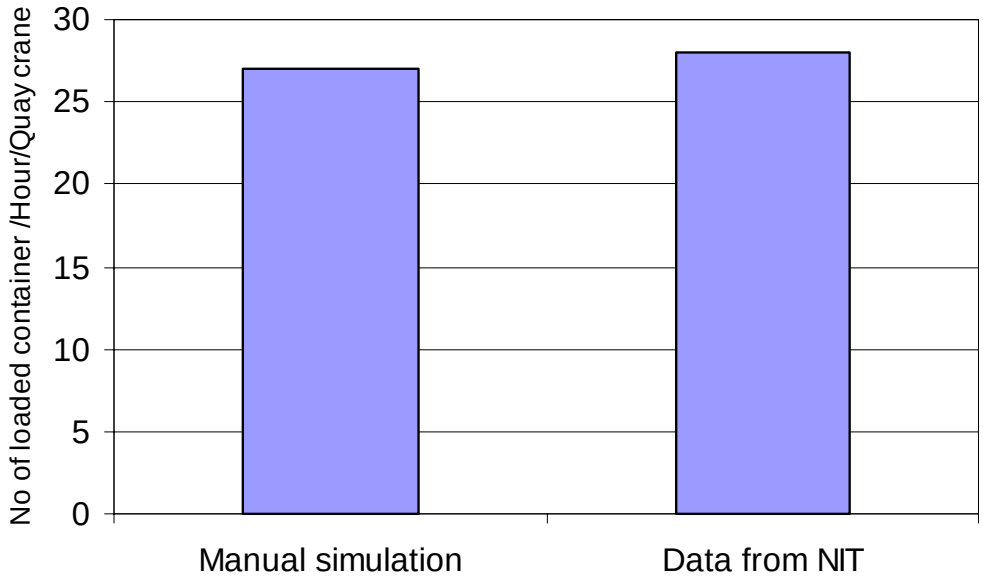
Microscopic Model

- Use Matlab/Simulink/Stateflow to simulate every piece of equipment and operations
- Use Simulations to calculate minimum number of vehicles to serve yard, gates, train and ship
- Validate model using real data

Cost Model

- Costs associated with container handling and storage operations within a terminal can be classified into the following three categories:
  - *Cost of Locations*: that is the cost of locations where activities (operations) take place, e.g. storage area, berth, etc.
  - *Cost of equipment*, the cost of yard equipment e.g. yard cranes, quay cranes, AGVs, etc.
  - *Labor costs*.
- A cost model in EXCEL for computing the average cost per container (ACC) has been developed and used to evaluate the cost of each proposed concept.

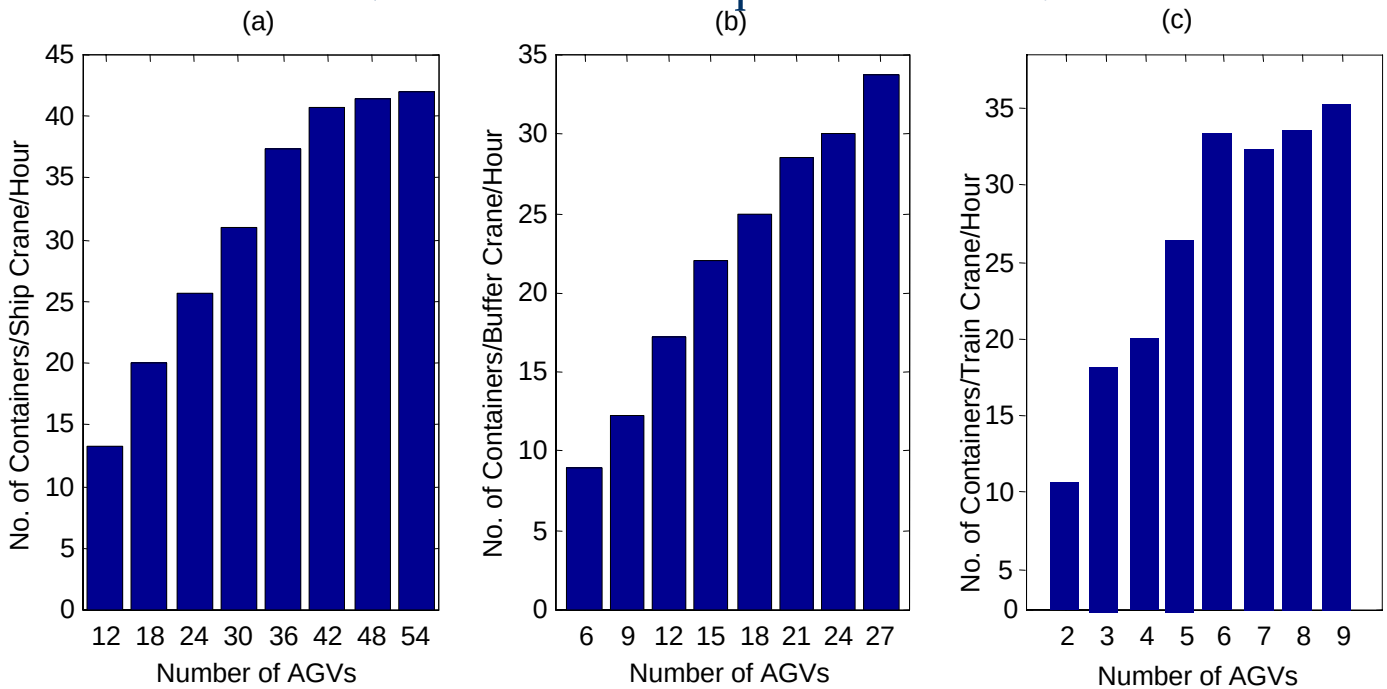
Model Validation



Throughput of the manual loading operation, simulation and actual data from NIT (Number of vehicles 18).

Number of AGVs

- The number of AGVs is obtained by exercising the simulation model
- The number of AGVs to meet the required demand: 80



(a) throughput of quay crane, (b) throughput of buffer crane and (c) throughput of train crane versus the number of AGVs used

Performance and Cost Measures

- ***Throughput:*** The number of moves per hour per quay crane
- ***Throughput per acre:*** The throughput per acre
- ***Ship turnaround time:*** The time it takes for the ship to get loaded/unloaded in hours
- ***Truck turnaround time:*** The average time it takes for the truck to enter the gate, get served, and exit the gate minus the actual processing time at the gate
- ***Gate utilization:*** Percent of time the gate is serving the incoming and outgoing container traffic
- ***Container dwell time:*** Average time a container spends in the container terminal before taken away from the terminal
- ***Idle rate of equipment:*** Percent of time the equipment is idle
- **Average Cost per Container (ACC):** The average cost to move a container through the terminal

Performance and Cost Measures (Cont'd)

Ship turnaround time	16.81 hours
Throughput of terminal	40.45 containers/ship crane/hour
Per acre Throughput of terminal	0.576 containers/ship crane/acre /hour
Gate utilization	66.03%
Truck turnaround time	126.75 sec. (doesn't include time at the gate)
Throughput (train crane)	29.42 containers/hour/crane
Throughput (buffer crane)	33.7 containers/hour/crane
Idle rate of AGVs over 24 h	36.3%
Idle rate of yard cranes over 24 h	70.2%
Idle rate of buffer cranes over 24 h	12.7%
Idle rate of train cranes over 24 h	23.0%
Idle rate of ship cranes over 24 h	31.7%
Container dwell time	19.1 hours
Average cost per container (US$)	77.3

Performance Comparison

	Manual Estimates	AGV-ACT
Ship turnaround time [hour]	>24	16.81
Throughput of terminal, while the ship is at berth[moves/quay crane/hour]	28	40.45
Throughput of terminal per acre, while the ship is at berth[moves/quay crane/acre/hour]	0.4	0.579
Average cost per container (US$)	130 to 200	77.3

Conclusions

- The capacity of existing terminals can be dramatically improved by using automation
- AGV-ACT concept is designed to meet the future demand. The implementation of this concept requires additional studies where labor issues and concerns about job losses due to automation need to be addressed.