PORT EQUIPMENT MANUFACTURERS ASSOCIATION

THE PEMA PAPERS: Automatic Stacking Crane Performance

Kari Rintanen

Chair, PEMA Automation & Control Technologies Committee

THE PEMA PAPERS

12 June | TOC Europe 2018 | Rotterdam

Automatic Stacking Crane Performance

A PEMA Information Paper

BACKGROUND

- When driven manually by a driver, the performance of a container handling crane is dependent on crane driver’s skill.

- The introduction of unmanned robotized cranes (ASC) made cycle times “deterministic”.

- Main driver of automation: to reduce the cost per handled container while ensuring a consistent level of productivity

BACKGROUND

- It thus became relevant to measure crane performance in terms of cycle times, rather than purely by traditional gantry, trolley and hoist speeds.
- Thus, performance simulation data are often required by equipment buyers.
- Interest of all parties that performance figures are clearly understood and results comparable.

SCOPE

- Primary aim of this paper is to support understanding of the measurement and definition of the performance of an “isolated” ASC or ASC stack, however…
- …TOS, ECS and horizontal transport and their effects on stack performance are also analyzed to reflect integrated terminal operations.

AUTOMATION HISTORY [1]

1993 Rotterdam Delta Terminal	ARMG + AGV
1997 Singapore Pasir Panjang	OHBC + TT
2000 London Thamesport	ARMG + TT
2002 Hamburg CTA	ARMG* + AGV
2002 Brisbane Fishermans Island	AutoSC
…	
2008 Tobishima Container Berth	ARTG + AGV
…	

*overlapping ARMGs

- Heterogeneous approaches
- Slow start, however accelerating since 2005

ASC – AUTOMATIC STACKING CRANE

- More than 1100 driverless stacking cranes in operation worldwide
- More than 35 automated terminals launched since 1993 (more than 15 since 2012)
- ARMGs dominate the current yard automation landscape, becoming a standard product

ASC YARD LAY-OUTS

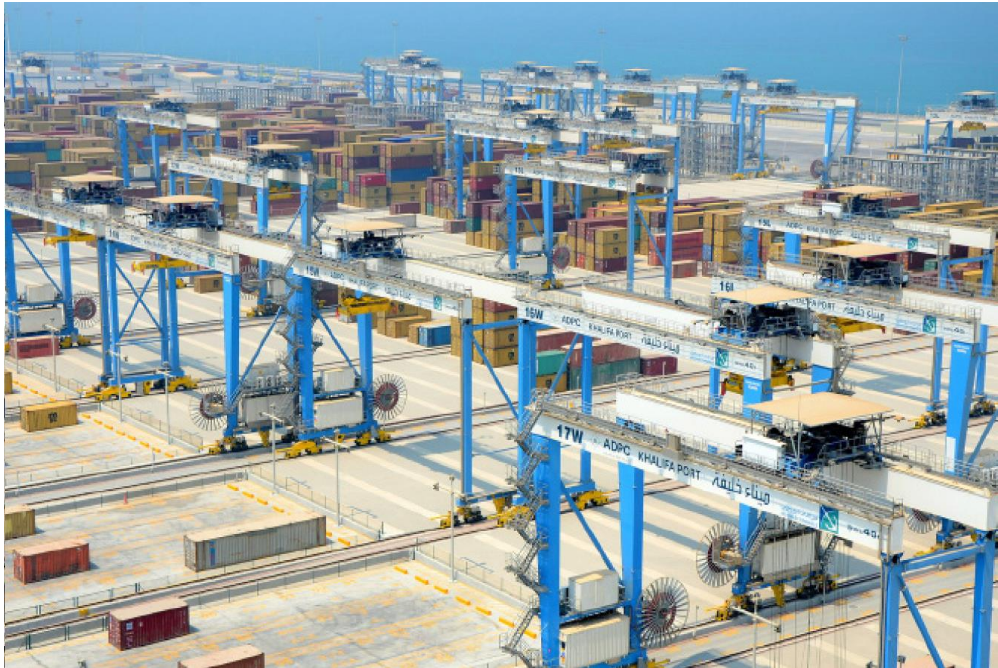
- End-loaded ARMGs with blocks perpendicular to quay
- Side-loaded ARMGs with blocks laid out parallel to the quay
- Automated RTGs without cantilevers, where trucks enter RTG truck lane
- Selection criterias: trans-shipment ratio, land utilization, green/brownfield

TRANS-SHIPMENT RATIO

- Range from below 15 per cent (especially in United States, in England and at the European continent)
- To nearly 100 per cent (é.g. Tanjung Pelepas, Singapore, Salalah, Port Said, Gioia Tauro, Malta Freeport, and Algeciras) [3]
- In transhipment operation containers are not moved all the way from quay to gate as in gateway terminal

END-LOADED ASC LAY-OUT

- Separates waterside and landside operation enabling use of automated vehicles on WS
- Clearly marked interchange areas, improving safety
- Fixes the handling capacity at either end
- Exception: “passing” ARMGs Hamburg CTA, CTB



SIDE-LOADED ASC LAY-OUT

- Interchange areas under the cantilevers
- Double cantilevers may be used to separate pathways for internal vehicles and external trucks
- Allows capacity to be deployed more flexibly to WS/LS side, increasing peak capacity
- Efficient with high trans-shipment ratios

HORIZONTAL TRANSPORT SYSTEM

- Serving ASC cranes, two logistic loops:

- Waterside transport: moving containers from quay cranes to ASCs and vice versa

- Landside transport: moving containers from terminal truck gate or intermodal railhead to ASCs and vice versa

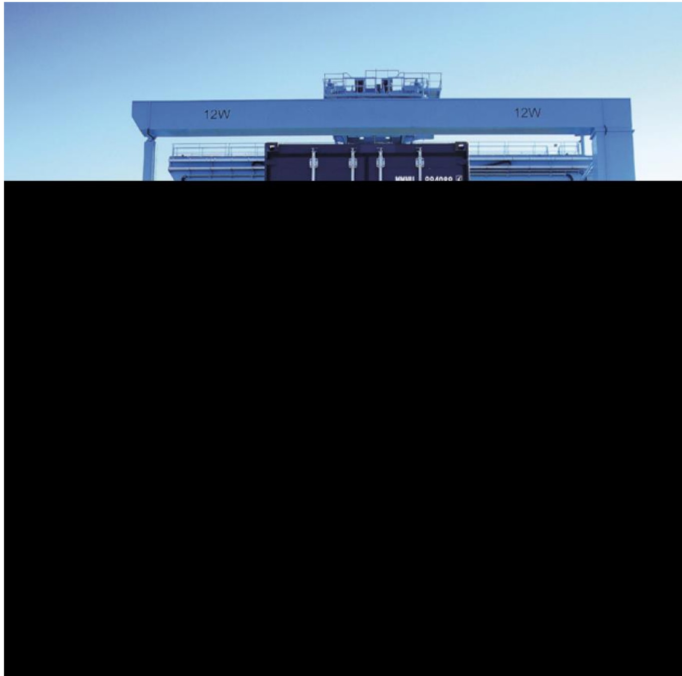
- Synchronized/ de-coupled operation
- Manned/ unmanned vehicles
- Automated/ remotely operated handling

WATERSIDE TRANSPORT SYSTEM

- Number of different equipment combinations used:

- Traditional tractor & trailer sets
- AGVs and Lift-AGVs (de-coupling on ASC)
  - automated handling by ASC
- Manually driven or automated straddle carriers
  - de-coupling, both ASC and QC
  - automated handling by ASC
- Shuttle Carrier: 1 over 1 straddle carrier

- Safety aspects for manned vehicles



LANDSIDE TRANSPORT SYSTEM

- External street trucks and labour entering the terminal, sometimes unfamiliar with unmanned cranes: special attention to safety (considered simpler for end-loaded ASC)

- Street trucks typically handled with remote operation, full automation at some terminals

TOS AND ECS (EQUIPMENT CONTROL SYSTEM)

- ECS is a software between TOS and the Container Handling Equipment (CHE). ECS controls processes at equipment level, either for a single CHE or group of CHE

- ECS implements many tasks that were executed by the human driver before, e.g.:

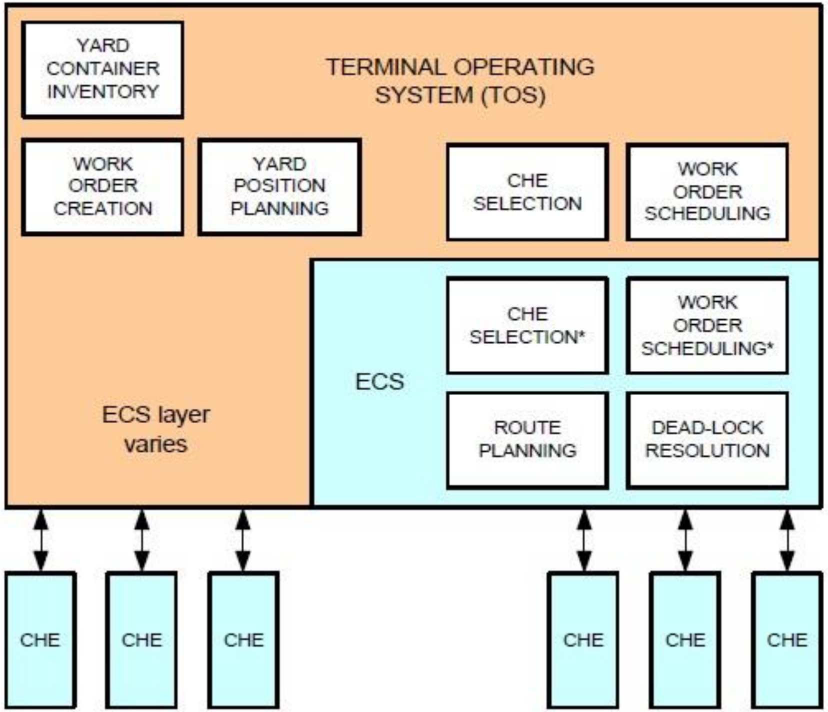
    - collision avoidance and dead-lock resolution for RMG cranes in the stack (“who will execute it’s job first”)

- At TOS level, some differences between manned and unmanned CHE; “computers do not improvise container moves”

TOS FUNCTIONS

- Maintain correct container inventory, i.e. report all container moves reported by CHE
- Plan container storage locations in terminal and create work orders
- Schedule work orders*
- Assign work orders to CHE*

*May also be performed by ECS



ECS LOCAL OPTIMIZATION ?

- ECS local optimization could improve performance:
  - Control of container positions in the blocks (based upon attribute sets and assignment etc.)
  - Scheduling the order and dispatching at the time of transport
  - Selection of CHE to execute a particular transport order

TYPES OF CONTAINER MOVES IN ASC OPERATION

- The challenge in performance measurement is the large spectrum of operations:
  - Container storage into the stack (LS/WS)
  - Container retrieval from the stack (LS/WS)
  - Shuffling moves (retrieval only)
  - Housekeeping moves (night-time)

Container moves per hour (cmph) typically mesures only "productive" container moves:
container storage to stack
container retrieval from stack

Performance decline 1:

- Long move distances (trans-shipment vs. through-the-stack)

Performance decline 2:

- "Shuffle" container moves (digging containers)

Performance decline 3:

- Housekeeping moves

CRANE PERFORMANCE FACTORS

- Top speeds significant when move distances long (e.g. end-loaded design)
- Optimized trajectories, e.g. minimize hoisting, if possible (collision avoidance)
- Theoretical “minimum-time” cycle times not reached in practise (speed vs. accuracy)

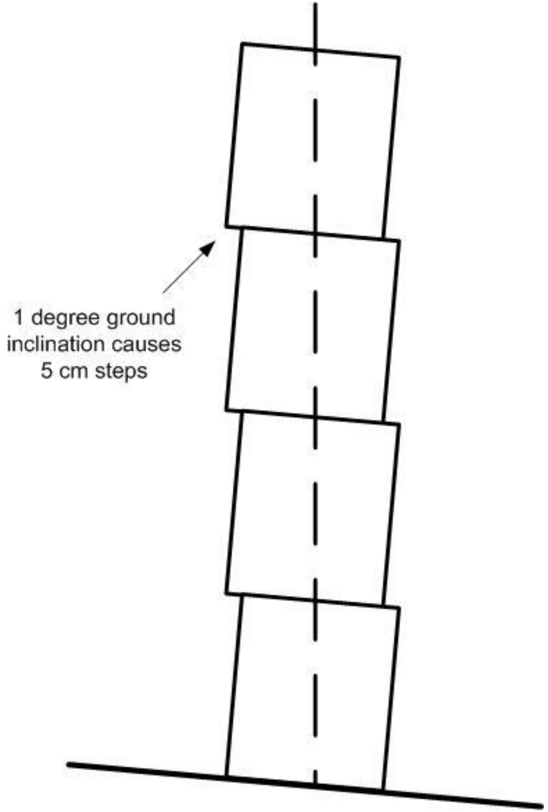
Theoretical kinematic performance is defined by top speeds and acceleration ramps
Performance improvement 1: Optimized trajectories from A to B (simultaneous trolley, hoist, gantry moves. i.e. ”shortest path” moves)
Performance decline 1: Automation delays (sensor scanning times, slow-speed approach, stacking re-tries).

STACKING ACCURACY

- Stacking accuracy requirements often given as the maximum admissible offset between successive containers in the stack (typically e.g. 5 cm).

- However, there may also be a given limit between top and bottom containers.

- If terrain is not level, conflict may arise between these two requirements



PERFORMANCE AND WAITING TIMES

- Define clearly, what kind of performance is measured
- ECS intelligence plays a role in minimizing waiting times
- ASC performance benchmarks typically include only house-keeping -type of moves (e.g. buffered interchange zones)

Peak performance = Single ASC performance with no idle time
Performance decline 1: • Multiple ASC synchronization in stack (colli-sion avoidance, dead-lock resolution)
Perfromance decline 2: • Synchronization with horizontal transport (i.e. waiting times)
Performance decline 3: • Teleoperated workphases (e.g. landside handling)

KEY PERFORMANCE INDEXES

- Simple numerical indices to define performance ?
- Over-simplification should be avoided due to the variety of container stacking operations.
- KPI's more suited for following the trends in a particular operation than comparing two completely different operations

KEY PERFORMANCE INDEXES, EXAMPLES (1)

- Moves per hour (per crane or per stack)
  - Affected by ASC stack integration to terminal operations
  - Separate KPI's for WS, LS and intra-stack moves

- Cycle time
  - "Full work cycle for one ASC without external or internal waiting times"
  - Separate KPI's for WS, LS and intra-stack moves

KEY PERFORMANCE INDEXES, EXAMPLES (2)

- Truck service time
  - Could be defined as the total time that the truck is present on LS ASC interchange area
- Truck turn-around-time
  - Entire time a trucker is needed on site, (i.e. the time measured starts when the truck arrives at the terminal and ends when the truck leaves the terminal.

KEY PERFORMANCE INDEXES, EXAMPLES (3)

- MMBF and MTBF
  - MMBF = mean moves between failure (preferred)
  - Define “failure” clearly, e.g.: “event that causes a stop of the crane, excluding third party impacts, external factors, (damaged containers, containers displaced by wind, wind speeds greater than specification), incorrect operation and such exceptions to remote operator that could be safely handled and reset without maintenance actions.”

KEY PERFORMANCE INDEXES, EXAMPLES (4)

- Availability
  - For example: “crane ready to use (excluding planned stops such as maintenance) in ratio to the time of the crane where it is supposed to be in operation”.

SIMULATED SCENARIOS

- Due to large spectrum of different operations in ASC stack, it may be difficult to describe performance with KPIs, e.g. for tendering process.

- Predetermined scenarios by given job-order lists of container moves.

- Performance of ASC or stack defined based on, for example, the time needed to perform the scenario.

SIMULATED SCENARIOS

- Scenario to be simulated by the equipment provider using a realistic model of ASC stack
    - It is typically necessary to include the ECS also in simulation to model the delays caused by, for example, multi-crane coordination and dead-lock resolution
- After the installation of the site, these simulations are typically to be proven by field tests, i.e. to show that the simulation model was realistic.

SIMULATED SCENARIOS

- Performance simulations typically without external events that require synchronization, (for example, only using housekeeping moves or buffer areas for feeding in new containers and delivering containers out).

- Forced or free job order selection ?

- Forced or free crane selection ?

  - Theoretically, free job order and/or crane selection by ECS could improve performance
  - “TOS emulation”

SIMULATED SCENARIO, EXAMPLE

- The total number of moves in this kind of test scenario is typically several hundred

Move number	Sequence number (optional)	Container id	Container size	Weight	Crane number (optional)	From-slot	To-slot	Note
1	1	c1	20	2.0t	1	LS-02	ST-35-07-02	From truck to stack
2	3	c2	40	10.0t	1	LS-04	ST-38-09-01	From truck to stack
3	5	c3	40	10.0t	1	ST-20-01-02	ST-20-09-03	Shuffle move
4	7	c4	40	4.0t	1	ST-20-01-01	LS-01	From stack to truck (remote operated phase assumed constant duration)
5	9	c5	20	2.0t	1	ST-13-03-04	ST-13-04-02	Shuffle move
6	11	c6	40	10.0t	1	ST-13-03-03	ST-13-04-03	Shuffle move
7	13	c7	40	4.0t	1	ST-13-03-02	LS-03	From stack to truck (remote operated phase assumed constant duration)
8	15	c2	40	10.t	1	ST-38-09-01	ST-12-03-01	House-keeping
9	17	c1	20	2.0t	1	ST-35-07-02	ST-13-02-02	House-keeping
10	2	c8	20	2.0t	2	WS-01-01	ST-10-07-02	Waterside to stack (transshipment)

SUMMARY

- For unmanned cranes, relevant to measure crane performance in terms of cycle times, rather than gantry, trolley and hoist speeds.
- Simple KPIs for defining performance:
  - Over-simplification should be avoided due to the variety of container stacking operations.
- Simulated scenarios:
  - Realistic simulation model to be provided by equipment manufacturer, including ECS

THANK YOU !