Putting AGVs to the test

A recent simulation into the use of cassettes with AGVs provided evidence that they could improve crane utilisation rates, writes **Dr Lawrence Henesey**

DUE TO GLOBALISATION and the growth of international trade, many container terminals are trying to improve performance in order to keep up with demand. The transport of containers is continuously growing and many terminals are subject to congestion and capacity problems. Enormous pressure is on terminal management to find more efficient ways of handling containers, and increasing terminal capacity.

One technology that has been proposed is the use of cassettes with Automated Guided Vehicles (AGVs) or manned translifters in container handling within terminals.

The use of AGVs is not a recent development. The first AGV system was introduced in 1955 for horizontal transport of materials, and AGVs were first used for transporting containers in 1993 in Rotterdam's Delta/Sea-Land Terminal. There has been much subsequent research into incorporating AGVs into container terminals.

Following two EU-sponsored projects – IPSI (Improved Port Ship Interface), and INTEGRATION (Integration of Sea Land Technologies) – an optimised system for handling containers using cassettes and AGVs has been developed and a manual version has recently been implemented at APM Terminals' new US east coast hub in Portsmouth, Virgina.

The cassettes are steel platforms – detachable from the AGV – on which containers can be set for transporting.

The containers can be double-stacked so that either 2x40ft or 4x20ft containers can be moved. This is possible since the cassettes are able to handle 80 tonnes (there are examples of 120-tonne versions used in the steel industry).

One of the advantages of using cassettes is their ability to act as a "floating" buffer, since containers can be placed on it without an C-AGV or a Translifter (equipment used for the manual version) being attached. Thus, this decoupling action gives the C-AGVs the possibility to be more productive.

To evaluate and test this new development, TTS Port Equipment was contracted by a major global terminal operator to work with a third-party simulation company, TBA Nederland, to compare four types of horizontal transport systems: Cassette-AGVs (C-AGV), conventional AGVs (AGV), Shuttle Carriers (Shc) and Automated Shuttle Carriers (AShc).

In the problem studied, two scenarios were identified in which ships arrive at a container terminal during a 24-hour period with 2,000 containers to be unloaded and loaded.

The first scenario, presented in Figure 1, has six quay cranes (QCs) operating at an average of 45 crane cycles per hour (ccph). The cycle time is 80 seconds, leading to 297 box-moves/hour with 36 RMGs (Rail Mounted Gantry Cranes that could be automated) assigned to 18 RMG modules.

In the second scenario, presented in Figure 2, 10 QCs are assigned with an average of 45ccph. Cycle time is also 80 seconds leading to 495 box-moves/hour and 60 RMGs are assigned to 30 RMG modules.

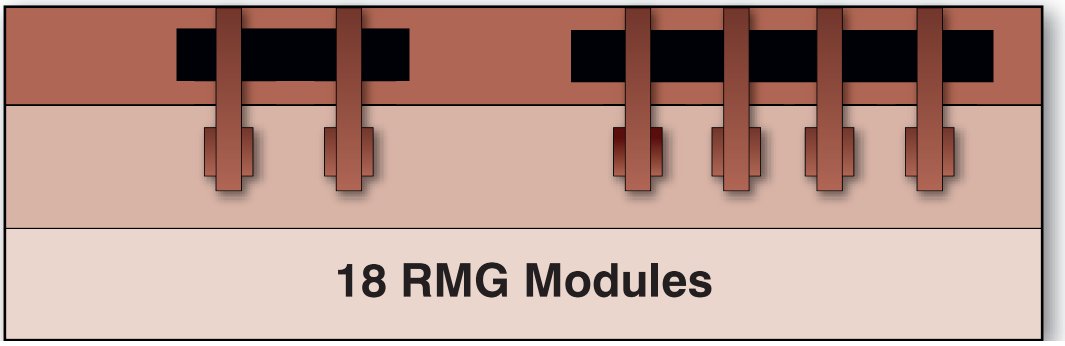
In both simulations, the twistlock handling is conducted within the crane cycle; 20% of the containers are twin-lifted; and all vehicles can twin-carry (resulting in 11% twin-lift cycles).

A relatively low landside load (166 box/hour) is implemented in order to avoid this becoming a bottleneck and to focus more on comparing horizontal transport systems.

The backreach area behind the QCs have a 10 second penalty on the cycletime. The RMG modules are configured to be 60teu long, 8teu wide and 5teu high at an 80% filling rate.

Furthermore, a number of

Figure 1. Scenario with 6QCs



A manual version for handling containers using cassettes and AGVs has recently been implemented at APM Terminals' new US east coast hub in Portsmouth, Virgina

transfer points (TPs) and highways are configured in the traffic setting in the simulation with the assistance of the terminal experts. The traffic rules implemented are:

- Four waterside RMG TPs for the AGV model
- Five waterside RMG TPs for the C-AGV model
- 5x4teu TP ground slots for the ShC model
- 5x2teu TP ground slots for the AShC model
- 4 ShC highways
- 4 AGV/AShC/CAGV highways

It is important to note that the C-AGVs are free-roaming in that there are no fixed paths marked into the pavement.

Instead of installing transponders, the C-AGVs incorporate the latest technology developed by Danaher Motion, which has been implemented in over 1,000 applications including Disney World, and the navigation is based upon Micro Radar and laser.

The navigation system assists the C-AGVs to execute a myriad number of moves, such as crab-walking and bi-directional. The C-AGV can either remain with the cassette or pick up the next cassette for an accessible QC.

The two QC configurations use four TPs for each QC. Traffic between the TPs of these QCs is not possible. This is done to maintain the balance between all QCs in the assignment. Additional traffic assumptions were made for each of the horizontal transport systems for comparison in the simulation.

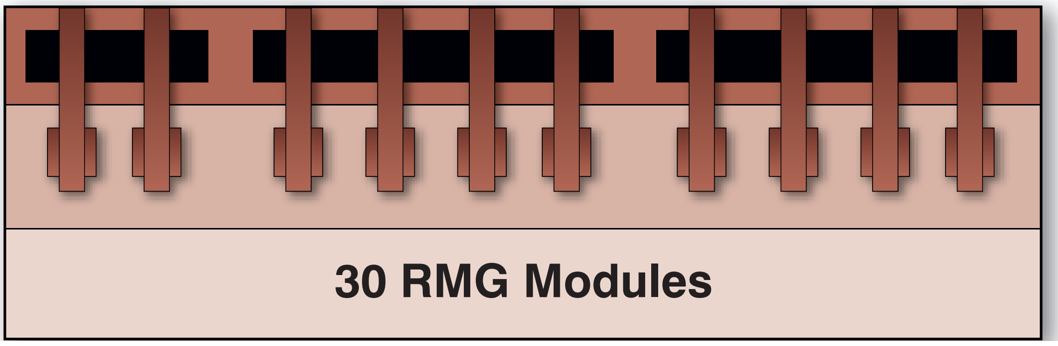
Additional input values defined by the terminal experts for the various horizontal equipment are: maximum straight speed, curve speed, acceleration and deceleration speed, interchange time, and position time.

Some of the RMG values considered in the simulation model were: gantry speed, acceleration, deceleration, trolley speed, trolley acceleration and deceleration, spreader speed, spreader acceleration and deceleration, and interchange times.

In a further test, the conventional AGV's results indicate that 42 vehicles would be required to maintain the QCs at 42 box-moves/hour, while the C-AGV results in 24 vehicles needed. Similar to the C-AGV results are the AShc, which requires 24 vehicles. Finally, the manned shuttle carriers, Shc, would require 18 vehicles.

The simulation results that were conducted for the second scenario, in which 10 QCs are employed, are similar to the first

Figure 2. Scenario with 10QCs



scenario. The number of AGVs required to keep all 10 QCs productive at 42 box-moves/hour would be 70 vehicles. The number of C-AGVs and AShc is similar at 45 vehicles each. Finally, the Shc shows that 35 vehicles would be required.

The results of both scenarios are compiled in Table 1 for comparison. The number of vehicles required per QC is similar between the scenarios.

Table 1: comparison of horizontal transport systems and scenarios

System	10 QCs: Required vehicles per QC to reach 85% of the possible QC productivity @ 45 ccpc	10 QCs: Required vehicles per QC to reach 90% of the possible QC productivity @ 45 ccpc	6 QCs: Required vehicles per QC to reach 85% of the possible QC productivity @ 45 ccpc	6 QCs: Required vehicles per QC to reach 90% of the possible QC productivity @ 45 ccpc
Cassette AGVs	3.5	5.0	3.5	4.5
Regular AGVs	6.5	8.0	6.5	8.0
Shuttle carriers	2.5 (3)	3.5 (4)	2.8 (3)	3.5 (4)
Automated shuttle carriers	4	na (not able to reach this level)	3.5	4

Table 2: Specifications of AGV systems

	C-AGV	AGV
Speed in km/h	20	15
Max. Transport Capacity in TEUs	4	2
Lifting/lowering time	15 sec	n.a.
Capital cost in millions of US$ (includes navigation system)	0.5	0.39
Capital cost per cassette in US$	11,500	n.a.

Table 3: settings examined in the simulator for a single ship

	AGV Type: C-AGV	AGV Type: AGV
No. of Containers	493	493
No. of QCs	3	3
No. of Cassettes per QC for each C-AGV	1-4	n.a.
No. of AGVs per QC	1-5	1-5
Range of container handling time for QC in min.	1-2	1-2
Range of AGV travel cycle time in min.	3-6	3-5

The most significant results suggest that the C-AGVs and AShc are similar in productivity. The lowest productivity is the conventional AGVs, and the highest is the more expensive manned system, the Shc. Unfortunately, according to the simulation consultants, the AShc could not reach 90% of QC productivity.

Further questions arose, such as comparing operating costs for the various horizontal transport systems, and choice of dispatching strategies for the AGVs.

To analyse these questions, a simulation model was implemented. The system modeled an automated container terminal comparing C-AGVs and AGVs for serving a single ship. We focused on modeling the operations that involves the QCs and the AGVs that transfer containers or containers on cassettes between the quay and stacks.

The time it takes to perform a transport move (including the return without container(s) as well as the load and unloading operations) is called the AGV cycle time. The stacks are located in different areas of the yard and therefore have varying distances to the QC, implying different transport times. We model this by letting the AGV cycle time have a random component for each transport.

We also consider the time for the unloading and loading of containers from and to a ship by a QC, called the container handling time.

The technical specifications of the two AGV systems are presented in Table 2.

The performance criteria used for evaluating and comparing systems are:

- Service Time: the time it takes to complete the unload/load operations for a ship, also known in the maritime industry as "turn-around time".
- Utilisation Rate: Arrival time/Service Time (Arrival time + Idle time). The time a piece of container terminal equipment is busy, such as moving a container from the QC to a stack and Idle time is the time that it is not working. The utilisation rate for the following container terminal equipment is recorded: QC, AGV and Cassette.
- Throughput: Average number of containers handled per hour during Service time for QC, AGV and cassette.
- Total Cost: Equipment cost for serving a ship is calculated in the following ways (OPEX = operating cost per hour for a unit of container terminal equipment):

– QC cost: number of QCs x OPEX for QC x Service Time.
– AGV cost: number of AGVs x OPEX for AGV x Service Time.
– Cassette cost: number of cassettes x OPEX for cassette x Service Time.
– Total Cost: QC costs +AGV costs + cassette costs

The scenario settings were based upon data provided by industrial partners. The results from the simulations are based on average values, which necessitates that a number of simulation trials are made in order to get a valid estimation.

The cycle times used in the simulation have been determined from prior analysis in which the stack distances and maximum speeds of the AGVs were tested. We used an approximated method to calculate that 100 runs would be sufficient. In the simulation experiments, we use the settings listed in Table 3 for serving a single ship.

An "average ship" is used in which 493 containers are to be either unloaded or loaded. From information that was provided by operators, the number of QCs to serve the ship is determined to be three.

The AGVs possess a

random travel cycle time ranging between three to five minutes. Cycle time for the C-AGV includes the lifting of a cassette, transporting it from a QC to a stack, detaching the cassette and then returning to the QC with an empty cassette; or the cycle time for the opposite direction. The cycle time for AGVs is similar to C-AGVs, but does not have a lifting time for transporting a cassette.

Simulation experiments were run to evaluate various combinations of allocated terminal resources in serving three QCs.

Ship service time results suggest that when three or more C-AGVs operate with two or more cassettes each, the service time is close to its smallest value and the capacity of the QCs becomes the bottleneck. Ship service time results for the AGV system are similar to the C-AGVs when assigned with one cassette.

The average ship service time appears to be faster at 5.13 hours when two or more C-AGVs are assigned with two or more cassettes. The fastest ship service time is 4.10 hours using five cassettes and either four or five C-AGVs. The use of an additional C-AGV when using five cassettes appears not to influence the ship service time.

An increase in the number of cassettes and AGVs adds extra capacity for transporting containers.

The extra capacity provided by cassettes allows the C-AGVs to decouple the load of containers that can number 1-4teu on a cassette and fetch another cassette. This activity assists in lessening the idle time of the QCs so that they can be more productive.

Thus, from the above results it can be concluded that it is useful to introduce a certain amount of C-AGVs and cassettes to maintain crane productivity throughout the simulation. As crane operating cost is higher than the AGV operating cost, these results can be helpful for container terminal management in deciding, for example, how many cranes, C-AGVs or AGVs, and cassettes to be allocated to a ship.

In Table 4, the total operating costs for employing the three types of container terminal equipment is presented. The assumed hourly operating costs include the depreciation, maintenance, labour and fuel in the following calculations:

- QC: $130/hour
- AGV: $6/hour
- C-AGV: $8.5/hour
- Cassette: $0.07/hour

The operating costs for both AGV systems increase as more AGVs are used. However, C-AGVs operating costs decrease as more cassettes are deployed to work with each C-AGV. There exists a trade-off in that additional cassettes increase the operating costs associated for cassettes, hence the need to consider the total costs.

In comparing the total operating costs in Table 5, the addition of AGVs and cassettes leads to lower costs until three C-AGVs and three cassettes are employed. The total costs when adding further equipment increases, and the time gained does not compensate for the extra costs. A possible choice for assigning container terminal equipment in the scenario studied would be the use of three C-AGVs with three cassettes each.

The cassette-based system (C-AGV) possesses some advantages in that it provides container terminal management with a suitable means for maintaining the QCs to keep unloading/loading and not having to wait for a transporter to become available. Waiting time is lower for the QCs and thus they are obtaining better utilisation rates.

The initial results from the prototype C-AGV simulator provide some interesting observations useful for determining the number of units to allocate for serving a ship. The experiments also point to a trade-off between service time and the costs for purchasing and operating equipment. ■

Table 4: Total terminal equipment operating costs (US$)

No. of AGV	No. of Cassettes 0	+1	+2	+3	+4
Total quay crane operating costs					
1	3,913.5	3,841.2	3,986.2	3,685.2	3,599.4
2	2,787.2	2,742.2	2,001.4	1,910.5	1,865
3	1,812.9	1,786.9	1,682.4	1,650.3	1,650.3
4	1,689.2	1,676.3	1,663.3	1,617.8	1,598.4
5	1,637.2	1,637.2	1,630.8	1,6111.4	1,598.4
Total AGV operating costs					
1	185.8	260.6	254.6	244.2	238.6
2	264.9	363.7	265.4	253.4	247.3
3	258.5	355.4	334.8	328.3	328.3
4	321.1	444.7	441.2	429.2	424
5	389.2	543.1	540	534.2	529.9
Total cassette operating costs					
1	n.a.	2.2	4.4	6.2	7.9
2	n.a.	3	4.5	6.3	8.2
3	n.a.	3	5.6	8.2	10.9
4	n.a.	3.7	7.3	10.8	14.1
5	n.a.	4.6	9	13.4	17.7

Table 5: total operating costs (US$) for serving a ship

No. of AGV	No. of Cassettes 0	+1	+2	+3	+4
1	4,096.7	4,193.7	4,099.1	3,934.7	3,846.5
2	3,052.1	3,108.4	2,270.3	2,169.3	2,119.6
3	2,071	2,144	2,023.1	1,986.9	1,989.7
4	2,010.5	2,124.6	2,111.8	2,057.7	2,035.7
5	2,025.6	2,183.9	2,179.8	2,158.3	2,145.4

Dr Lawrence Henesey is business development manager of R&D for TTS Port Equipment, and assistant-professor at the Department of Systems and Software Engineering, Blekinge Institute of Technology, Sweden.

Concurrent with his research on improving the performance of container terminals by applying Artificial Intelligence techniques, Henesey devotes half his time to business development of new port technologies at TTS.