Introduction
The Port of Singapore Authority (PSA) was founded in 1964 and is nowadays one of the world’s leading companies in container handling. PSA’s core business is loading and discharging vessels. The company is currently active in sixteen countries, including the PSA HNN terminals in Belgium and the Voltri Terminal Europa (VTE) in Genoa, Italy.

Quay Cranes are used for loading and discharging the containers of the vessel. In many terminals, Gantry Cranes are used to stack the containers in the yard and Prime Movers are used for the transportation of containers between the quay and the yard. Finally, trucks are used for the transportation between the yard and the mainland.

Problem Formulation
The project setting is at the yard where both Prime Movers and trucks have to be served by the same Gantry Crane. Prime Movers bring containers to the stack, where trucks come to pick up containers from that stack. Always serving trucks will lead to low throughput at the quay, while always serving prime movers might lead to gigantic traffic jams, blocking even the public road system. The project goals are:

- To analyze the performance of service disciplines (i.e., the rule that the Gantry Crane driver uses to choose between serving a Prime Mover and serving a truck)
- To describe a good policy that is not too complicated to be used in practice
- To optimize the number of Prime Movers
Mathematical Model
We assume that the discharging process is a never-ending continuous process that is not interrupted by any other loading or discharging process. We have chosen two performance measures:
- Long-term fraction of time that the Quay Crane is idle (“Idle time”)
- Average waiting time of trucks
The container discharging process by the Quay Crane is split in two phases. The first phase (discharging from the vessel) can already be performed before the arrival of the Prime Mover at the quay. In the second phase, the container is loaded onto the Prime Mover.

Solution Approach
We assume that the service times and the inter-arrival times of trucks at the terminal are exponentially distributed. Then, the problem can be formulated as a Markov Decision Process in which we minimize a cost function. This cost function can be interpreted as a weighted average of the two performance measures. The optimal service discipline can be iteratively derived from the Markov Decision Process.

Results
We do the analysis for both a fixed and a flexible number of Prime Movers. If the number of Prime Movers is flexible, a Prime Mover can be removed from or added to the quay. We investigate the effect of the input parameters (e.g., mean service time) on the optimal service discipline and the corresponding performance. We also discuss service disciplines that can be easily applied.

<table>
<thead>
<tr>
<th># Prime Movers (PMs) at the yard</th>
<th>Serve PM if QC in 1st Phase and:</th>
<th>Serve PM if QC in 2nd Phase and:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>#trucks ≤ 4</td>
<td>#trucks ≤ 9</td>
</tr>
<tr>
<td>2</td>
<td>#trucks ≤ 11</td>
<td>#trucks ≤ 14</td>
</tr>
<tr>
<td>3</td>
<td>#trucks ≤ 15</td>
<td>#trucks ≤ 16</td>
</tr>
</tbody>
</table>

In this example, a Prime Mover has to be served if the Quay Crane (QC) is idle (i.e., 3 PMs at the yard and QC in 2nd phase) and the number of trucks at the yard is 16 or lower. The idle time is 8.4% and the mean sojourn time of trucks 15 minutes.

Conclusions
We conclude that the optimal service discipline can be described by thresholds, which depend on the phase of the Quay Crane and the number of Prime Movers at the yard and the quay. The Gantry Crane has to serve a Prime Mover if the number of trucks is lower than this threshold. An error in the measurement of the Gantry Crane service rate can have a big effect on the performance. However, it does not matter if the Gantry Crane driver does not know the phase of the Quay Crane. But, an estimation of the number of trucks is necessary for a good performance.

Contact
For further information please contact: Ivo J.B.F. Adan, iadan@win.tue.nl, +31 40 247 2932

Mathematics for Industry

Web site  http://www.win.tue.nl/oowi/  Department of Mathematics and Computer Science
Phone    +31 40 247 4759 / 2808  Mathematics for Industry
Fax      +31 40 247 2717  P.O. Box 513
Email director s.j.l.v.eijndhoven@tue.nl  5600 MB Eindhoven
Email secretary w.w.p.warringa@tue.nl  The Netherlands