Summary

The objective of this research assignment is to extend the Duinkerken (2006) study of AGV routing with performance results of terminals using fixed guide path layout (loop, mesh) using Möhrings algorithm (2008, 2004) for AGV routing; this was done by building a computer simulation model. Routing is the process of determining routes for a set of AGVs to fulfil their respective transportation jobs.

The research goal of the study by Duinkerken was to compare the theoretical capacity of terminals using fixed routing with terminals applying a linear cross-over approach. Duinkerken built a discrete event model to compare performance of different trajectory planning strategies and presents performance indicators in the form of jobs completed per hour for a certain number of AGVs.

In the work by Möhring, a dynamic online AGV routing model for an arbitrary graph is studied. The goal of Möhrings algorithm is to compute a shortest path with respect to costs (costs = transit time + possible waiting time) that respects the given time windows. The main advantage of this algorithm is that the time-dependent behaviour of the AGVs is fully modelled, such that both conflicts and deadlock situations can be prevented already at the time of route computation. Another key ingredient of the algorithm is the representation of the physical dimensions of the AGV by using so-called conflict sets.

Two important interpretation decisions were made concerning the implementation of Möhrings algorithm: first, in our interpretation, because of simplicity purposes, conflict sets are not determined by polygons; a simplified way to develop these was used. Second, because it is unclear what Möhring exactly means "shortening, erasing or leaving unchanged the time windows" as well as where he would allow AGVs to wait, in our interpretation, AGVs are not allowed to wait en-route but only on a quay- or stack crane location.

From these assumptions, a computer model was built for the experiment, which was subsequently verified and validated. Then an experiment has been conducted using this model. The objective was to provide performance indicators (e.g. jobs/hour for set number of AGVs, transport distance) for loop- and mesh-layout variants and compare them to results of Duinkerken.

Two hypotheses were constructed; hypothesis nr. 1: "*A high-resolution, mesh-layout, AGV routing system making use of Möhrings algorithm, will result in a smaller capacity (jobs/hour for a set number of AGVs) than the cross-close- and cross-safe variants researched by Duinkerken, 2006.*"
Hypothesis nr. 2 was defined in the following way: "*When more AGVs are added to the same grid-layout, the number of jobs per hour performed will increase less than linear and will eventually even decrease. In other words: adding AGVs to the network ultimately has an inversed-proportional effect on harbour capacity due to congestion.*"

In the conclusions, the first hypothesis is rejected: although the AGV routing system that makes use of Möhrings algorithm has a smaller capacity than the cross-close variant by Duinkerken, it does have a higher capacity than the cross-safe variant.

The second hypothesis can only partially be accepted: the increase of the number of jobs completed per hour drops as the number of AGVs used in the system increases, so indeed the performance will not increase on a linear scale. But for high numbers of AGVs simulation runs take that long, that an absolute decrease in performance can not be measured. It can be concluded though, that the network is up to limits of capacity for these amounts of AGVs and probably, if the number of AGVs gets large enough, this effect will result in an absolute decrease in performance.

Some other congestion effects can also be observed: above 35 AGVs the wait time approaches the order of magnitude of the travel time to complete the route. Also it can be observed that above 25 AGVs the average distance travelled already increases about 10%.

For higher number of AGVs some park conflicts occur, but this effect remains marginal compared to the number of park conflicts for the cross-close and cross-safe variants researched by Duinkerken. This difference is probably due to the fact that in the cross-close and cross-safe variants, travel time is much shorter and wait time much longer.

Concluding the report, it is recommended to see in future research what the effects on harbour performance are when en-route waiting is allowed. Another recommendation is to research the effect of grid resolution on performance and to research wait times for the cross-close and cross-safe variants researched by Duinkerken (and compare them with results of this research). Finally, it is recommended to research the effect of Möhrings algorithm on the performance of a harbour using a loop layout.