Summary

Since the introduction of containerized trade in 1956, containerization has spread across the globe and still shows a strong yearly volume growth. This growth supported port expansions all around the world and in the case of the port of Rotterdam the growth in container volume contributed in the port expansion project Maasvlakte 2. The Maasvlakte 2 is constructed next to the already existing Maasvlakte 1 area and increases the ports total container capacity up to almost 35 million TEU annually. To be able to transport all this cargo efficiently through the combined Maasvlakte area an Inter Terminal Transport (ITT) system is considered.

In Diekman and Koeman [2010] a few scenarios are presented containing future ITT demands. These scenarios were used by Tierney et al. [2012] as an input for building an integer optimization model, which optimizes the flow of containers and vehicles through the Maasvlakte area by minimizing the occurred delays of containers. With this model the researchers try to provide a tool for the Port of Rotterdam Authority to be able to determine the specifics of an ITT system which can guide them in their decision making process. In order to determine the performance of the integer model this report will find an answer to the research question: to what extent will the model of Tierney et al. [2012] give reliable and realistic results and what improvements could be made to increase its reliability?

To be able to give an answer to this question a model based on the same working principles as in Tierney et al. [2012] has been build in Matlab using the CPLEX for Matlab integration to solve the optimization. First the basic principles of the model are presented, followed by model structure including assumptions, constraints and objective. Finally a verification is made where the model is verified for small scale models after which a conclusion can be drawn about the reliability and realism of the model.

This research will contribute to the understanding of the feasibility and realism of integer programming models for ITT systems. Also a critical view on the research presented in Tierney et al. [2012] is given, which may result in an update of their paper. It will also provide some recommendations for further research to make an integer programming model more realistic and reliable.

The mathematical principles of the integer model are based on the minimal cost flow theory using a graph or network consisting of nodes and arcs, where flows can travel through this network from a source node to a sink node. A time expansion is added, which copies the base graph and makes layers of the base graph on top of each other. The layers are connected by adding arcs between the same nodes through time which are called stationary arcs. The arcs connecting different nodes to each other in the base graph will now be connected from a node to the other node one or several layers above. A representation of the time expanded model containing two nodes is shown in Figure 2.2. To add multiple demands of containers to model, the multi-commodity flow theory is introduced. This theory adds a new set of variables and constraints for each individual demand to the network ensuring that demands will flow correctly through the network.

The ITT system is build from a base network, where each terminal represents a node which is connected to an intersection, terminal or LT node by arcs. Intersections are also modelled by nodes and combine the flows from all directions entering the intersection and directs them through a funnel before directed out of the intersection towards the destination. This funnel is in place to represent congestion arising at the intersection when the supply of vehicles exceeds a certain value. This funnel is modelled by creating two nodes for every intersection. These nodes
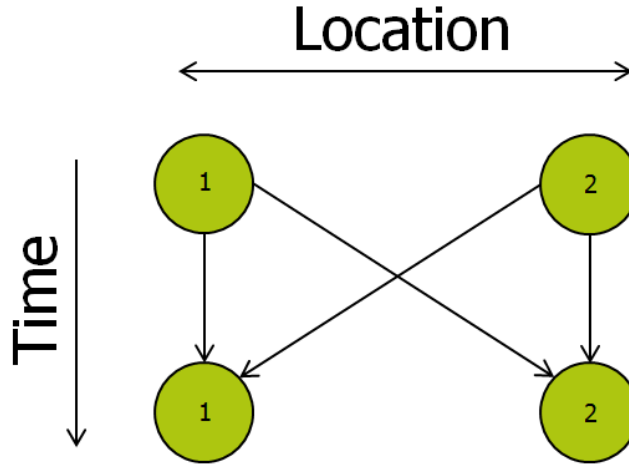
Figure 1: Representation of a time space network

are connected by so called fan arcs as presented in Kohler et al. [2002], where each fan arc is assigned with capacity and a transverse time.

Next to road vehicles the model also provides the opportunity to use other transportation options such as barges or trains. Because these options require additional loading and unloading time LT nodes are introduced to be able to implement a correct representation of long term vehicle usage. The LT node network is a separate set of variables and can therefore be added or removed from the total network when LT vehicles are present or not.

As already has been mentioned both road vehicles as well as long term vehicles can be implemented in the model. There are three possible road vehicles: Automated Guided Vehicles (AGVs), Automated Lifting Vehicles (ALVs) and Multi Trailer Systems (MTSs). At this stage, one type of LT vehicle can be incorporated: barges. These vehicles have several assigned properties such as speed, handling rate and load quantity. These properties are used to realistically constrain the flows through the network.

The vehicles will transport the container flows through the network. These flows are generated by a demand generator determining the number of containers to be transported, the priority of these containers and assigns an origin and destination terminal. The generator also determines the start time and the delivery or due time for the containers. This data is combined in a demand vector and can contain multiple demands, thanks to the introduction of multi-commodity flow theory. The amount of demands generated is influenced by the user who can give a total number of containers flowing through the network as an input. This total number is divided in individual demands with a random amount of containers between 1 and 50 containers.

The constraints that are introduced will constrain the model in such a way that the flow is only able to follow the arcs through the network. The flow is bounded by the demand vector, which stores the information on number of containers, origin/destination and start/delivery period. Every container flowing through the network requires a transport vehicle to do so. These transport vehicles are constraint in number and a balancing constraint ensures that it is not possible that more vehicles are able to leave a node than there are vehicles present in that node. The vehicle type also constraints the loading and unloading rate of containers at a terminal. To model congestion some additional constraints are required identifying which fan arc is allowed to have a flow over the arc. Finally all stationary arcs can be used by all vehicle types and are unconstrained in the amount of flow over the arc.

These constraints are combined and are used by the objective function to calculate the minimum amount of delay for all container demands to reach their destination. This objective function assigns a penalty to arcs entering the destination node after the given delivery time of the demand. The height of this penalty is determined by the amount of delay and the priority of the cargo.

The model has been verified for small size problems, with 2 nodes and a maximum of three time periods. This allowed the writer to manually verify the flows through the network and the optimization results. The model is verified for all vehicle types and for multi-commodity demands. The verification showed that the behaviour of the model was as expected on forehand and therefore the constraints are implemented correctly. It is also shown that the size of the problem quickly grows in size when additional vehicles or commodities are added. This makes it important to optimize the layout of the network and to reduce the amount of base variables as much as possible to limit the calculation times and required memory.

The main research question of this research is to what extent will the model presented by Tierney et al. give realistic and reliable results for the application of integer optimization models in the development process of inter terminal transportation systems? The following conclusions answer this question:

First of all it is important to realize that it is an optimization model optimizing transport routes by minimizing the total delay of containers. This means that the results are only useful when optimization of transport routes in the real ITT implementation is also incorporated in the system. Otherwise the results should be interpreted as the minimum requirements for an ITT system. However the implementation of an objective function can result in less overcapacity in the system and reduces the overall implementation and operational costs. Integer programming is easily adaptable to other port situations and a proper constructed base model can quickly provide guidelines for ITT development and decision making processes.

Unfortunately the mathematical principles also impose some drawbacks and the implementation of the model can be improved in some ways. The following itemization will give an overview of drawbacks and points for improvement.

- The discrete nature of the model imposes a drawback on the realism of operations that are performed, because operations having a duration less than one or a part of a time period will either be neglected or rounded to the nearest time period. This also makes it impossible to implement time distributions to container or vehicle operations.

- It can be questioned whether congestion will create any problems at all, because the total area covered by the ITT system is almost 30 km with a maximum amount of 125 vehicles. This means a low vehicle density which makes the chance that more than 40 vehicles at the same time will cross each other at an intersection will be small.

- ITT by barge might be unrealistic, because there are long wait times before being handled at a terminal in the Port of Rotterdam.

- The demand generator has to be improved and validated to generate more realistic demands.

- Vehicle properties used in the model are outdated and should be updated to modern standards. Also the application in ITT might change the vehicle properties, because AGVs, ALVs and MTSs are only applied on terminals, where they have a different functionality.

It is recommended for future research to validate the integer programming model to real situations or other valid models to determine its own reliability for the use in ITT development. It is also recommended to investigate how ITT vehicle planning optimization should be implemented in ports to be able to have a meaningful model.