Imperial College London

T1

# A MODEL FOR THE COST-BASED DESIGN OF LINER SHIPPING NETWORKS

Annas-Giannis Slimpi
Department of Civil and Environmental Engineering, Imperial College London

## Introduction

Due to its numerous advantages and the continuous development of the global economy, containerised liner shipping has known a rapid growth since its introduction. This growth however increases the need for operational optimization in the industry since networks become more complex and competition fiercer. Nevertheless, the number of Operational Research studies focused on this industry is limited. This study aims to develop model that will address the Liner Shipping Network Design problem, with an increased attention in the allocation of container flows in the network's links.

| 54% | 356% | 32% |
|---|---|---|
| of the world's total trade is transported by the liner shipping industry | increase in the liner shipping capacity during the last 15 years | increase in the number of ships over the same period |

## Methodology

In this model, an initial population is first randomly created and assessed based on a Key Performance Index (KPI). Then, through the application of the Genetic Operators, additional points of the solution space are evaluated until the optimal design is identified.

### Solution Representation

Each candidate solution is consisted of strings that represent the vessels' routes. Identical strings are grouped together to form services that satisfy the weekly frequency constraint.

$$\begin{Bmatrix}[1\;3\;5\;7\;4]\\ [1\;3\;5\;7\;4]\\ [2\;4\;7\;6\;3]\\ [2\;4\;7\;6\;3]\end{Bmatrix}\begin{matrix}\text{Service 1}\\ \\ \text{Service 2}\end{matrix}$$

### Initial Population

The initial population is created by a random route generator that is applied to each vessel of the fleet. During this procedure, a number of constraints is taken into account. These are:

1. **Closed form routes**
2. **Weekly service frequency**
3. **Each service is consisted of vessels of the same type**
4. **Each service cannot call at the same port more than twice**

### Chromosome Evaluation

The KPI of this model is the total network cost imposed to the shipping company, which is composed of the following components:

1. **Port call costs**
2. **Container rental cost**
3. **Cargo inventory cost**
4. **Vessel Operation Costs**
5. **Opportunity cost of the containers not transported**

The port call costs can be directly calculated by the vessels' routes. The determination of the remaining cost components however, requires the assignment of the container flows to the networks' links. This is done through the incorporation of a container assignment model developed by Acchura-Gonzalez et al. (2016).

### Genetic Operators

Genetic Operators are techniques applied in Genetic Algorithms in order to enable the exploration of the solution space. These techniques are inspired by the natural evolution processes of reproduction and mutation.

**Crossover** is the operation of information exchange between 2 or more chromosomes. In this model, the building blocks interchanged between chromosomes are consisted of entire services.

$$\begin{Bmatrix}[1\;3\;5\;7\;4]\\ [1\;3\;5\;7\;4]\\ [2\;4\;7\;6\;3]\\ [2\;4\;7\;6\;3]\end{Bmatrix}\quad\begin{Bmatrix}[7\;9\;3\;4\;2\;1]\\ [7\;9\;3\;4\;2\;1]\\ [3\;5\;8\;2\;6]\\ [3\;5\;8\;2\;6]\end{Bmatrix}\quad\longrightarrow\quad\begin{Bmatrix}[1\;3\;5\;7\;4]\\ [1\;3\;5\;7\;4]\\ [3\;5\;8\;2\;6]\\ [3\;5\;8\;2\;6]\end{Bmatrix}\quad\begin{Bmatrix}[7\;9\;3\;4\;2\;1]\\ [7\;9\;3\;4\;2\;1]\\ [2\;4\;7\;6\;3]\\ [2\;4\;7\;6\;3]\end{Bmatrix}$$

**Mutation** is the operation of arbitrarily altering one or more port calls of the chromosome's service routes

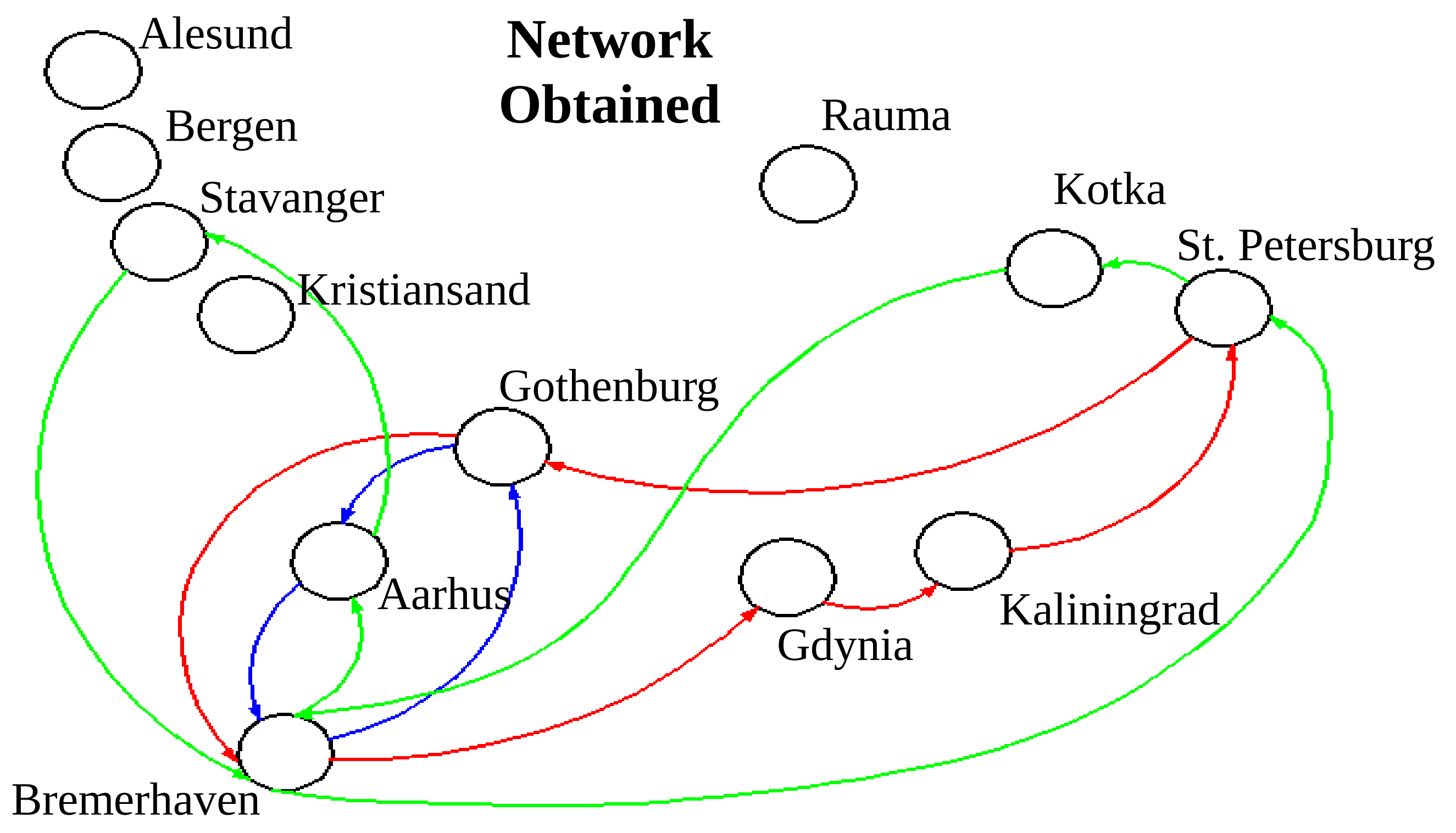
$$\begin{Bmatrix}[1\;3\;5\;7\;4]\\ [1\;3\;5\;7\;4]\\ [2\;4\;7\;6\;3]\\ [2\;4\;7\;6\;3]\end{Bmatrix}\quad\longrightarrow\quad\begin{Bmatrix}[1\;3\;9\;7\;4]\\ [1\;3\;9\;7\;4]\\ [2\;4\;7\;6\;3\;1]\\ [2\;4\;7\;6\;3\;1]\end{Bmatrix}$$

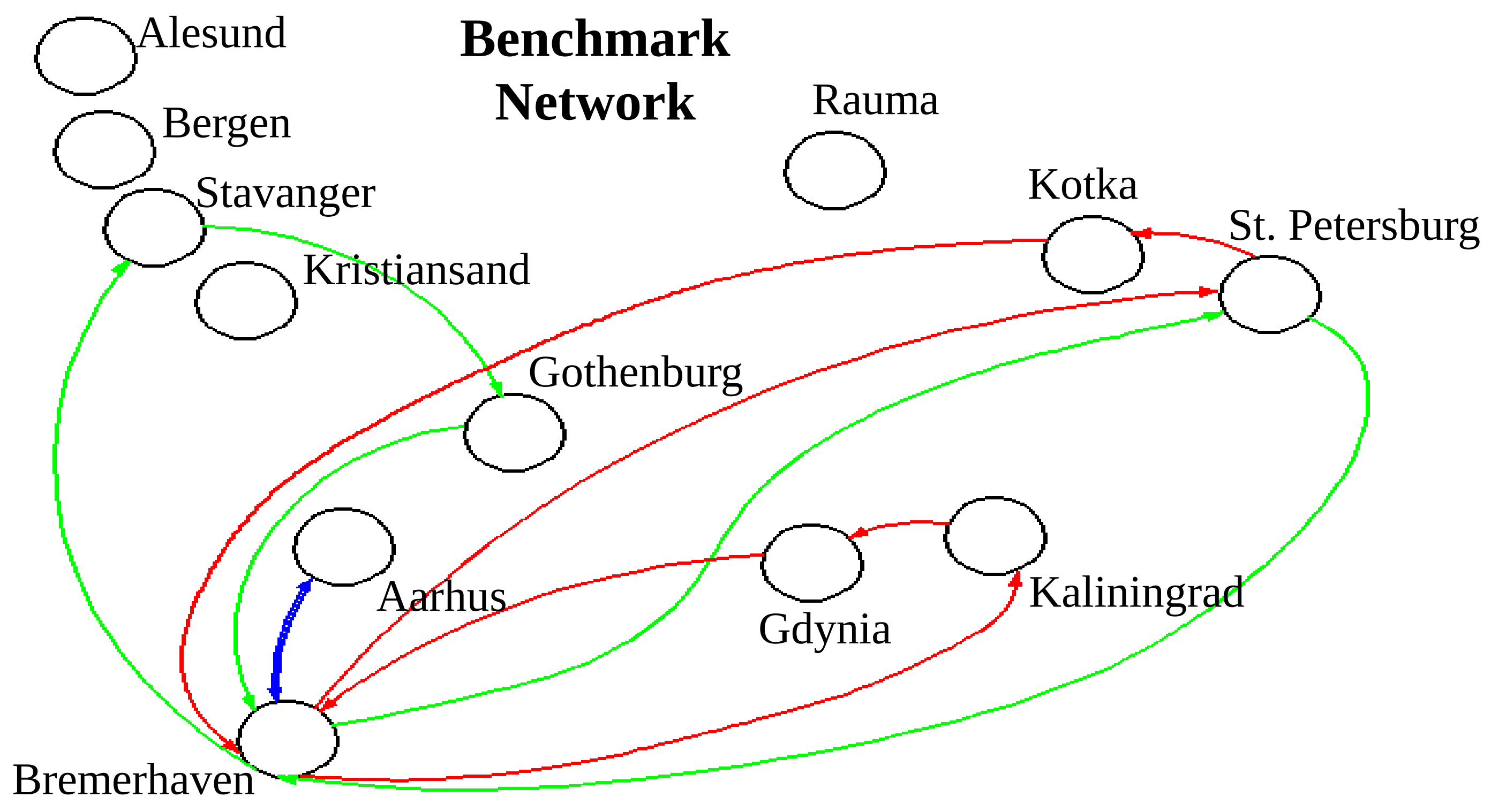
## Acknowledgements

For the completion of this report I would like to thank Dr. Panagiotis Angeloudis and Pablo E. Acchura-Gonzalez for their continuous support and supervision.

## Results

The model was applied to the Baltic Sea problem instance and the results were compared to the benchmark suite provided by Brouer et al. (2014). The comparison revealed a high correlation between the 2 networks.





| | Network obtained | Benchmark network |
|---|---|---|
| KPI | $2,154,676 | $2,482,160 |
| Number of services | 3 | 3 |
| Number of ports served | 8 out of 12 | 8 out of 12 |

Subsequently, the model's reaction to different scenarios was examined. These are:

- The relocation of the hub's position
- The simultaneous increase in the network's total demand and capacity
- The effect of slow `steaming

All the resulting networks in the 3 scenarios are justifiable and demonstrate the model's ability to adapt to changing circumstances. Thus, this model could, amongst other things, support shipping companies in their operational and strategic planning as well as international regulators in the assessment of the industry's environmental impact.

## Conclusions and next steps

The method developed consists a promising approach towards a model that addresses the Liner Shipping Network Design Problem. Its comparison to the benchmark study however, reveals that it underperforms in terms of identifying the lowest KPI. For the model's improvement and the reduction of the differences to the benchmark suite, **future work should focus on 2 directions**:

- **Improvement in the model's computational performance** through the implementation of more efficient genetic operators
- **Improvement in the results' validity** through the incorporation of additional operational aspects of the liner shipping industry

## References

Achurra-Gonzalez, P. E., Novati, M., Foulser-Piggott, R., Graham, D. J., Bowman, G., Bell, M. G., and Angeloudis, P., (2016). Modelling the impact of liner shipping network perturbations on container cargo routing: Southeast Asia to Europe application. Accident Analysis and Prevention. [Preprint]. Available from: doi: 10.1016/j.aap.2016.04.030

Brouer, B., Alvarez, J., Plum, C., Pisinger, D. and Sigurd, M. (2014). A Base Integer Programming Model and Benchmark Suite for Liner-Shipping Network Design. *Transportation Science*, 48(2), pp.281-312.