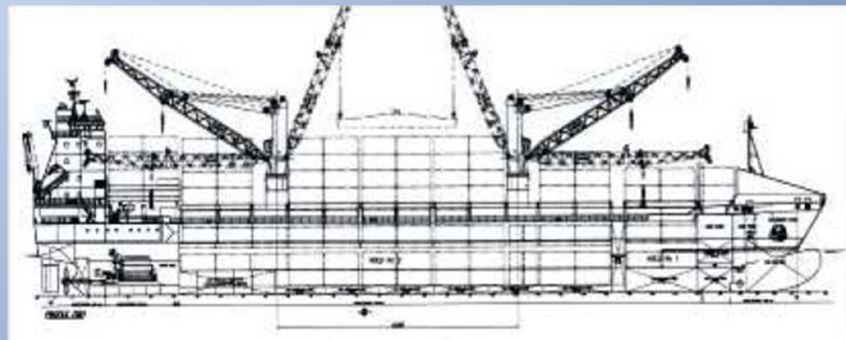
# Genetic Algorithms approach for containership fleet management dependent on cargo and their deadlines

IAME 2010 – 07/06/2010

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# Short Sea Shipping

Advantages

- Environmentally sound;
- Contribution to road safety;
- Low infrastructures cost (motorway is the sea);
- Reaches “peripheral” regions.

Disadvantages

- Customs bureaucracy;
- Port costs and efficiency;
- Dependency of environmental factors
- Travel duration;
- Inflexibility of routes.

# State of the art - optimization

- Container stowage problem (CSP)
  - ✓ Avriel *et al.* – binary programming (1993)
    – suspensory heuristics (2000)
  - ✓ Wilson and Roach – two phase method (1999)
    – branch and bound application (2000)
  - ✓ Several authors – different implementation methods

- Ship routing and Scheduling
  - ✓ Christiansen and Nygreen (1998)
  - ✓ Agarwal and Ergun (2008)

- Vehicle routing problem with time windows - supply chains
  - ✓ Gendrau et al. (2006)
  - ✓ Moura and Oliveira (2009)

# Problem definition (1)

Scenario definition:

- Five ports A , B , C , D,  E
- Distances between ports < 1000 nm  - *10 possible arcs*
- Fleet of Two containerships

  *i. dimensions*  *ii. deadweight*

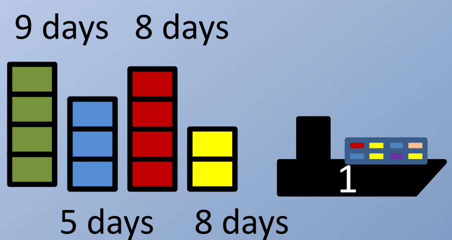
  *iii. speed*  *iv. fuel consumption*

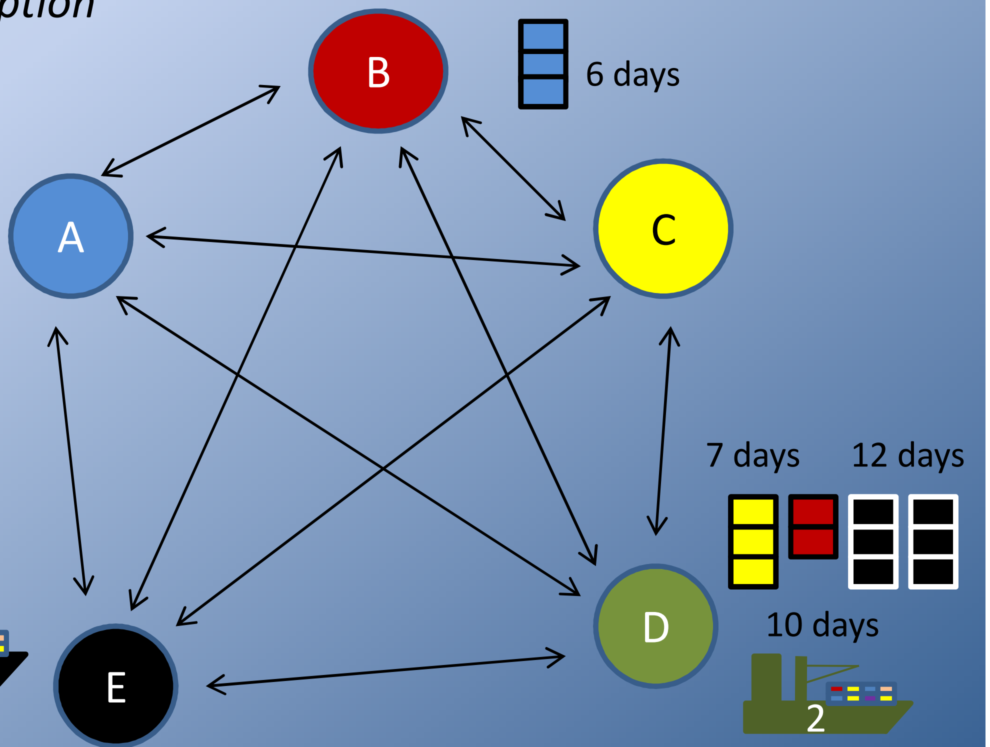
  *v. stability characteristics*
- Several containers

  *i. origin*  *ii. destination*

  *iii. weight*  *iv. deadline*
- Costs at each port

Harbour fee €
Berthing €
Facilities €
Pilot €
Duration €
ETC …



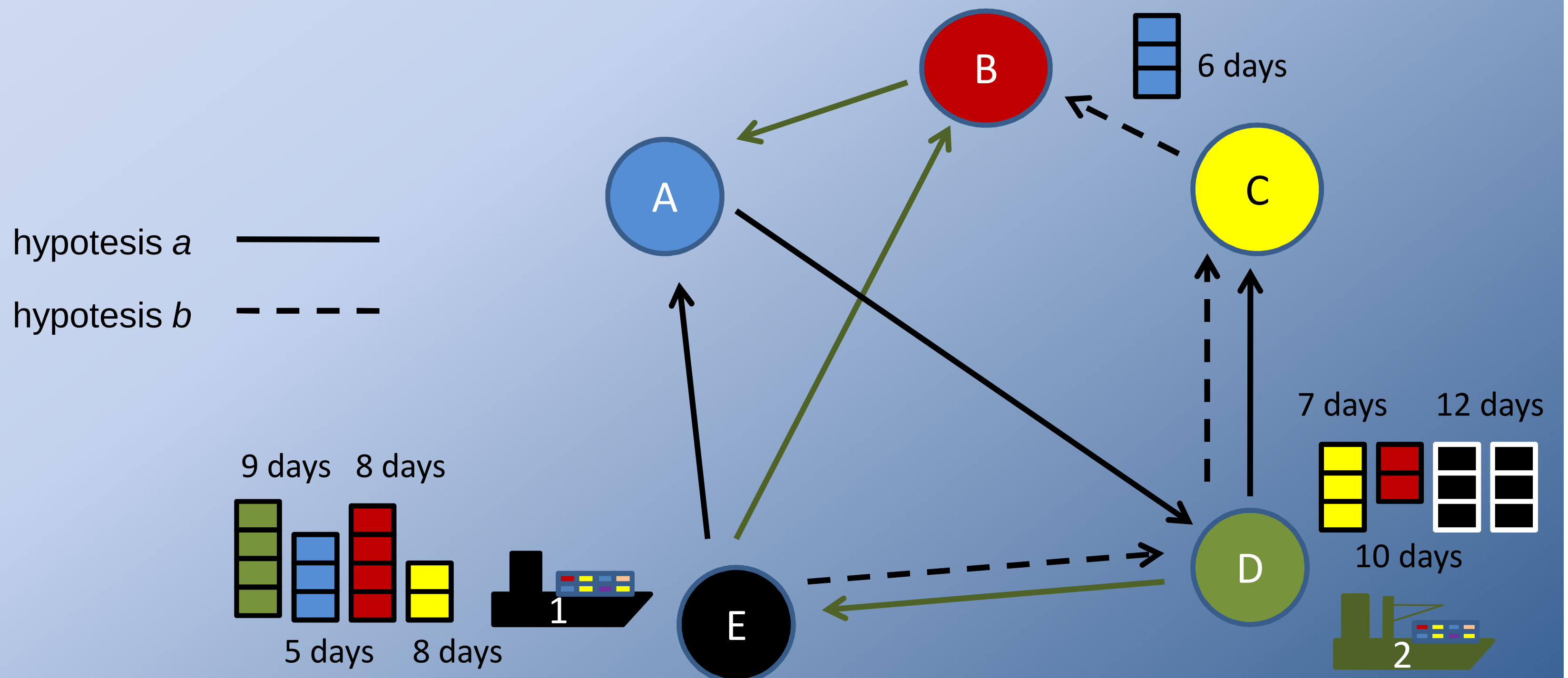
# Problem definition (2)

Stage 1

- Containers characteristics and deadlines
- Containership characteristics
- Containership operation cost

What **route for each ship?**

What **containers to carry?**

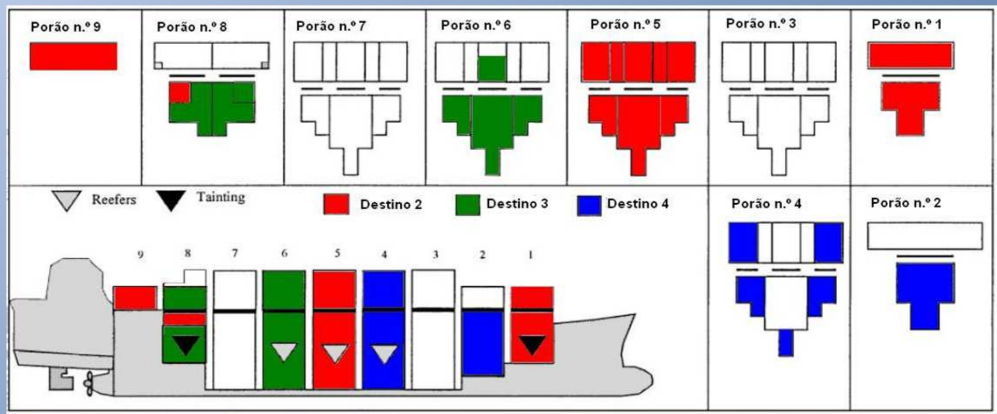


# Problem definition (3)

## Stage 2

- Containers characteristics and deadlines
- Containership characteristics
- Containership operation cost
- Containerships routes
- Containers carried in each journey

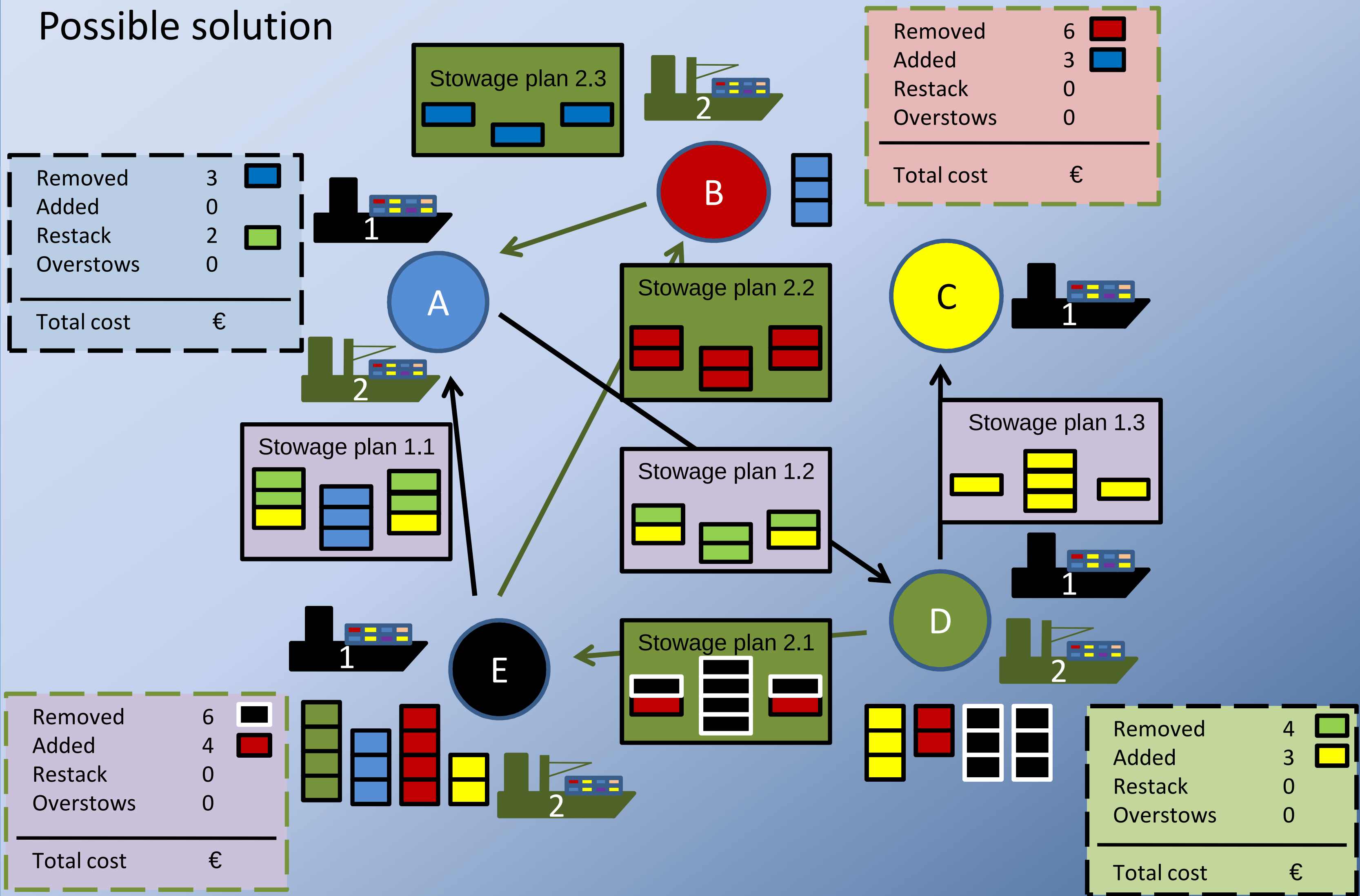
How to stow the containers




Altered from Wilson and Roach (1999)

# Problem definition (4)

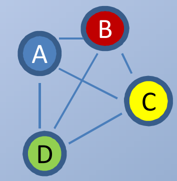
## Possible solution



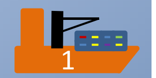
# Mathematical formulation (1)

## Input variables

- Ports and Scenario characteristics
- Vessels characteristics
- Containers characteristics
- Associated costs (money and time)




- distances;
- port fees;
- time to move each container




- dimensions
- fuel consumption;
- speed;
- slots arrangement;
- operation costs;

- weight
- origin;
- destination;
- dimensions;
- delivery deadline;

## Decision variables

very large binary matrices

- Route selection
  - for each vessel
  - at each journey
  - what's the port of origin
  - what's the port of destination
- Container distribution and stowage
  - for each container
  - what vessel carries it
  - where is it embarked
  - what journeys is it onboard
  - where is it stowed

# Mathematical formulation (2)

Objective function :

- minimize cost; AM6
- deliver all cargo within the time limits (accepted loss?) AM5

$$W_1 \sum_{i=1}^{p} \sum_{j=1 \wedge j \neq i}^{p} \sum_{k=1}^{v} \sum_{\phi=1}^{\phi_{\max}} (d_{ij} c_k x_{ijk\phi} + x_{ijk\phi} f_i)$$

Operation costs outside harbour

$$W_2 \sum_{i=1}^{p} \sum_{k=1}^{v} \sum_{\phi=1}^{\phi_{\max}} \beta_{ik\phi} \mu_{ik\phi}$$

Containers shift costs

$$W_3 \sum_{i=1}^{p} \sum_{j=1 \wedge j \neq i}^{p} \sum_{k=1}^{v} \sum_{\phi=1}^{\phi_{\max}} \sum_{\alpha=1}^{c} (Corig_{ik\phi} r_{jk\alpha\phi} + Cdest_{jk\phi} r_{ik\alpha\phi})$$

Containers load/ unload costs at the ports of origin and destination

## Diapositivo 10

**AM5** Para retirar
Ana Moura; 25-06-2010

**AM6** - Total cost minimization;

Objective function composed of three componentes
Ana Moura; 25-06-2010

# Mathematical formulation (3)

Constraints:

- route flow conservation - at each journey the vessel's port of origin is the previous port of destination; AM3
- time sequence – the vessel service at each port does not begin before she arrives there; AM2
- containers' deadline;
- vessel's capacity limit;
- containers' exclusivity – only one ship can carry each container at the same time; AM4
- cargo attribution – the vessel that carries a container has to visit its port of destination (simplification);
- slots occupation – if a slot is occupied than the ones bellow are also occupied (cargo hatches not considered).

**AM2** at each port, the time service does not begins untill the vessel arrives
Ana Moura; 25-06-2010

**AM3** if a vessel arrives at a node then it has to leave from that node to another one.
Ana Moura; 25-06-2010

**AM4** Each container is transported by one and only one vessel between ports.
Ana Moura; 25-06-2010

# Genetic Algorithms Implementation

- Formulation of the problem into two different stages:
  - a. Port sequence;
  - b. Containers distribution by vessel;
  - c. Container stowage problem.

(a–b) } 1st stage implemented

(c) } 2nd stage not yet implemented

- First stage chromosome construction:

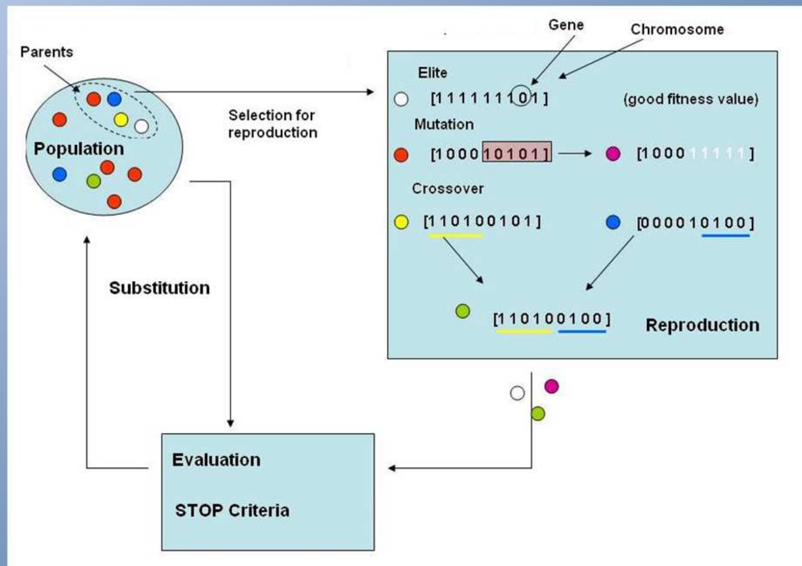
Port

[1 2 3 4 5 0 0 0 0 3 4 5 1 2 0 0 0 .... ]

Space to consider port repetition

Route for vessel 1 Route for vessel 2

Biological evolution




- Matlab and University of Aveiro Operators used

# Implementation Results

# Example – scenario

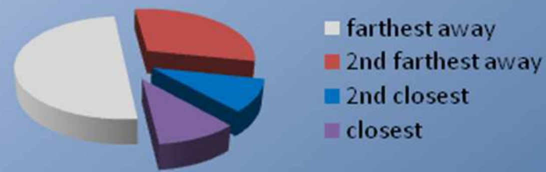
Scenario definition:

- Five ports A , B , C , D,  E
- Fleet of Two containerships
- Several containers
- Operation costs and port fees


| Ships | Length (m) | Beam (m) | Draught (m) | Speed (knots) | N.º TEU | Gross tonnage | Fuel (t/h) |
|---|---|---|---|---|---|---|---|
| AXE | 95 | 15.6 | 6.15 | 12.5 | 348 | 3814 | 0.378 |
| HEAVY | 132.2 | 20 | 7.7 | 16.5 | 641 | 8445 | 0.945 |

| Port tarifs (ship related costs) | Containers related costs | Voyage costs |
|---|---|---|
| • pilot charges;<br>• berthing;<br>• space;<br>• tugs and towing; | • port tariff p/ TEU;<br>• container embarkation;<br>• container disembarkation;<br>• container shift; | • fuel;<br>• crew related; |

Container's  Port of destination




Container's deadlines


Container's weight

# Example – Problem 1

MatLab Implementation:

- Each square stands for 50 containers
- No shift nor stowage constraints considered
- *Heavy* departs from C and *Axe* departs from A
- After 1 circular route – 100 not delivered
- After 9 ports following a circular route – 300h, all delivered but 9 deadlines were surpassed
- After 9 ports following a GA route – 271h, all delivered but 32 not in time, 5% cost reduction


**Containers distribution:** A – 200 B – 100 C – 200 D – 100 E – 100

| | Ship | Route | Travelled miles | Time interval | Deadlines surpassed | Total cost |
|---|---|---|---|---|---|---|
| Circular routes | Axe | A – B – C – D – E | 100 containers not delivered | | | |
| | Heavy | C – D – E – A – B | | | | |
| | Axe | A – B – C – D – E – A – B – C – D | 3372 | 300 h | 9 | 469500 |
| | Heavy | C – D – E – A – B – C – D – E – A | 3164 | 232 h | | |
| GA | Axe | A – B – E – D – B – A – B – E – D | 3083 | 271 h | 32 | 446060 |
| | Heavy | C – D – B – A – E – B – D – C | 2693 | 209 h | | |

# Example – Problem 2

MatLab Implementation:

- Each square stands for 100 containers
- No shift nor stowage constraints considered
- *Heavy* departs from C and *Axe* departs from A
- After 1 circular route – no solution was found
- After 9 ports following a circular route – 100 containers not delivered
- After 9 ports following a GA route – 315.5h, all delivered but 68 not in time

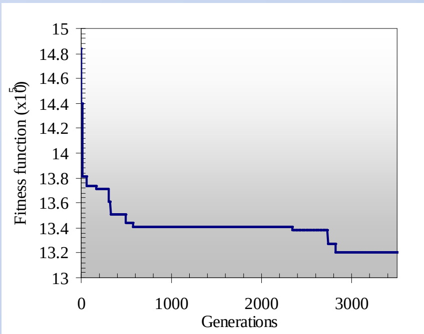

**Containers distribution:** A – 400, B – 200, C – 400, D – 200, E – 200

| | Ship | Route | Travelled miles | Time interval | Deadlines surpassed | Total cost |
|---|---|---|---|---|---|---|
| Circular routes | Axe | A – B – C – D – E | Not every container was embarked | | | |
| | Heavy | C – D – E – A – B | | | | |
| | Axe | A – B – C – D – E – A – B – C – D | 100 containers not delivered | | | |
| | Heavy | C – D – E – A – B – C – D – E – A | | | | |
| GA | Axe | A – B – D – E – B – A – B – D – E | 3134 | 315.5 h | 68 | 634960 |
| | Heavy | C – B – A – B – E – B – D – C | 2653 | 236 h | | |

# Example – Problem 3

University of Aveiro software:

- No shift, deadlines, nor stowage constraints considered
- *Heavy* departs from C and *Axe* departs from A;
- Following a circular route it was found that 15 ports had to be visited by each ship
- Two solutions better were found, with cost reductions of  7% and 14%


| Container distribution: from/to | A | B | C | D | E |
|---|---|---|---|---|---|
| A | 0 | 100 | 500 | 300 | 100 |
| B | 250 | 0 | 150 | 50 | 50 |
| C | 500 | 100 | 0 | 100 | 500 |
| D | 250 | 50 | 50 | 0 | 150 |
| E | 250 | 50 | 150 | 50 | 0 |

| | Ship | Route | Travelled miles | Time interval | Deadlines surpassed | Total cost |
|---|---|---|---|---|---|---|
| Pre-defined | Axe | A - B - C - D - E - A - B - C - D - E - A - B - C - D - E | 6536 | 637.3 h | - | 566039.1 |
| | Heavy | C - D - E - A - B - C - D - E - A - B - C - D - E - A | 6844 | 620.3 h | - | 958090.1 |
| | Axe | A - B - E - D - A - B - E - C - A - D | 5437 | 561.7 h | - | 551051.4 |
| | Heavy | C - D - B - A - E - D - C - A - C | 4367 | 527.6 h | - | 871738.4 |
| GA | Axe | A - C - A - B - E - D - C - B | 3831 | 435.2 h | - | 481087.7 |
| | Heavy | C - A - B - C - D - C - E - B - A | 3657 | 451.8 h | - | 833674.2 |

# Conclusions

- Conceptual and mathematical models have been built for the containership fleet management considering cargo deadlines, which included:
  - ✓ Route selection;
  - ✓ Cargo distribution per ship;
  - ✓ Container stowage problem solution.
- A Genetic algorithm implementation for route selection and cargo distribution has been done;
- Using a simple scenario of 2 containerships and 5 ports with distances between them smaller than 1000 nm, it was seen that:
  - ✓ There are routes better than circular pattern ones;
  - ✓ It is possible to manage a fleet considering the cargo deadlines and reducing time duration when necessary;
  - ✓ It is possible to turn the maritime transport more flexible with cost reductions.

# Future development

- Mathematical model improvement
- Implementation of the CSP in the GA model
- Analysis of different methods efficiency to solve the model other than GA
- Analysis of real scenarios with real data (collaboration required)
- Analysis of the impact of vessel characteristics in the results
- Use the model to define owner requirements for new ship constructions based on known scenarios