Preliminary design of river ship accounting for ice class in life cycle cost

Gorka Olaran Mateos

gorka.olaran@tecnico.ulisboa.pt

ABSTRACT: Transport volumes in the Baltic Sea Region are expected to grow significantly in the next decades. However, the inland transportation sector in Finland is not sufficiently developed to handle additional transport volumes due to navigation restrictions as well as weather conditions, like the ice limitations during the winter resulting in a short navigation season. To overcome this problem, the Emma project is developed with a principal objective to extend the navigation season of the rivers and increase the size of the vessel that may operate there. Making the inland waterway transportation more attractive to the shippers and companies. So the thesis will analyze the actual situation of the Saimaa canal, starting with the preliminary design of a river ship (hull, power prediction, stability etc.). The life cycle cost analysis will be performed to identify the impact of the ice capacity of the vessel.

KEYWORDS: Inland navigation, ship design, ice class, cost analysis, Saimaa canal.

1. INTRODUCTION

Since the beginning of time, the human being has had a close relationship with the rivers, ancient civilizations started to modify river ways for irrigation purposes. It was on the Neolithic when the first trip by inland waterways was done (being considering like the first mode of transportation)[1].

Nowadays, the major mode of transportation is by road. However, this mode consumes a lot of energy to transport small quantities of cargo. The external costs associated like (pollution, accidents, congestion of roads and infrastructures) are really high compared with another modes like inland waterways or trains.

The dependence of oil imports as well as climate change have generated concerns about the energy efficiency in the economy. But the truth is that the shares of efficient transport modes (rail and water) is decreasing, meaning that we are moving in the opposite direction. So the Eu is trying to stablish a modern transport system, suitable for an economic and social as well as an environmental viewpoint.

So, in this context the inland waterways will gain more importance. Over the last years the shares of the inland waterways have been volatile[2][3].

Figure 1. External costs associated with the different modes of transportation

Figure 2. Shares of inland waterway transportation
The coaster/river ships of Europe have a high age, hence there will be a necessity of renew the actual fleet.

Considering all the next points, the thesis will focus on a preliminary design of a cargo vessel. The place chosen to operate the ship will be the Saimaa lake.

Saimaa Lake is the fourth largest natural freshwater lake in Europe (with and area of approximately 4,400 square kilometers). The lake is connected to the Gulf of Finland by the Saimaa canal. It’s 43 km long with 19.6 km Russian territory and 23.3 km in the Finnish lands.

Unfortunately, Saimaa canal trade is very dependent of the weather conditions, being closed a minimum of two month due to the presence of ice. The icy waters of the area requires vessels with an ice class, so it will also be studied how is increment the cost with the ice class.

After designing the open water vessel, we will modify some parameters in order to see the main differences with an ice class vessel, in terms of cost.

2.SHIP DESIGN

The concept design of the vessel will define the ship type, dimensions, deadweight, propulsion, autonomy and crew. Like is listed on the table below[4].

<table>
<thead>
<tr>
<th>Type of ship</th>
<th>Saimax dry cargo vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension(L,B,H)(Limited by the locks in Saimaa canal)</td>
<td>82.5 m,12.5 m,7.5 m</td>
</tr>
<tr>
<td>Classification society</td>
<td>Lloyd's Register</td>
</tr>
<tr>
<td>Deadweight (Saimaa)</td>
<td>Aprox-2500 tonnes at draught of 4.35 m</td>
</tr>
<tr>
<td>Speed</td>
<td>11 knots at B55/4/3</td>
</tr>
<tr>
<td>Propulsion</td>
<td>Medium speed engine + gearbox CPP propeller</td>
</tr>
<tr>
<td>Autonomy</td>
<td>20 days</td>
</tr>
<tr>
<td>Crew</td>
<td>8</td>
</tr>
</tbody>
</table>

The preliminary design will determine the parameters necessary to estimate the ship building and exploitation cost[5].

2.1.Hull offset

we will start modeling from an existing hull from the program Delfship. By means of parametric transformations, we will obtain a suitable offset. The hull, like it’s typical from rivers ships, will have a big block coefficient in order to achieve a good cargo capacity in shallow waters.

Table 1. Concept design of the vessel

<table>
<thead>
<tr>
<th>Hydrostatics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft Amidships</td>
<td>4.35</td>
</tr>
<tr>
<td>Displacement</td>
<td>3659</td>
</tr>
<tr>
<td>Volume (displaced) m3</td>
<td>3658.928</td>
</tr>
<tr>
<td>Length m</td>
<td>80.897</td>
</tr>
<tr>
<td>Beam max extent on WL m</td>
<td>12.497</td>
</tr>
<tr>
<td>Wetted Area m^2</td>
<td>1448.56</td>
</tr>
<tr>
<td>Waterpl. Area m^2</td>
<td>918.302</td>
</tr>
<tr>
<td>Prismatic coeff. (Cp)</td>
<td>0.941</td>
</tr>
<tr>
<td>Block coeff. (Cb)</td>
<td>0.841</td>
</tr>
<tr>
<td>Max Sect. area coeff. (Cm)</td>
<td>0.995</td>
</tr>
<tr>
<td>Waterpl. area coeff. (Cwp)</td>
<td>0.909</td>
</tr>
<tr>
<td>LOB from zero pt. (cum heel) m</td>
<td>41.785</td>
</tr>
<tr>
<td>CPP from zero pt. (cum heel) m</td>
<td>46.25</td>
</tr>
<tr>
<td>BMt m</td>
<td>3.007</td>
</tr>
<tr>
<td>BML m</td>
<td>116.172</td>
</tr>
<tr>
<td>GMt m</td>
<td>5.272</td>
</tr>
<tr>
<td>KML m</td>
<td>118.436</td>
</tr>
<tr>
<td>Immersion (TPc) tonne/cm</td>
<td>9.189</td>
</tr>
<tr>
<td>MTc tonne.m</td>
<td>53.899</td>
</tr>
</tbody>
</table>

Table 1. Hydrostatics of the hull

Figure 4. Preliminary design stages

2.2. General arrangement

The vessel is subdivided on the next way(frame spacing of 600mm):

**Compartment I.** From frame 2 to 7. Limited by the fore bulkhead, inside it we will allocate the steering room and part of the habilitation.

**Compartment II.** Between frame 7 to 27. It’s the place of the engine room, inside there are tanks for Freshwater, sewage, daily MDO and lube oil (adjacent to the daily tank).
Upper of the engine room there is the main accommodation part. There will be located the common spaces (kitchen, mesh room...) and rooms for all the members of the crew, except the captain and who will be allocated on the first floor of the superstructure.

**Compartment III or cargo space.** From frame 27 to 120. It's the biggest space of the ship and will be divided into two movable bulkheads. In our case we will allocate a steel pontoon hatch covers that could be removed by a gantry crane installed on the deck, these solutions provide faster handling of the cargo when the ship is in port. The ballast tanks have a watertight division of 12 (m) and 7.7(m) for the part close to the engine room.

**Compartment IV.** Between frames 120 to 124. MDO storages tanks will be allocated in this position (for stability reasons). The tank will be surrounded by ballast tanks, ensuring no fuel spill.

**Compartment V.** From frame 124 to 127.5. It allocates the bow thruster room.

**Compartment VI.** Between frame 127.5(collision bulkhead) to 135. The volume above the front peak ballast tank will be used for the paint store and CO2 fire extinguisher.

The double bottom height and the double side width are equal(1m) in accordance with the MARPOL.

Regarding the engine room, it has a height of 5 meters and a length of 12 meters. Divided into two floors, the first one will be dedicated to supporting the main and auxiliary engines, the other to hold the MDO daily and lube oil tank. Two sea chests, with different heights, were installed on the aft part on the engine room.

The foundations of the engine were modelled to have an idea of the elevation of the shaft. A Cpp propeller with a 2.5 m diameter is installed.

**2.3. Power prediction**

The calculations were performed using the Maxsurf Resistance. For a speed of 11 knots, the necessary power to deliver to the propeller (DHP) will be 810 kW[6]. A PTO with a power of 250 kW is chosen, to provide electrical supply when the vessel is sailing (saving the fuel of the auxiliary engines)[7]. Finally, it was chosen an engine from the manufacturer Wartsila (model 6L20) with a power of 1200 kW. Running most of the time at the best consumption point (85% of the MCR)

**2.4. Midship design**

Using the rules of the Lloyds Register[8], the main scantling and bulbs are dimensioned. Some spacing where chosen for the web frames (2.4 m), intermediate frames(0.6 m) and hatch coaming stays(1.2 m).

After developing all the calculations, the scantlings are checked with the program MARS 2000.

In our case the maximum thickness is located on the inner bottom (13 mm), so we will use steel of grade A, with an elastic limit of 235 N/mm2 and a Young's modulus of 206 kN/mm2.

**2.5. Lightweight and endurance**

A good calculation of the weight of the ships allows having a bigger cargo capacity. The main component of the lightweight is the steel, to calculate the D.S.Aldwinckle method was used. The autonomy is 20 days and the corresponding weights are calculated in accordance. The main weights are summarized on the table 3[9].
2.8. Cargo capacity, gross and net tonnage

The final value obtained of cargo capacity (2440 tons) not differs a lot from the maximum allowed in the Saimaa canal. The values of gross and net tonnage are 2118 and 1020 respectively.

2.7. Stability analysis

The stability analysis has a big importance on the design of river or coaster vessels. It’s necessary to ensure that the draft in all cargo situations is smaller than the maximum allowed for the Saimaa canal. In other words, the design of the ship is mainly dependent on the stability.

After calculating the freeboard (1.165 m), it’s time to obtain the equilibrium results for the different load conditions considered. For this purpose, we model some interior surfaces in Maxsurf Modeller[10]. Once the model is ready, an input for the program Maxsurf Stability[11] is created(accounting for the different tanks and weights considered).

Figure 6.Maxsurf Stability model

Five cargo conditions were studied:
- Full load departure (Saimaa Canal). Load condition at the start of the voyage (2440 tons of cargo, 100% of MDO, fresh water, and lube oil, 10% sewage).
- Full load arrival (Saimaa canal). Load condition at the end of the voyage (2440 tons of cargo, 10% of MDO, fresh water, and lube oil, 50% sewage). This condition is done to see how the free surfaces affect the stability of the ship.
- Ballast departure (Saimaa canal). Load condition with no cargo at the start of the voyage (no cargo, 100% MDO, fresh water and lube oil, 10% sewage).

All the conditions satisfy the IMO requirements for stability (A.749 Ch 3.1) with good values trim and ensuring always the immersion of the propeller.

3. COST ANALYSIS

On this part, the main causes of increment in cost within the ice class will be analyzed. By using empirical formulas we will see the differences in cost. The ice classed studied will be IC/IB/IA and IA super.

3.1. Voyage costs

Fuel type.
The majority of ships operating in ice-covered water or arctic routes uses MDO like the primary fuel, because it’s cheaper and there is not a significant energy demand for heating the fuel (to obtain the adequate viscosity). In more severe ice conditions, vessels burn naval distillate fuel, like for example the Canadian Coast Guard which uses P50(NATO code F75) or the naval feel operating in arctic regions with a P60 fuel. Distillate fuels have a lower freezing point, but the prices per ton are high (around 35% more). Our vessel will operate with MDO which a price of 650€ per ton (bunkerindex.com price for October 2018).

Insurance.
Another significant rise in expenses is due to the risk of operating in ice waters. Icy waters can cause more problems in the vessel and crew integrity than in open waters, so the insurances are more expensive for this case. Premiums depends on several factors like crew experienced in icy water, availability of icebreakers on the route, ice class, weather conditions, experience of the company in ice waters...

Ports of call.
There is not a difference in port prices for ice classed vessels.

Canal tolls. Finnish waterway association establish a price to cross the Saimaa canal depending on the ice class. Higher ice classes have reduced tariffs because there is less risk of icebreaker assistance.

Table 3. Lightweight and endurance

<table>
<thead>
<tr>
<th>Lightweight</th>
<th>Steel 686</th>
<th>Equipment 175</th>
<th>Acommodation 48</th>
<th>E.Room 138</th>
<th>MDO 128</th>
<th>Lube oil 2</th>
<th>Fresh Water 23</th>
<th>Sewage 11</th>
<th>Provisions, crew and spares 12</th>
</tr>
</thead>
</table>
3.2. Capital costs

In order to have a better understanding of ice-class ships respect to an open water vessel. The main changes to accomplish an ice-class will be analyzed[12]

Ice class hull
The design of shape for an icebreaking/ice class ship is a compromise between open water and ice performance. The bow form to break level ice effectively should promote flexural failure instead of crushing, meaning shallow flare buttocks and stem angles.

Structure
Ice sheets and lumps generate compressive pressures and contact loads, so the hull of an ice-class vessel should be strengthened. To withstand these loads, an ice belt on the side shell is created. The extend of this belt depends on the on the lower and upper ice waterline and the ice class of the ship.

The process to calculate the increment in weight due to the ice belt is done by using the program Rhinoceros. With this software, we will define the different ice belts for the ice classed considered. After, we will calculate the different ice pressures and the corresponding scantlings (using the formulas given by Finnish-Swedish ice class rules). By offsetting the different thickness, we can have an estimation of the volume of the ice belt. Subtracting this volume to the one for the open water vessel, the added weight of steel is obtained.

![Figure 7. Open water hull and ice classed hull (IA Super) for an OPV vessel][13]

Regarding vessels operating in Saimaa, most of them have an ice-class IB or IA. It is logical because there is ice presence in the canal around 5 to 6 months per year (and two of these months the canal is close).

For the calculation of the ice belt[14], it has been have considered two types of structures (longitudinal and transversal) and two kinds of steel (regular and high strength). The results of the added weight and the thickness can be seen in the table 4:

<table>
<thead>
<tr>
<th>Ice class</th>
<th>Increment in weight</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC/IB</td>
<td>15%</td>
<td>1.5</td>
</tr>
<tr>
<td>IA</td>
<td>20%</td>
<td>2.0</td>
</tr>
<tr>
<td>IA Super</td>
<td>25%</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 4. Added weight and thickness

Power and propulsion
The power required for ships in icy waters can be obtained using the formulas given by the Finish-Swedish ice formulas or in ice model laboratory.

For this thesis, Aker Arctic provided data about the increment in power. Apart from the engine power, we will analyse how the settling capacity is increment as well as the added weights (engine and propulsion equipment).

Ice class IC is not considered, because requires the same power than the open water vessel. The results can be seen on the next table 5:

<table>
<thead>
<tr>
<th>Ice class</th>
<th>Increment in power (kW)</th>
<th>Increment in settling capacity (%)</th>
<th>Additional weight (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC/IB</td>
<td>15%</td>
<td>10%</td>
<td>5.0%</td>
</tr>
<tr>
<td>IA</td>
<td>20%</td>
<td>15%</td>
<td>10.0%</td>
</tr>
<tr>
<td>IA Super</td>
<td>25%</td>
<td>20%</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

Table 5. Increments in power, settling capacity, consumption and additional weight.

Propellers for ice waters differs from the conventional one[15], to resist the ice milling (large ice blocks trapped between hull and propeller) and ice impact (small-size pieces that are accelerated through a propeller or thrown out radially and pushed around the edge of the propeller disk). The last ones are less strong but occurs more frequently). All these loads result in propellers with thick...
blade sections, high strength materials, larger blades areas or hubs (and little or no rake). These features increment the cost of the propulsion. The election between controllable pitch propellers (CPP) or fixed propellers (FPP) depends mainly on the kind of propulsion, being the first one used for diesel geared and the second one for diesel-electric propulsion. Even though CPP are more expensive, they have some advantages when operating in frozen seas like a wide range of operation with different cargo conditions, elimination of shaft reversals (avoiding ice damaged when starting or stopping) and easier start of rotation in ice conditions (neutral zero pitch position). Another cause of increment in cost due to the propeller is the material used for the construction, propulsions for ice used to be built with CuNiAl-Bronze alloys (for moderate ice conditions) and stainless steel (for massive ice operations). Apart from the related cost, there is an increment in the weight of the propeller from 20-25%(IC) to 250% (IA super).

Equipment

Ice classed ship will operate in low-temperature environments, so the equipment needs to be adapted for these operating conditions (to ensure the safety of the vessel). Also, additional equipment will be installed to prevent the ice accumulation on the decks, tanks or pipes. As a result, the construction and equipment prices will be higher, incrementing the capital costs[16]. The primary systems used on ice class vessels are:

- **Coatings.** Ice class paints are impact and abrasion resistance, adhesion and low friction property and superior anti-corrosive protection (with labyrinth effect by glass flake).
- **Sea inlets for cooling water systems.** We need to ensure that the suction pipe/sea chest will never get blocked by an ice block. To avoid this problem a wide range of solutions is available like heating coils, circulating of ballast water, air bubbling system.
- **Emergency appliances.** Life rafts must ensure operation in the lowest temperature considered and need to be protected from icing (in order to be all the time in an operative condition). Immersion suits will be fit for the environment and should be stored in heated spaces.
- **Winterization.** A vessel designed for Baltic trade does not require much individual since it is already projected for the Baltic winters. Like an example, with or without ice class, the air conditioning and heating systems will be designed to operate in -25/-30°C. Although there might be some simple heating measure for keeping the space ways clear of ice.
- **Navigation.** The vessel will be equipped with an ice radar and heating on the bridge windows.
- **Tanks.** All the tanks above the waterline must have anti-freezing devices.
- **General arrangement.** This vessel will navigate in extreme darkness and extremely cold temperatures. To avoid problems, they have some unique features line more interior access ways, extra insulation and lighting. In some cases, they can also close some spaces like a bow and stern mooring systems to facilitate the operation of the crew.

3.3. Operational costs

Maintenance

The three most common damages of vessel in ice waters are hull ice damage, collisions and propeller damage. The first one is mainly due to ice scratching paint, with a small percentage of incidents involving frame damages or ruptures. Collisions occur when the icebreaker is escorting the ship, this situation is even worst on the case of Saimaa canal due to the small maneuvering space. The causes of ice damage on the propeller were explained on the capital cost. All of these damages involve a higher rate of maintenance than for ice-free waters.

Like an example, shipping companies in the Northern Sea Route reported that ice damage was incurred on more than 30% of the vessels[17].

Crew

For all vessels sailing in ice waters, the master, chief mate and officers in charge of a navigational watch requires an ice training or course. There are two types of training: advance training (ice concentration bigger than 10%) or basic training (for concentrations smaller than 10%) in this case the training is only mandatory for the master and chief mate of tankers and passenger ships. Ice concentration in Saimaa (during winter) is always bigger than 10%[18].

3.2. Cost model

This part of the thesis will give values about the feasibility of shipping in the Saimaa canal. On this thesis we will only analyse a cost model for Saimaa, meaning that there will be a minimum of two months (closed period of the canal) that won’t take into account. During this period the vessel can operate in other areas increasing the economic efficiency of the ship. The voyage created will be from St. Petersburg to Varkaus(256nm) loaded with timber or pulp wood (there is a paper factory demanding this kind of cargo). Once discharged this cargo the vessel will move to in ballast condition to Koupiu(45nm). Now it will load crushed stone to deliver to St.Petersburg. The calculation gives a round trip of 5 days.

Even knowing that Saimaa canal is closed two months per year (usually February and mid-January and March), there is a period before and after this two month that the canal could be navigable only for the higher ice classes. In other words, vessels with non or smaller ice class cannot operate the maximum days available. It will be established that the classed IA Super/IA will operate 305 days, IC/IB 285 days and 260 for the open water vessel.
It is essential to know the number of round trip for all the classes considered. For the open water vessel, it will be able to complete 52 round trips, IC/IB 57 and IA/IA Super 61.

![Figure 9: Trip considered](image)

So, the different values will give the feasibility of the trip considered. The capital cost associated with the construction of an ice classed vessel are show in the table 6.

<table>
<thead>
<tr>
<th>Ship</th>
<th>Cargo capacity(tn)</th>
<th>Days of operation</th>
<th>Round trips</th>
<th>Revenue per year</th>
<th>Operating cost</th>
<th>Voyage costs</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open water</td>
<td>260</td>
<td>67</td>
<td>2 857 156.84 €</td>
<td>789 440.07 €</td>
<td>3 242 704.36 €</td>
<td>-1 174 987.59 €</td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td>1938</td>
<td>335</td>
<td>2 507 352.05 €</td>
<td>753 240.07 €</td>
<td>2 329 279.34 €</td>
<td>-23 419.85 €</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1 893 031.66 €</td>
<td>2 792 735.09 €</td>
<td>153 383.07 €</td>
<td>2 512 637.98 €</td>
<td>1 839 635.93 €</td>
<td>599 980.80 €</td>
<td></td>
</tr>
<tr>
<td>IA Supern</td>
<td>1 163 383.45 €</td>
<td>2 082 334.83 €</td>
<td>1 987 683.25 €</td>
<td>2 507 352.05 €</td>
<td>1 839 635.93 €</td>
<td>599 980.80 €</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Capital cost increment with the ice class

3.2.1. Profit model and influence of the EMMA project

Asking to the Finish administration and looking on the internet we could get a value for the freight rate. For the route, Kuopio- St. Petersburg will be 11.2€/tones and for St. Petersburg-Varkaus. 10.8€/tones[19]. In a round year of operation (excluding the months that the canal is close) the final values of the cost and profit can be seen on the next table:

<table>
<thead>
<tr>
<th>Ship</th>
<th>Days of operation</th>
<th>Round trips</th>
<th>Profit</th>
<th>Operating cost</th>
<th>Voyage costs</th>
<th>Revenue per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open water</td>
<td>260</td>
<td>67</td>
<td>2 857 156.84 €</td>
<td>789 440.07 €</td>
<td>3 242 704.36 €</td>
<td>-1 174 987.59 €</td>
</tr>
<tr>
<td>IC</td>
<td>1938</td>
<td>335</td>
<td>2 507 352.05 €</td>
<td>753 240.07 €</td>
<td>2 329 279.34 €</td>
<td>-23 419.85 €</td>
</tr>
<tr>
<td>B</td>
<td>1 893 031.66 €</td>
<td>2 792 735.09 €</td>
<td>153 383.07 €</td>
<td>2 512 637.98 €</td>
<td>1 839 635.93 €</td>
<td>599 980.80 €</td>
</tr>
<tr>
<td>IA Supern</td>
<td>1 163 383.45 €</td>
<td>2 082 334.83 €</td>
<td>1 987 683.25 €</td>
<td>2 507 352.05 €</td>
<td>1 839 635.93 €</td>
<td>599 980.80 €</td>
</tr>
</tbody>
</table>

Table 7. Profit for a round year of operation

Now it is time to see how the EMMA project will influence the revenue of the ships. The objective of this project is to reduce in one month the time that the Saimaa canal is close and increase the maximum cargo capacity to more than 3000 tonnes. The table 8 show the influence of this project in the profit.

<table>
<thead>
<tr>
<th>Ship</th>
<th>Cargo capacity(tn)</th>
<th>Days of operation</th>
<th>Round trips</th>
<th>Revenue per year</th>
<th>Operating cost</th>
<th>Voyage costs</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open water</td>
<td>260</td>
<td>67</td>
<td>2 857 156.84 €</td>
<td>789 440.07 €</td>
<td>3 242 704.36 €</td>
<td>-1 174 987.59 €</td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td>1938</td>
<td>335</td>
<td>2 507 352.05 €</td>
<td>753 240.07 €</td>
<td>2 329 279.34 €</td>
<td>-23 419.85 €</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1 893 031.66 €</td>
<td>2 792 735.09 €</td>
<td>153 383.07 €</td>
<td>2 512 637.98 €</td>
<td>1 839 635.93 €</td>
<td>599 980.80 €</td>
<td></td>
</tr>
<tr>
<td>IA Supern</td>
<td>1 163 383.45 €</td>
<td>2 082 334.83 €</td>
<td>1 987 683.25 €</td>
<td>2 507 352.05 €</td>
<td>1 839 635.93 €</td>
<td>599 980.80 €</td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Profit for around year of operation with EMMA project.

We can see that the EMMA project has a significant influence on the annual profit, making higher ice classes more profitable.

3.2.2. Life cycle costs

On this part, we will analyse the life cycle cost of operating the ship. We will only analyse the ice classes IC and IB. IA and IA supper shows a negative revenue per year, so it does not make too much sense to study this classes. Some assumptions were used for this study:

- We will assume the same 2 years for both ships.
- No bank loan will be used, due to the small price of the ship. Some assumptions were used for this study:
- The depreciation of the ship will be calculated for 24 years.
- The crew or manning will experiment an increment of 1% every year
- Periodic maintenance will be done every 4 years with an increment of 2% for the period considered.
- The annual maintenance will increase over the years considered (a rate of 2%)
- The fuel of price will rise 1% every year
- No bank loan will be used
- We will assume a life of 25 years for both ships.
- The fuel of price will rise 1% every year
- The annual maintenance will increase over the years considered (a rate of 2%)
- The fuel price will rise 1% every year
- All this analysis will be done assuming an off-hire period of 2 months (time that Saimaa canal is close).
Finally, it was obtained that ice class IC will be amortize in 22 year with an accumulative cash flow of 750000€. In the case of IB during the entire life it won’t be amortized and that the acumulative cash flow gives a value of more than -7000000€.

4. CONCLUSIONS

The work presented in this thesis represents a real problem. With the future investment in waterways by the European Union, the different shipper companies will need to think about changing to this mode of transportation. However, a cost analysis should be done in order to maintain economic efficiency.

One of the disadvantages of doing a thesis in a remote place like it is the Saimaa area is the lack of information. This thesis has much research behind, but even with it, the data available is not enough. Another problem encountered is the difficulty of finding facts related to the increment in cost due to the ice class. Most of the times manufacturers do not show their tariffs.

For the ice classed studied, we can extract some conclusions. The primary influence in the cost is the fuel expenses, higher ice classes implies more power, meaning more significant values of consumption. In the case of the ice classed IA and IA super it will be necessary to introduce changes in the hull offset to make it more icebreaking capable, in this way the power needed will be smaller and the economic efficiency of these two ice classes will be improved. However, these high class can obtain a more significant freight rate when the conditions in Saimaa are more extreme and smaller ice classes cannot operate.

The loss of cargo capacity is proportional to the ice class. Nevertheless, the quantity of trips per year is more significant, in the end, one thing makes up for the other. Regarding the other ice classes, we can say that the most profitable is the ice class IC like the base ship Noorderlicht (vessel optimised to operate in the Saimaa area). The more significant power of the class IB and the assuming increment on fuel price during the life cycle cost makes it nor profitable. Like we show, the EMMA project has a significant influence on the feasibility of operating in the Saimaa canal. The extension of the navigational season to one month can generate more profit and will enable higher ice classes like IB or even IA to operate in the area (without losing economic efficiency).

There are a lot of future works related with this topic, first of all, it will be really interesting to optimise the vessels hull and structure for all ice class considered, in order to have a more realistic point of view. Another future work could be to contact shipping companies to get more accurate values of port cost in the Saimaa area.

Emma project is going to be developed in the next years, we did the preliminary design with the actual maximum dimensions, but an interesting task will be to redo the design with the new dimensions to see how significant is the influence of this project.

5. REFERENCES

[16] Liudmila Alexandrova (2012) “The Utilization of Leftover Stones from Mines a Quarries in North Savo Region” Saviona University pp50-70
<table>
<thead>
<tr>
<th>Amortisation in year</th>
<th>Accumulative cash flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 22</td>
<td>749,127.81 €</td>
</tr>
<tr>
<td>IB no amortisation</td>
<td>-7,542,341 €</td>
</tr>
</tbody>
</table>