EconomyPlanner; optimal use of inland waterways

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ABSTRACT

In order to strengthen the position of inland shipping it is important to make optimal use of inland waterways. This paper reviews the state-of-the-art of the EconomyPlanner system which enables skippers to reduce fuel consumption by energy efficient ship operation. The development of the EconomyPlanner is commissioned by the European Commission (FP7 EU project MoVeIT!) and the Directorate-General for Public Works and Water Management Rijkswaterstaat (Dutch projects IDVV and Covadem [5]). The projects are carried out by a consortium in which knowledge institutes, waterway authorities and representatives of the inland navigation branch participate.

By using the EconomyPlanner the vessel owner gains fuel efficiency, reliability in terms of ETA and a maximised cargo capacity regarding real time and future riverbed information, water levels and flow velocities. The main goal of the EconomyPlanner is to create a real time local water depth chart based on cooperative navigable depth measurements. In addition the Virtual Ship module of the EconomyPlanner is able to determine the optimal track and advises skippers on optimal rpm settings during the voyage in relation to the desired ETA, for which fuel consumption and emissions are minimal.

A prototype version of the EconomyPlanner has been developed and tested successfully. In the middle of 2014 about 40 inland ships have been equipped with the EconomyPlanner concept. The validation results and the onboard measurements will be used to calibrate and further improve the EconomyPlanner.

Keywords: EconomyPlanner, inland navigation vessel, Covadem, IDVV, MoVeIT!, sharing water depth information, real time water depth chart.
1. INTRODUCTION

The use of existing inland waterways can be optimized if the available water depth and clearance below bridges are known more accurately. First of all this information can be used to maximize the cargo capacity and to avoid grounding and collisions with bridges. During low water (Fig. 1) ships cannot be fully loaded and measures need to be taken in order to pass the critical sections on the route. On the other hand during high water levels, the air clearance under bridges becomes important (Fig. 2).

![Fig. 1 Low water in the river Rhine, Rijkswaterstaat 2011 foto GPD](image)

![Fig. 2 Cargo too high, foto Waldnet](image)

Furthermore real time and future water depths and flow velocities can be used to determine the most energy saving track. In addition to that the EconomyPlanner advises skippers on optimal rpm setting during the voyage. Therefore one of the main goals of the EconomyPlanner is to create a real time local water depth chart based on cooperative navigable depth measurements. The principle of sharing information is also used in car navigation systems for many years. As you drive with a navigation device, you generate location data. This data on your device is anonymous, aggregated and redistributed, to make everyone journeys faster and more predictable. The EconomyPlanner system, enables individual inland vessels to share existing sensor data like GPS, loading gauge and echo soundings with a server on shore. These data has to be processed for the generation of a real time local water depth chart. Data processing involves intelligent water level predictions and advanced trim and squat calculations.

This paper has been organised in the following way. The first section of this paper describes the system architecture of the EconomyPlanner in general. First the focus will be on the process of collecting and sharing water depth information, which will be the basis of the other functionalities of the EconomyPlanner. Next briefly the hydrodynamic and hydrological prediction models will be reviewed. The third chapter explains how a real time water depth chart can be generated based on cooperative water depth
measurements. The fourth chapter is concerned with the working of the Virtual Ship model used to determine the optimal track and advise skippers on optimal rpm setting during the voyage. Next the first validation results are analysed. Finally, the conclusion gives a brief summary and critique of the findings.

2. SYSTEM ARCHITECTURE ECONOMYPLANNER

2.1. Functionalities EconomyPlanner

In general, the EconomyPlanner integrates both current and upcoming water depth information in order to provide the best possible voyage information and planning in terms of economy, environment, efficiency and logistics. Fig. 3 shows the basic functionalities of the EconomyPlanner.

The developed EconomyPlanner is able to:

- Generate a real time local water depth chart based on cooperative depth measurements.
- Determine the maximum allowable loading condition for a voyage based on real time and future water depth information.
- Determine the optimal track in terms of minimum fuel consumption.
- Advice skippers on optimal rpm during the voyage in relation to the desired ETA, for which fuel consumption and emissions are minimal.

A detailed description of the design overview of the EconomyPlanner is completed in “ECPlanner - DesignOverview” [4], including the description of the file formats of data that have to be exchanged between the different modules used in the EconomyPlanner, the technical description of the interfaces and several use cases.

2.2. Cooperative depth measurements

The main focus of the development of the EconomyPlanner is on the generation of a real time local water depth chart based on cooperative depth measurements. This is important to conclude before further developments of other EconomyPlanner functionalities can be done efficiently. Together within the European MoVeIT! project and the Dutch Covadem project about 40 inland vessels are equipped with the EconomyPlanner. These vessels, navigating the European inland waterways, continuously sharing water depth information.

The echo-sounder, loading gauges and GPS already present onboard an inland vessel are linked to one another via a compact device of the EconomyPlanner. Each second this clever device gathers data from these sensors and every hour this collected data will be forwarded to an on shore server, Fig. 4.
Fig. 4 A compact device enables inland vessels to share sensor data like GPS, loading gauge and echo soundings with the server.

Fig. 5 shows a schematic overview of the data process to make real time water depth data available on a web server. First, each individual ship forwards real time measurement data to a server on shore with an upload frequency of 1 Hz. The most important measurement parameters are: local time, under keel clearance, initial draught and GPS position. Furthermore some main particulars of the ship are required, which has to be defined once during the installation of the EconomyPlanner device on board. This measurement database (M-db) gathers data of all the participating ships and makes these data available via an interface.

Next the data processing unit polls the measurement server at a certain interval period. The time interval can be set, for example every 3 hours new data will be requested. The measurement data will be filtered and processed by the data processing unit. Since we are interested in the local water depth, the measured under keel clearance has to be corrected for initial draught and squat. Squat is the reduction of under keel clearance resulting from bodily sinkage and change of trim, which occurs when a vessel moves through the water, especially in confined water. The next sections addresses the implementation of this hydrodynamic phenomenon in the EconomyPlanner. The data processing unit provides an ASCII based file as result. This database file will be updated with the same time interval as the measurement database is polled by the data processing unit. How the water depth chart is generated based in this file is explained in Chapter 3.

The web server and its html pages are based on the ASCII database file. An http request via the internet browser or mobile phone triggers the web server to read the ASCII database file again.

Please note, with permission of all the participating vessels, measurement data of individual vessels is anonymous, aggregated and redistributed, to the benefit of all participants. We create profiles of the European waterways, not of people.
2.3. Squat prediction model

Squat plays an important role in the calculation of the local water depth based on measurement data. The measured under keel clearance has to be corrected for initial draught and squat. Squat is the dynamic trim and sinkage resulting in a reduction of under keel clearance. The moving vessel displaces the water. As this displaced water is also bounded by the cross section of the waterway, the water needs to be accelerated as it has to pass the reduced available cross section area in the same time than the flow would have using the full cross section area without a ship. The velocity field produces a hydrodynamic pressure change along the hull (Bernoulli effect). The weight of the ship is carried by this reduced hydrodynamic pressure, such that equilibrium can only be reached when the ship is sinking deeper to be exposed to higher pressures. This equilibrium is usually found at an increased sinkage (positive downward) and at a different trim (positive bow up). This combination of sinkage and change in trim is called ship squat [1].

The initial draft of the ship is known at the beginning of the voyage and can be automatically retrieved from the on board loading computer. The Virtual Ship, as developed by MARIN, calculates squat based on the squat prediction model proposed by Ankudinov [1]. Also the contributions of Prof. E.O. Tuck to the field of mathematical ship-squat prediction [2] is considered. Nowadays, squat coefficients are checked by systematic CFD calculations at MARIN. At this stage the ship squat predictions of Ankudinov seems to be the most promising for our purpose.

The Ankudinov methods uses easily obtainable vessel parameters for calculating sinkage and trim coefficients. These vessel parameters have to be defined once during the installation of the EconomyPlanner. Besides vessel data, morphological data and current velocities along the entire route are required for the calculation of squat. The data processing unit of the EconomyPlanner obtains these data via a web server from Deltares. Deltares uses their FEWS-Waterways hydrological forecasting system to predict the water depths, flow velocities and air clearances, which is addressed in the next section.

The contribution of squat to the total sinkage and trim of the vessel can be substantial, especially in shallow water. An example for a typical inland vessel is given in the chart below. In here you can see the theoretical influence of vessel speed and water depth on the vessel’s sinkage and trim. In shallow water (constant sounded depth of 2 [m]) and with a high speed of 16 [km/h] the bow sinkage goes to 60 [cm]. However, validation results of the participating vessels are required to calibrate and further improve the Virtual Ship of the EconomyPlanner.
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2.4. FEWS-Waterways: hydrological prediction model
An essential role in the EconomyPlanner plays FEWS-Waterways model. This model is based on the Delft-FEWS [6], which is an operational real time hydrological forecasting system which links data and models in real time. Because of its unique characteristics concerning data importing and model connections, Delft-FEWS is very suitable to interconnect and run several different operational models and update these models using new measurements. (Real time) data are imported, numerical calculations are performed using these data, and the results of forecasts are exported/presented to an external server or website. As a start, the system has been developed for the Dutch waterways, but can be extended quite easily as soon as hydrodynamic and morphological models of other countries become available.

The operational system computes actual and future water depths and flow velocities in two dimensions (width and length of the waterway). These data are input for the EconomyPlanner in order to calculate the optimal track in the river and the maximum amount of cargo that can be transported. In addition the optimal speed during the entire voyage will be calculated in relation to the desired ETA, for which fuel consumption and emissions are minimal.

Since the calculation of future predictions needs the real time situation as input, the more ships collect and share their data with each other, the more detailed and accurate the actual navigation depth chart becomes, and the more accurate the future predictions become. More detailed information about the FEWS-Waterways module can be read in the paper [3], which describes FEWS-Waterways as part of a tool for economically and efficiently navigating on inland waterways.

Fig. 6 Bow sinkage for constant sounded depth

Fig. 7 Example detail of the hydrodynamic model of FEWS-Waterways, compared to real situation of a Rhine branch in the Netherlands.
3. REAL TIME WATER DEPTH CHART

One of the main goals of the EconomyPlanner is to create a real time local water depth chart based on cooperative navigable depth measurements, which will be the basis of other functionalities of the EconomyPlanner like the determination of the optimal track and maximum allowable cargo capacity.

This section describes how the local water depth chart is generated. First, the navigable river waterway will be divided in a grid of 25 x 25 [m] squares. For each grid cell a water depth will be determined. Every second, vessels equipped with the EconomyPlanner provide measurement results. This will be done for every grid cell they pass during a preset time interval (e.g. 3 hours). Next, the data processing unit of the EconomyPlanner will correct this data for initial draught and squat effect in order to determine water depths in centimetres. In case more than one water depth result is available for a grid cell, the mean value will be used. The following use cases are possible for each grid cell:

- No water depth results are available during the preset time interval. So, the water depth cannot be determined for this cell. In the follow up projects water depth values for these cells will be determined by using history data and interpolation between cells containing a water depth value.
- In between 1 to 4 water depth results are available during the preset time interval. A mean water depth value with a low reliability can be determined for this cell. The cell will get an orange boundary. An example is given in Figure Fig. 8.
- More than 5 water depth results are available during the preset time interval. A (mean) water depth value with a high reliability can be determined for this cell. The cell will get a green boundary.

Incorrect measurement data and calculated water depth data will be filtered by the data processing unit of the EconomyPlanner. This will not be discussed in this document, details can be read in [4]. Finally a real time water depth chart can be generated and presented on a Google Earth map, as shown in Fig. 9. The cell colours vary from green (deep water) to red (shallow water). Please note, the current water depth chart presented in Google Earth with the chosen cell colours are just a choice made by the participants of the involved research projects to show that it is possible to create a reliable real time local water depth chart based on cooperative depth measurements. In the future a further discussion with ship owners is required about the representation of real time water depth data, which is convenient for them.

For research purposes, besides the water depth value, the number of measurement results and the number of vessels who provided these data are shown for each grid cell, see Fig. 10.
Based on real time water depth information, services are being developed that support energy efficient ship operation. One of the services of the EconomyPlanner is the Virtual Ship module developed by MARIN which optimizes total fuel consumption for a given route. Furthermore, the Virtual Ships advises skippers on optimal rpm during the voyage. In this chapter the main principle of the Virtual Ship is explained.

Restrictions in water depth and width are important factors in the energy consumption of inland vessels. In confined waters the propeller hull interaction becomes less favourable resulting in a reduced propeller efficiency and therefore in increased fuel consumption. Since restrictions in water depth have a negative effect on the fuel consumption, the Virtual Ship will look for the deepest part of a river for a given route, taken into account the turning circle of the vessel. In order to determine the optimal track not only real time water depths are needed, but also the expected water depths along the entire route and during the entire voyage. Real time water depth information is
obtained from the cooperative depth measurements and future water depth information from the Deltares server as explained in the previous chapters. The red line in Fig. 11 shows the optimal track on the ECDIS.

![Fig. 11 Optimal track showed on ECDIS, based on real time water depths](image)

A route is just a sequence of waypoints to indicate the point of departure and arrival and the track to be taken. The skipper has to input this route in the user interface of EconomyPlanner. In addition he has to provide the time of departure (ETD) and the desired expected time of arrival (ETA). Considering the cost criterion, voyage planning is finding the best balance between ETA and the total cost of the voyage. The first check by the Virtual Ship is whether the ship is able to execute the voyage for a given loading condition. The loading condition is obtained from the on board loading computer.

The effective thrust to counteract any resistance that the vessel may experience will be calculated by the Virtual Ship. This calculation requires main ship parameters and engine characteristics as input, which only has to be provided once during the installation of EconomyPlanner. The power and resistance calculations in the Virtual Ships are based on MARIN’s QDESP software version developed for inland vessels. QDESP predicts the resistance and propulsion characteristics of displacement ships. The predictions are based on formulas obtained from a regression analysis on results of MARIN model experiments and sea trials. The Virtual Ship corrects the calculated speed power tables for shallow water effect based on Schlichting &Landweber methods.

When an ETA becomes critical the ship may use its maximum power to meet the ETA, but that should remain an exception. The Virtual Ship divides the optimal track in a number of legs with corresponding gradient, current speed and water depth. Optimisation of the power and fuel consumption for a voyage consisting of several legs with different water depths, in such a way that given ETA is achieved. From work previously performed within the scope of the RISING project [7] it has been found that minimum fuel consumption is achieved on a waterway by operating in constant power mode as long as there are no limits with regard to current velocities and power setting.
Constant power does not imply constant rpm since rpm depends also on propeller hull interaction which is affected by keel clearance and channel width. In general on inland vessels engine rpm is set and controlled by the engine regulator, resulting in variable power and therefore variable fuel consumption depending on the waterway conditions. For a complete voyage, optimum fuel consumption is achieved by keeping the power constant, which requires rpm setting to vary with waterway conditions. The rpm advice of the Virtual Ship will be provided as a table for each leg. Adjusting revs according to this table makes that the vessel reaches destination just in time and with minimum fuel expenditure.

Note, the results of the measurements are required to calibrate and further improve the current Virtual Ship. Also the definition of “optimal track” is still under investigation as the local water depth is not the only aspect that plays a role. For example waiting times at terminals and locks on the route also influence the operating time and the overall transport efficiency.

5. VALIDATION

At this stage of the running research projects involved with the development of the EconomyPlanner, only a limited amount of time has been spent on validation of the results. Until now the main focus has been on the development of the EconomyPlanner concept and make it up and running on the participating vessels. At the moment some 40 vessels are equipped with the EconomyPlanner concept. The more location data that is generated the more accurate our products and services become and the better the experience for everyone.

The main focus is now on the generation of the real time local water depth chart, which is important to conclude before further developments of other EconomyPlanner functionalities can be done efficiently. Though, first quick checks regarding the accuracy of the results lead to promising conclusions. At the moment a few water depths calculated by the EconomyPlanner based on measured data by ships have been compared with reference measurements on locations with a relatively fixed bottom profiles. Due to many uncertainties it is complex to find good reliable reference measurement points on the inland fairways for validation. At a certain time t and a position P, a reference water depth $D_{ref}$ is calculated by the water level height $h_{water}$ minus the height of the river bed level $h_{bed}$, both in relation to NAP (Amsterdam Ordnance Datum). Reference points errors can be made with the determination of the components $h_{water}$ and $h_{bed}$. Errors like; wrong measurements, interpolation between measurements of two measurement stations, due to differences in water level height within a cross section of the river, due to existence of river dunes etc.

Currently an advanced data analyses is being performed within the Covadem project [5]. Multi beam measurements are carried out by the company IGL, which is accredited by Rijkswaterstaat, in order to have very accurate water depth reference points. Unfortunately, this validation is work in progress and results cannot be published yet.

Fig. 12 reviews the many parameters involved in order to determine the local water based on measurements by an individual vessel. Besides the errors that can be made by the determination of these parameters, also dependencies between those parameters exist, which makes validation even more complex.
Fig. 12 Parameters involved in the determination of local water depth based on ship measurements

a) River bed position related to fixed point of reference
b) Distance between depth sensor and river / bottom
c) Longitude
d) Latitude
e) Vertical distance between waterline and depth sensor at zero speed
f) Dynamic squat and trim of the vessel
g) Vertical distance between waterline and highest point of the vessel at zero speed
h) Bridge clearance
i) Actual water depth
j) Vertical distance between the bridge related and fixed point of reference
k) River current longitudinal direction
l) River current transverse direction
m) Longitudinal speed over ground vessel
n) Transverse speed over ground vessel
o) Water level starboard river bank related to mid-river
p) Water level port side river bank related to mid-river
q) Time (moment of measurement)
r) Distance between GPS sensor and depth sensor
s) Reference water depth

The figure above illustrates the complexity of generating a real time water depth chart based on cooperative measurements. However it is necessary here to clarify that the goal of the EconomyPlanner is not to create the most accurate bottom profile of the river. The main goal is to provide real time water depth information along the entire route and entire voyage of vessels using the European inland waterways, with at least the same accuracy as the currently available water depth information. Nowadays, water depth information is not real time and not available for every part of the European waterways.
6. CONCLUSIONS AND RECOMMENDATIONS

A concept version of the EconomyPlanner has been developed and installed on about 40 vessels navigating the European inland waterways. The EconomyPlanner is able generate a real time water depth chart based on cooperative depth measurements. Based on the generated real time depth information, services are being developed that support energy efficient ship operations in terms of; more cargo, less emissions and a more reliable voyage. The first added value for ship owners is the provision of the maximum allowable loading condition for a given a route, in such a way that critical points on the route can be passed. The Virtual Ship module of the EconomyPlanner determines the optimal track in relation to minimum fuel consumption. In addition the optimal rpm is provided during the journey, in such a way that given ETA is achieved with a minimized fuel consumption.

The main focus of the development of the EconomyPlanner is on the provision of real time river depths and air draught information, which needs to be further validated on accuracy and availability. This is important to conclude before further developments of other EconomyPlanner functionalities can be done efficiently. It should be emphasized that it would be already a great improvement if the EconomyPlanner provides real time water depth information along the entire route and entire voyage of vessels using the European inland waterways, with at least the same accuracy as the currently available water depth information. Validation results are also needed to further calibrate and improve the hydrodynamic and hydrological prediction models of the EconomyPlanner.

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