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Executive Summary

This document reports about developments and results with the VISIR ship routing model, as carried out in the frame of GUTTA project. A new model in Python was designed, implemented, and validated. It was deployed in the Adriatic Sea for assessing the potential of voyage optimization for reducing the CO2 emissions from ferries. The preliminary results are encouraging, as CO2 reductions up to 7% and carbon intensity reductions up to 11% were computed for the case study considered. The statistical significance of these figures needs to be assessed through the operational system, which is also going to be developed in the frame of GUTTA.

1. Introduction

In April 2018, the International Maritime Organization (IMO) adopted an "Initial Strategy" to reduce carbon intensity by 40% by 2030, taking 2008 as a baseline year [1]. The strategy included short, medium, and long-term time horizons. For the short term, a possible operational measure consists of improving energy efficiency gains via a Ship Energy Efficiency Management Plan (SEEMP). It considers cost-efficient measures such as speed optimization and speed reduction, and the quantification of savings via the Energy Efficiency Operational Indicator (EEOI) [2].

According to the MRV dataset of 2018, despite the fact that the number of Ro-Pax ships (transporting both vehicles and passengers) was only about 3% of all ships reporting calls in the EEA, the quota of their CO_2 emissions was an over-proportional 10%. For this reason, this kind of vessel is the perfect candidate to test ship routing effectiveness.

The Adriatic Sea, is routinely crossed by several ferry lanes joining ports in Italy with ports in Croatia, Montenegro, and Albania. This region is characterized by a maximum H_s of about 3 m and a maximum width of just about 100 nmi in direction normal to its elongation axis.

In GUTTA, we have been developing a new version of the VISIR ship routing model for assessing to what extent path optimization influences navigation times and CO_2 emissions from ferries. These developments will then feed into the operational tool for computation of least-CO2 ferry routes (which will be documented in D. 4.4.1). This document presents a shorter version of the full documentation provided in [3]. Here, the Methodology used for VISIR developments is briefly reported in Sect. 2 and some of the results in Sect. 3. Conclusions are drawn in Sect.4.

2. Methodology

A new version of VISIR ship routing model (www.visir-model.net) [3-5] is being developed in the frame of the GUTTA project and is termed “VISIR-2”. It presents a number of architectural innovations and new technical features with respect to VISIR-1. Here we just list some of the technical novelties:

- Least-CO_2 routes. VISIR can compute optimal routes by suggesting a spatial diversion which leads to avoidance of rough sea and related ship speed loss. Besides least-distance and least-time routes, we added a capacity to compute routes of least-total-CO_2 emissions. This required a further generalisation of the time-dependent Dijkstra's algorithm which is at the core of VISIR [4].

- Visualization. Mapping of the routes was improved by including the fronts of the locations reachable within a given time since departure (isochrones) and the environmental fields were sliced among isochrones. The latter were compared with lines of equal distance from route origin (or: "isometres") and lines of equal amount of CO_2 emissions (or: "isopones", i.e. "equal effort").

- Vessel performance modeling. A new vessel model was introduced in VISIR-2, based on a simulator, from which the performance and emissions of a ferry were estimated in various sea conditions.

The CO2 emission rates is related to both engine load (P) and fuel consumption (SFOC) and is given by:

$$\frac{dCO_2}{dt} = SFOC \cdot P \cdot C_f \qquad \text{(Eq.1)}$$

where C_f is a conversion factor, set equal to 3.206g/g accounting for the use of marine diesel oil fuel.
This equation can be evaluated using the inputs (SFOC and P) from the bridge-engine coupled simulator hosted by the GUTTA Partner UniZd already described in Deliverable 3.2.2. Related progress and results on the ferry kinematics and propulsion performance will be documented in Deliverable D.4.1.1.
Furthermore, following recent regulatory developments at IMO, a Carbon Intensity Indicator (CII) can be introduced to define the efficiency of a route:

$$CII = \frac{CO_2}{DWT \cdot L} \qquad \text{(Eq.2)}$$

where *L* is the length of the path and *DWT* the maximum cargo capacity.

3. Results

A hypothetical ferry connection between Zadar (Croatia) and Barletta (Italy) was considered. The route optimization was performed on a graph with a grid spacing $\Delta x = 1/12$ degree and a level of connectivity ($\nu = 4$).

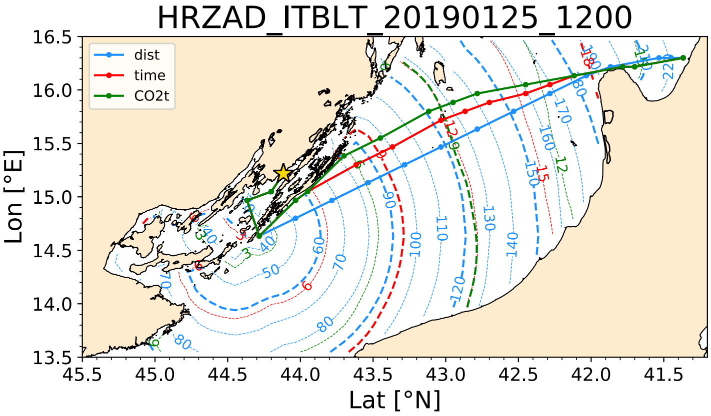

Figure 1 Exemplary results of route optimization. Least-distance, least-time, and least-CO2 routes from Zadar (Croatia) to Barletta (Italy) are displayed respectively as cyan, red, and green lines with dots at the computed waypoint locations.

In Figure 1, all three types of optimal routes of are displayed: i.e., with respect to distance, duration, or CO2 emissions. In addition, for each optimization type, corresponding isolines are shown. It can be noted that each isoline is locally normal to its related optimal route. This property of normality follows from optimality: the isolines are fronts of the 2D field of the optimization objective. Small deviations from normality are due to the graph resolution, affecting both the land-sea mask and inter-waypoint distance. Both the time- and CO2 optimal routes divert inshore towards Croatia (“route refraction”). This is due to the coastal environmental conditions favouring a slower increase of the objective functions (cf. Figure 2). This understanding in terms of route refraction is complemented by the isolines, which bulge along gradients of the 2D field of the objective function. Some bulges and recessions of the isolines can be noted, as navigational obstruction makes its downwind and environmental conditions effect the length of the trajectory and, consequently, both the sailing time and the related emissions (cf. Table 1).

CO2- and time-optimal routes have similar spatial features because of the weak dependence of the CO2 rate on the sea state experienced by the vessel. This implies that - via Eq.1 - the CO2 emissions are roughly proportional to the time needed for sailing across them. This is seen also in Figure 3, where least-time and least-CO2 routes are compared, finding small (but non-zero) differences.

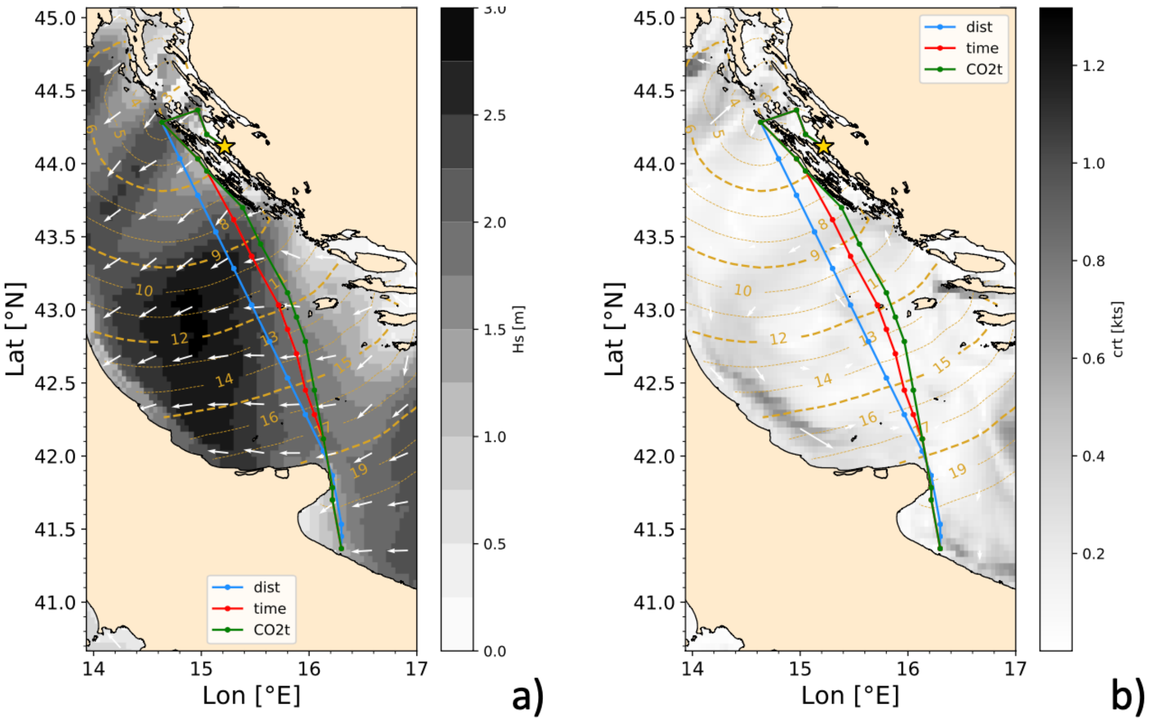

Figure 2 Optimal routes of Figure 2 shown on top the marine fields used for optimization (a): Significant wave height Hs; (b): Sea surface current.

Table 1 Performance metrics and some CIIs for the routes in Figure 2, both in physical and relative units, for the

Optimization	L [nmi]	T [hr]	CO$_2$ [t]	AER [g/(nmi t)]	EEOI$_{pax}$ [g/(nmi pax)]	LmDIST [g/(nmi m)]
Length	226.1	22.17	16.88	18.44	186.7	59.73
Duration	227.8	21.55	16.18	17.54	177.6	56.83
Emissions	229.8	21.62	16.18	17.39	176.0	56.33

In order to investigate how environmental conditions affect optimal routing in the Adriatic Sea, different routes across the Adriatic Sea were considered. The chosen ones connected Ancona with Dubrovnik, Barletta with Zadar and Bar with Bari. Both waves and sea currents were considered. As a preliminary study, the simulations were limited to January 25th 2019, having 3 hours between each departure. For each departure dates, multiple simulations using different engine load levels (varying from 70% to 100%) were executed.

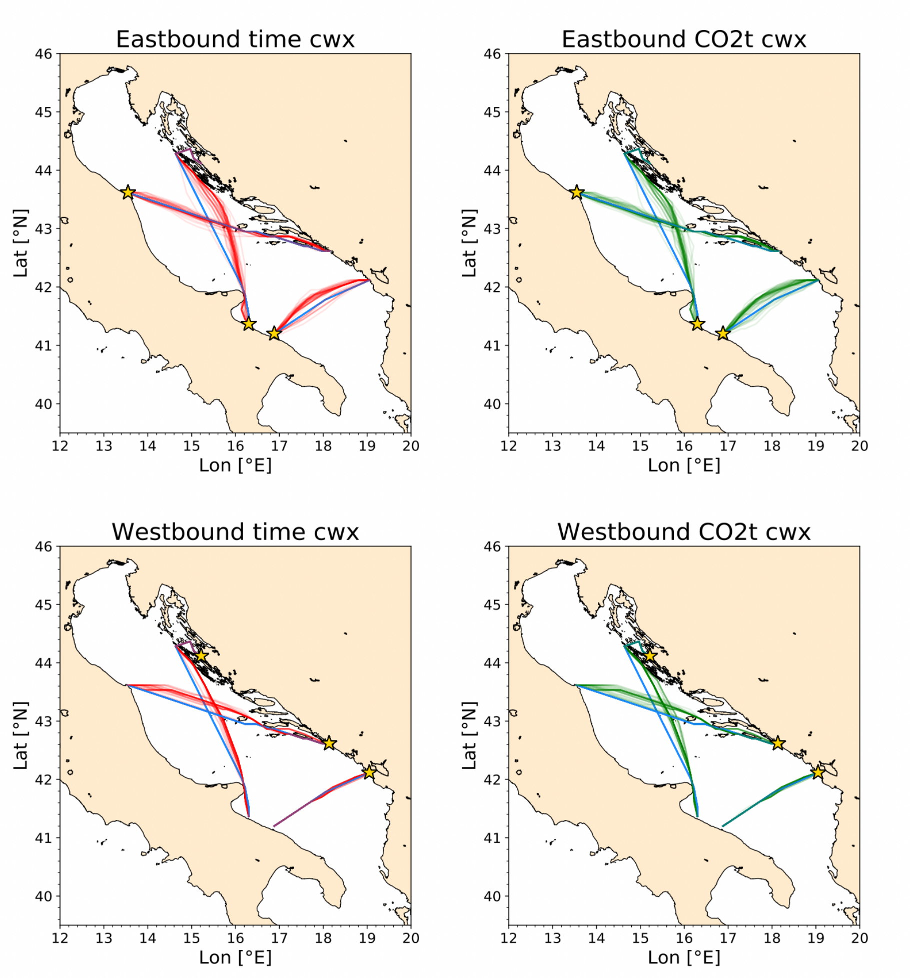

Figure 3 Bundles of least-CO2 routes considering both waves and currents for three crossings in the Adriatic Sea. Upper (lower) panels refer to Eastbound (Westbound) routes. Left (right) column panels refer to least-time (least-CO2) routes.

Related resuls are displayed in Figure 3 and Figure 4.

The general sea conditions on the date the simualtions refer to were dominated by North-Easterly winds, which led to diversions towards the Croatian coast. This deviation can be appreciated for every crossing, but the Bar-Bari one, where the bundle overlaps the least-distance route because of the prevailing following wind conditions.

Carbon intensity savings (CII) obtained from spatial diversions were quantified using the CII defined in Eq.2 and having least-distance route as benchmark.

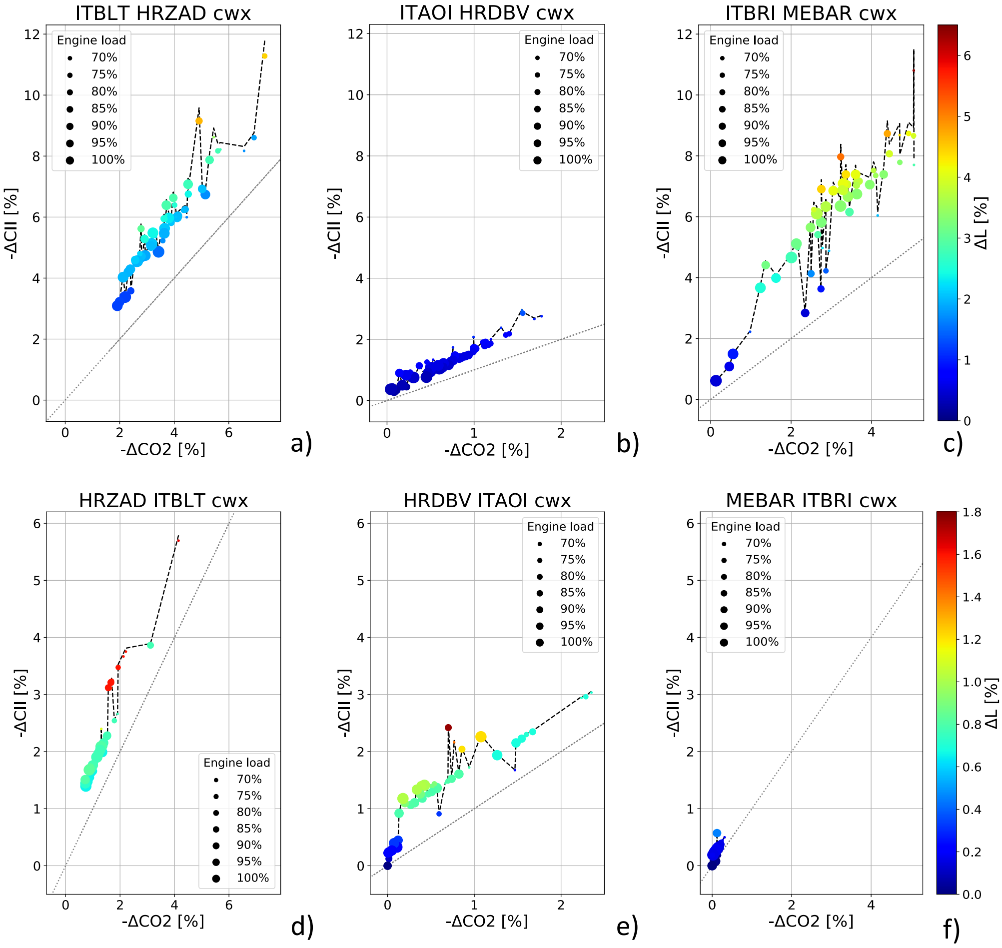

Figure 4 CII vs. CO2 savings for the least-CO2 routes with respect to the least-distance one, with path lengthening ΔL as marker colour and engine load as marker size. Data refer to the same routes of Figure 5. (a–c) Eastbound routes; (d–f) Westbound routes.

They are displayed in Figure 4 and a correlation between CO2 emissions savings and path lengtheneing is seen: the greater the diversion, the smaller the emissions.

The routes most improved by optimization are the ones from Barletta to Zadar, having CO2 savings up to 7% and CII savings up to 11%. On the other hand, the lack of diversion in the routes Bar-Bari and Ancona-Dubrovnik results in extremely low savings.

4. Conclusions

This report documented some development and results of the VISIR-2 model, achieved in the frame of the GUTTA project. The new model will be put into operations later on during the implementation of GUTTA.

The investigated case study shows some promising features. In presence of rough seas, and despite the short ferry routes in the Adriatic Sea, the least-CO_2 routes were found to significantly differ from least-distance routes. This difference can be visualized through both the spatial diversions and the reduction of the CO_2 emissions. The CO_2 savings depend on the actual crossing considered, with a top value of 7% computed so far. Correspondingly, the CII savings reached up to 11%. Winter navigation conditions with a specific wind pattern were selected for this case study. In order to verify the statistical significance of this figure, a systematic investigations in presence of different other meteo-oceanographic conditions is required. However, savings of this size are encouraging, as it is not negligible when compared to the carbon intensity curbing target of 40% by 2030 required by both IMO and EU.

Thus, this work supports the thesis that voyage optimization could represent a viable option to help ships meeting short-term targets for both absolute emission and carbon intensity reduction. The present results demonstrate on the scale of short-sea shipping an effect that had previously been known at ocean scale only [4].

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