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# An Analysis of Basic Parameters of Ro-Pax Ships and Double-ended Ferries as Basis for New Hybrid Ferries Designs

**Abstract**

The paper presents an analysis of the basic parameters of Ro-Pax ships and double-ended ferries. The study was carried out within the framework of the project METRO (Maritime Environment-friendly TRanspOrt systems), funded from 2014-2020 Interreg V-A Italy-Croatia CBC Programme. The aim of the project is an improvement of the environmental sustainability in the field of maritime transport, with particular emphasis on multimodality and “green” solutions for the coastal transport. The specific focus is on touristic connections in the North Adriatic area. One of the project goals is a development of short-medium range hybrid ships and of concern are Ro-Pax ships and double-ended ferries, which are the most common ship types for coastal shipping in the Adriatic area. Two extensive databases were created encompassing a large number of ferries that operate in Europe, by one for each ship type. The databases will serve as basis for the preliminary design of the new hybrid Ro-Pax ship and double-ended ferry.

**Keywords:** ship design, Ro-Pax ship, double-ended ferry, basic parameters, database

## 1. Introduction

The process of ship design combines wide range of disciplines and analysis methods, and by no doubts it should be methodically approached. The ship design may be considered as being composed of four main phases: a concept design, a preliminary design, a contractual design, and detailed design [1]. The first two phases are also known as basic design.

One of the usual steps when the preliminary ship design is elaborated is data gathering of built similar ships. Data to be gathered may include a ship type, size, deadweight, speed, main engine power, etc. These data are available in various publications or databases. Until present days, a lot of databases were made in which ship's basic parameters were gathered and analyzed. These studies were mostly made for cargo ships, i.e. containerships, bulk carriers, tankers, general cargo ships [1, 2, 3, 4] and only few were focused on Ro-Pax and double-ended ferries [5].

One of the goals of the project METRO (Maritime Environment-friendly TRanspOrt systems) is the development of new hybrid Ro-Pax and double-ended ferries that are assumed to operate in the Northern Adriatic Sea. For the purposes of the EU Interreg project METRO (Maritime Environment-friendly TRanspOrt systems) it is necessary to estimate a Ro-Pax ferry and double-ended ferry that are assumed to operate in Northern Adriatic Sea. The main idea is the implementation of hybrid technologies to get more environmentally sustainable ships. The Ro-Pax ferry is intended for the Trans Adriatic routes between Croatia and Italy while the double-ended ferry is intended for short routes between Croatian coast and islands.

In order to get a broader picture of the basic parameters of these types of ferries, the formation of extensive databases was undertaken. The established databases will serve as guidelines for the design of two new hybrid Ro-Pax and double-ended ferries.

## 2. Database formation

Two separate databases were formed, one for each ferry type. The data were mainly gathered from three databases [6, 7, 8], but also some other websites that are focused on ferries and ferry transport were used [9, 10]. The available data for ferries were mainly related to basic parameters such as the length overall ($L_{OA}$), breadth ($B$), draft ($T$), power of the main engine(s) ($P$), service (or average) speed ($V$), gross tonnage ($GT$) and deadweight ($dwt$).

Many of the data required additional verification. For example, the speed was usually referred to as speed in service but for some specific ferries it was taken from [8] as an average speed. Since the passenger and vehicle capacities are of particular importance for the ferries, these data were also gathered and analyzed.

In addition to these basic parameters, some other useful data were additionally gathered. These additional data include route lengths, ferry lane meters, number of passenger and cargo decks, whether a ferry has a bow thruster or does it has an ice class. However, because these data were not available for all ferries, they were not analyzed and presented in this study. Some of the other parameters, such as depth or freeboard were not specified for some ferries so it was also decided not to include these data in the databases. The vehicle capacity is often defined as the length of lanes but it was not possible to validate available figures so these data were also discarded as unreliable.

Data were gathered for ferries that operate in the European seas. Scandinavian and Baltic countries are all connected via ferry lines and sea traffic network there is highly branched, hence major part of data consists of ferries from that area. Other navigation areas where ferries listed in the database operate include Mediterranean Sea, English Channel, Adriatic Sea and Celtic Sea, Figure 1.

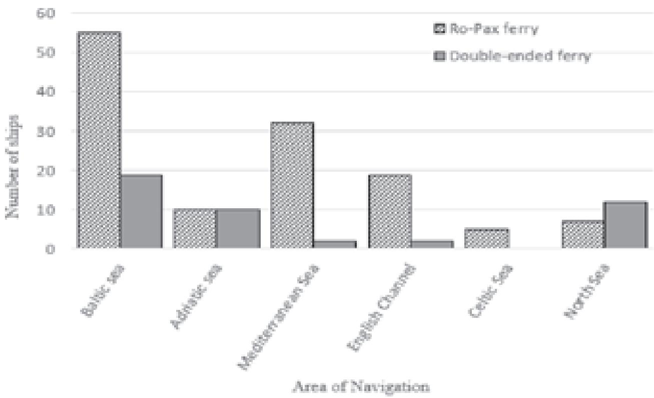


*Figure 1: Number of ferries and the area of navigation*

While creating the database of Ro-Pax ferries, two main filtering criteria were set. The first one was a built year, and only ships built after 1980 were taken into account, Figure 2. The second criterion was $L_{OA}$ in a way that only ferries up to 200 m were included in the database. The only exceptions were three ferries slightly longer and $L_{OA}$ of the longest goes up to 203 m. The first criterion was set because ferries have changed over the years and it was decided that parameters of older ferries would not be relevant for the databases. The second criterion was set because of the METRO project's program area which is Northern Adriatic. Ferries that operate between Italy and Croatia, particularly passenger ports Ancona and Split, are much shorter than 200 meters, with the maximum $L_{OA}$ of 147.97 m. Therefore, ferries longer than 200 meters were not included in the database.

For the double-ended ferries, the $L_{OA}$ criterion was not considered since the $L_{OA}$ of the existing double-ended ferries fit perfectly for the double-ended ferries that can operate in the area of the Northern Adriatic. When forming this database, only the built year was considered. But, since number of these ferries was much smaller than the Ro-Pax vessels, all ferries built between 1970 and 2019 for which data were available were included in the database.

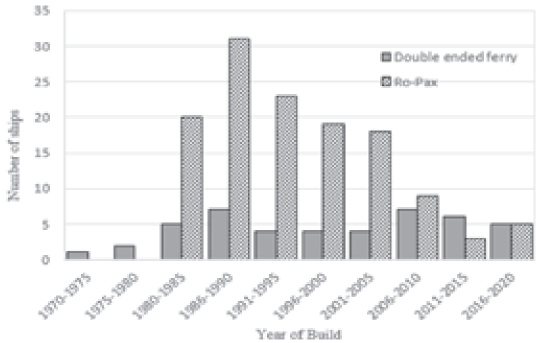


*Figure 2: Number of ferries and built year*

Finally, only monohull ferries were included in the database since it was concluded that multihulls with the speed of over 30 knots were not of interest for the project. It was also important to sort out all the sisterships and exclude them from the databases in order to get reliable results. The databases contain 128 Ro-Pax ferries and 45 double-ended ferries, for which the parameters were gathered in the second half of 2019.

## 3. Data analysis

In this chapter, the results of the analysis of following basic parameters are presented: $L_{OA}$ (m), $B$ (m), $T$ (m), $P$ (kW), $V$ (kn), $GT$, $dwt$ (t) and passenger and car capacity. For a better presentation, the results for each database were shown separately. In the first part, the analysis of main parameters of Ro-Pax ferries is shown while the analysis of double-ended ferries is presented in the second part, in the same way as for Ro-Pax ferries.

### 3.1. Ro-Pax ferries data

The histogram in Figure 5 shows the number of ferries as a function of $L_{OA}$. The ferries were grouped according to their lengths within 10 m. It can be noticed that a significant part of ferries (71%) fall within the range of $L_{OA}$ between 150 to 200 m. It can be further noticed that a major part of them (39%) are in the range of $L_{OA}$ between 160 to 180 meters.

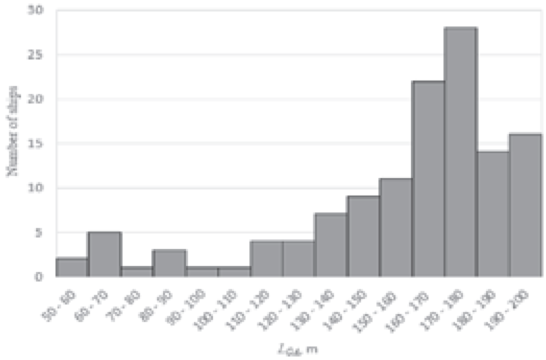

*Figure 3: $L_{OA}$ and number of Ro-Pax ferries*

Figures 4 and 5 show the number of ferries as a function of *B* and *T*. The results largely follow those obtained for the $L_{OA}$ and something like that could have been expected. *B* mostly ranges between 24 and 30 m (77.3%), with only few of them over 30 m, Figure 4. Also, most of the ferries (77,3%) have *T* between 5,5 and 7.0 m, which are the quite common values in relation to $L_{OA}$.

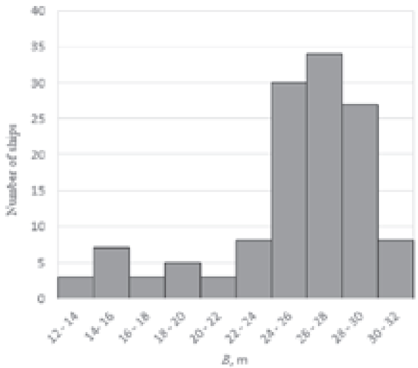

*Figure 4: B and number of Ro-Pax ferries*

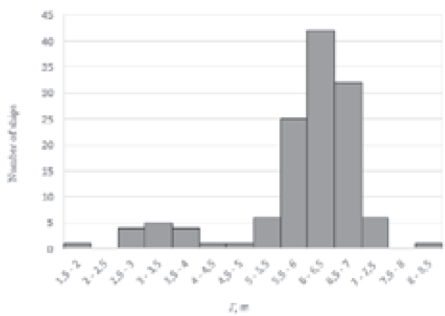

*Figure 5: T and number of Ro-Pax ferries*

The scatter plot shown on Figure 6. shows that $L_{OA}$ affects the *B* and *T* and it can be noticed that *B* and *T* change proportionally with $L_{OA}$. The ferries that are circled show some discrepancies from the rest of ferries. These are older ships, having the larger *B* in relation to the $L_{OA}$. A linear regression was made for these data, and the change of *B* can be represented with the formula:

$$B = 0{,}1026 \cdot L_{OA} + 8{,}8904. \quad (1)$$

The value of the $R^2$ coefficient is 0.6786. Ratio $L_{OA}/B$ ranges from 3.9 to 8.2, and the mean value is 6.23. It was noticed that $L_{OA}/B$ ratio slightly increases for new ferries.

While in years from 1980 to 2000 the mean value of $L_{OA}/B$ ratio was 6.04, the mean value of $L_{OA}/B$ ratio for the period between 2000 and 2019 raised to 6.7.

Figure 6 also shows the dependence of $T$ on the $L_{OA}$. A strong correlation can be observed between $T$ and $L_{OA}$, and the change of $T$ can be represented with the formula:

$$T = 0{,}0271 \cdot L_{OA} + 1{,}6105. \quad (2)$$

The value of the $R^2$ coefficient is 0.7262. Ratio $B/T$ ranges from 2.86 to 7.6, and the mean value is 4.32. It can be noted that there were no significant changes in this ratio over the years. In the period from 1980 to 2000, the mean value of $B/T$ ratio was 4.35, while in the period from 2000 to 2019, it was 4.24. Compared to other types of ships of similar $L_{OA}$, Ro-Pax ferries have relatively low $T$ to the fact that they carry relatively light mass cargos.

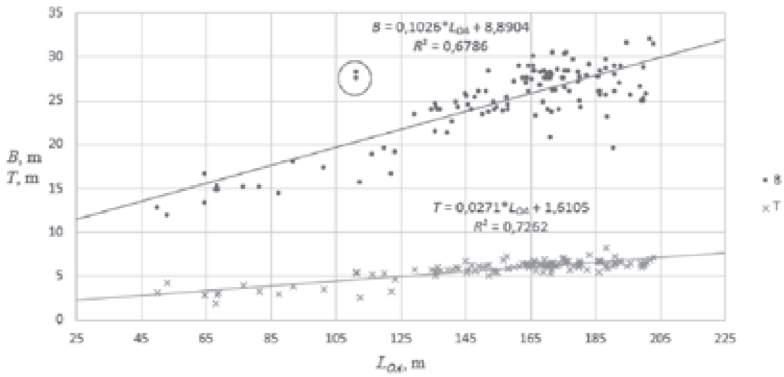


*Figure 6: B and T as a function of $L_{OA}$*

Figure 7 shows the number of ferries as a function of $GT$. The ferries were grouped according to their $GT$ within value of 5000. Figure 7. shows that significant part (75.6%) of Ro-Pax ferries has $GT$ ranging from 15000 to 40000, with only three ferries over 50000. A strong correlation can be observed between $GT$ and $L_{OA}$ in Figure 8, which can be represented with the formula:

$$GT = 0.8484 \cdot L_{OA}^2 + 57.358 \cdot L_{OA} - \cdot 6320.3. \quad (3)$$

The value of the $R^2$ coefficient is 0.7025.

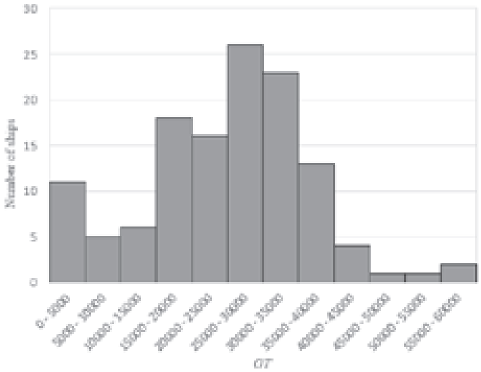


Figure 7: GT and number of Ro-Pax ferries

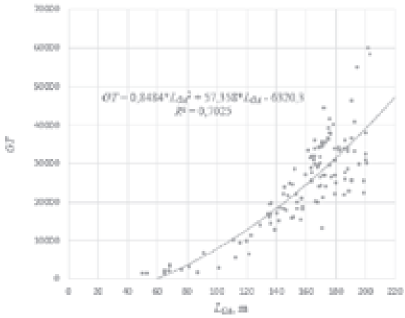


Figure 8: GT as a function of $L_{OA}$

Figure 9. shows the number of ferries as a function of *dwt*. The ferries were grouped according to their *dwt* within the value of 1000. For the most of the ferries (81%), *dwt* ranges from 2000 to 8000 t. Compared to other types of ships of similar size, *dwt* of ferries is considerably smaller due to the relatively light mass cargo with a large stowage factor. Only two ferries have *dwt* above 14000 tons, and one of them is intended for the transport of trains so this explains the *dwt* over 18000 tons. Figure 10. shows the relationship between *dwt* and $L_{OA}$. *Dwt* of Ro-Pax ferries can be approximately determined by the equation:

$$Dwt = 0.1866 \cdot L_{OA}^2 + 2.4361 \cdot L_{OA} - \cdot 655.67 \quad (4)$$

The value of the $R^2$ coefficient is 0.4492, so this formula should be used only as some kind of guideline.

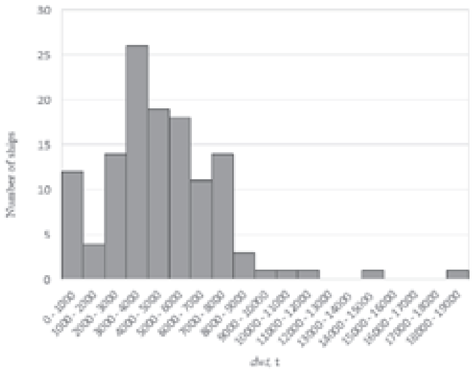


Figure 9: Dwt and number of Ro-Pax ferries

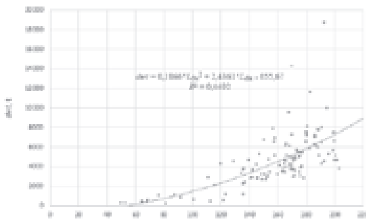

Figure 10: Dwt as a function of $L_{OA}$

Due to very various routes, the Ro-Pax ferry capacities are very heterogeneous. The different routes show different needs of capacities. Some routes require higher passenger capacity at the expense of smaller vehicle capacity, and vice versa and this partially explains the large scatter of data in Figure 11. The formula shown on Figure 10. practically cannot be used due to very low value of the $R^2$ coefficient which is 0.0771.

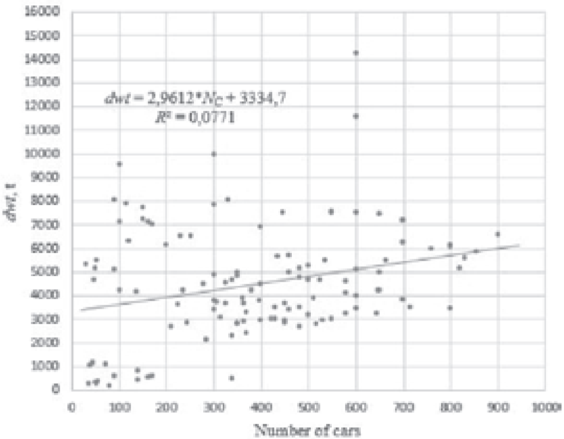


*Figure 11: Dwt as a function of number of cars ($N_C$)*

As already mentioned, Ro-Pax ferry capacities mostly depend on route demands and therefore passenger and car capacities vary from ferry to ferry. Consequently, it is difficult to connect these capacities with $L_{OA}$, as shown in Figure 12. There is some dependency between the passenger or car capacities and $L_{OA}$, but there is no strong correlation since the values of the $R^2$ coefficient are very low: 0.1121 and 0.2329. The passenger capacities for ferries between 120 and 200 m range from 79 to 3123, with the average value of 1316 passengers. As far as car capacities are concerned, they range from 30 to 900, with the average value of 425 cars.

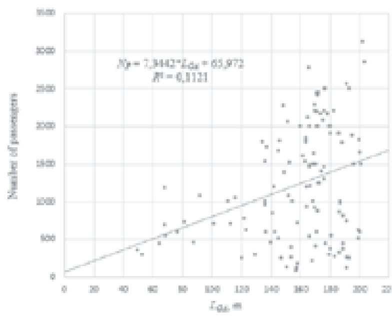


*Figure 12: Number of passengers ($N_P$ as a function of $L_{OA}$*

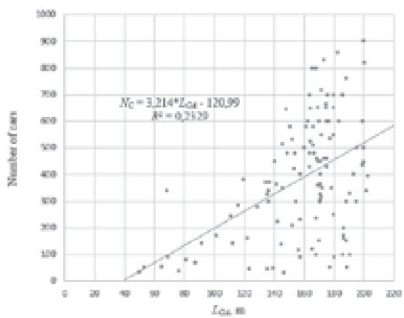


*Figure 13: Number of cars ($N_C$) as a function of $L_{OA}$*

*P* significantly depends on the $L_{OA}$ and *P* increases with increasing $L_{OA}$. Likewise, the ship speed undoubtedly determines the selection of the main engine and usually *P* is a nonlinear function of *V*. Figure 13. shows the *P* in relation to the $L_{OA}$. *P* of Ro-Pax ferries can be approximately determined by the formula:

$$P = 0.8334 \cdot L_{OA}^2 - 6.2693 \cdot L_{OA} - \cdot 350.34. \quad (5)$$

The value of the $R^2$ coefficient is 0.4508, so this formula also should be used with caution. It can be noticed that the regression curve tracks data well up to 150 m. For larger ferries, the data scatter is too large, which can be explained with different ferry mission profile and speed requirements. *P* for ferries with the $L_{OA}$ between 50 to 200 m varies from 8700 up to 50400 kW.

Similarly, as *P*, *V* can also be presented with the regression function in regard to $L_{OA}$, Figure 13. It can be noticed that the scatter of data is too large, particularly for $L_{OA}$ over 150 m. These disparities in *V* are mostly caused by lengths of routes and mission profiles of ferries. *V* for ferries with $L_{OA}$ between 150 and 200 m range from 10,7 to 28,5 knots, with average of 19,4 knots.

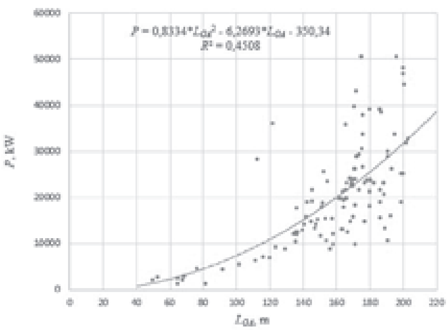


*Figure 14: P as a function of $L_{OA}$*

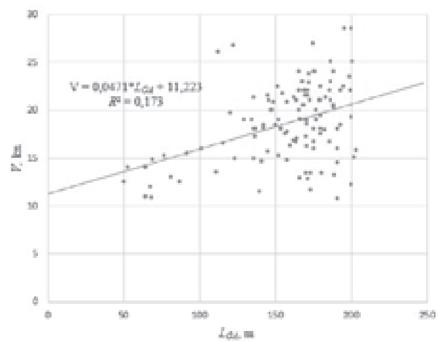


*Figure 15: V as a function of $L_{OA}$*

### 3.2. Double-ended ferries data

Figure 16. shows the number of double-ended ferries based on their $L_{OA}$, which ranges from 40 to 150 meters. Most ferries (84%) have $L_{OA}$ in the range between 40 and 100 m. Short routes on which double-ended ferries usually operate do not demand larger $L_{OA}$ and for this kind of routes it is important to sail frequently and not waste time in ports. Therefore, the need for adequate capacity is offset by a shorter port maneuvering, berthing and loading/unloading. Due to these requirements, a double-ended ferry has the specific symmetric hull form and propulsion system, allowing an equally efficient sailing ahead and astern.

Figures 17. and 18. show the number of ferries as a function of *B* and *T*. *B* of most ferries (82%) ranges from 12 to 20 m, with an average value of 15.9 m. *B* rarely exceeds 20 m. *T* mostly ranges from 2 to 5 meters (95%), with an average value of 3,4 m.

Scatter plots in Figure 19. show that $L_{OA}$ strongly influences the $B$ and $T$, and both $B$ and $T$ proportionally follow the increase in $L_{OA}$. The change of $B$ can be represented with the formula:

$$B = 0{,}1005\ L_{OA} + 7{,}3989. \quad (6)$$

The value of the $R^2$ coefficient is 0.5527. For double-ended ferries, $L_{OA}/B$ ratio ranges from 4.4 to 6.8, with an average value of 5.18 m. Similar to Ro-Pax ferries, a slight increase of $L_{OA}/B$ ratio was observed over the years also for these ferries, with an average value of 5 for ferries built between 1970 and 2000, and 5.4 for those built between 2000 and 2019. The values of these ratios are lower than ratios for Ro-Pax ferries because double-ended ferries are shorter and larger capacities are obtained by the wider hull form.

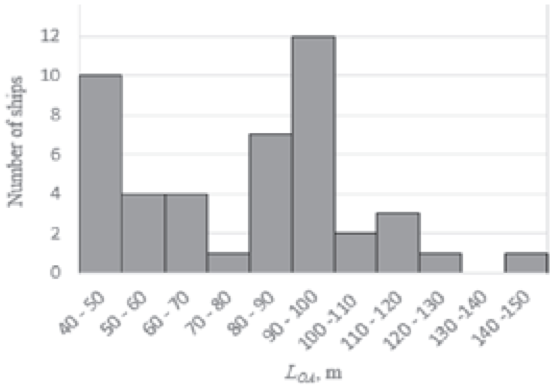


*Figure 16: $L_{OA}$ and number of double-ended ferries*

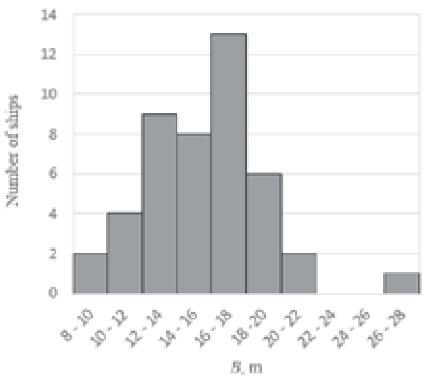


*Figure 17: B and number of double ended ferries*

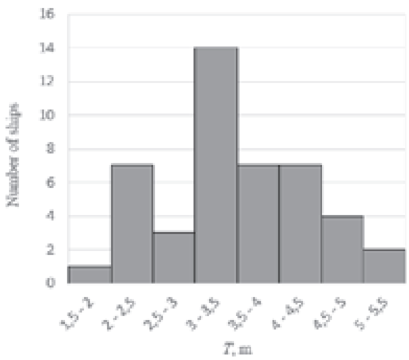


*Figure 18: T and number of double ended ferries*

The dependence of $T$ on $L_{OA}$ is shown in Figure 19 and the change of $T$ can be represented with the formula:

$$T = 0{,}0148\ L_{OA} + 2{,}2056. \quad (7)$$

The value of the $R^2$ coefficient is 0.2231.

Compared to Ro-Pax ferries, wider hull forms of double-ended ferries also cause an increase in the $B/T$ ratio. This ratio has also increased over the years, from an average value of 4.2 for ferries built from 1970 to 2000, up to the average value of 5.4, for ferries built from 2000 until 2019. The overall average value of $B/T$ ratio is 4.8.

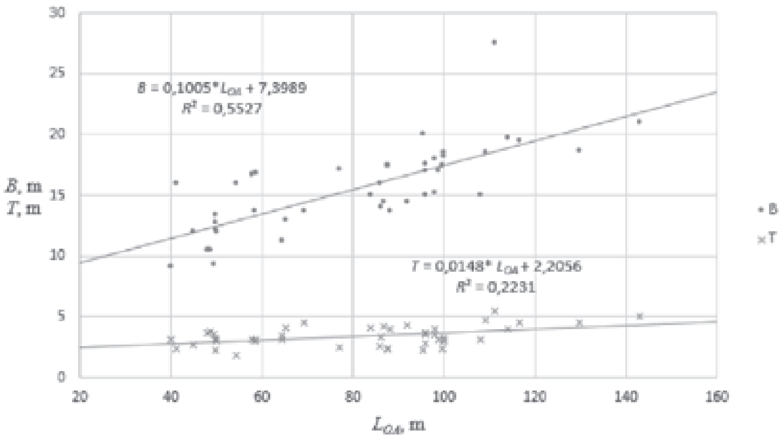


*Figure 19: B and T as a function of $L_{OA}$*

Figure 20. shows that significant part of double-ended ferries has *GT* in range from 0 to 5500, with only three cases above 7000. As seen in Figure 18., one ferry significantly deviates from that range with the value of 11434. This value can be explained with the high passenger capacity (1250) and car capacity (240) which can be noticed in Figure 25. and 26. Figure 21. shows *GT* as a function of $L_{OA}$.

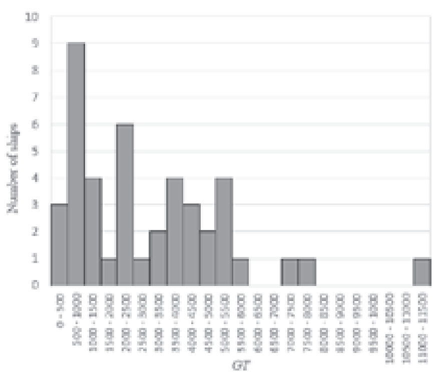


*Figure 20: GT and number of double ended ferries*

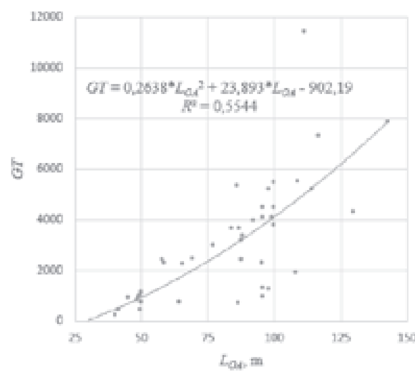


*Figure 21: GT as a function of $L_{OA}$*

*Dwt* for most of the double-ended ferries (91%) is within 1400 t, as is shown in Figure 18. *Dwt* of double-ended ferries can be roughly estimated form the formula, Figure 23:

$$Dwt = 0.0532 \cdot L_{OA}^2 + 5.2602 \cdot L_{OA} \qquad (8)$$

The value of the $R^2$ coefficient is 0.2699.

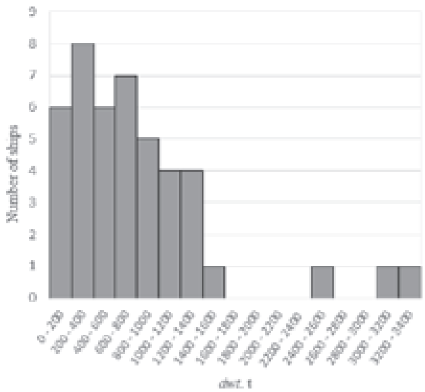


*Figure 22: Dwt and number of double ended ferries*

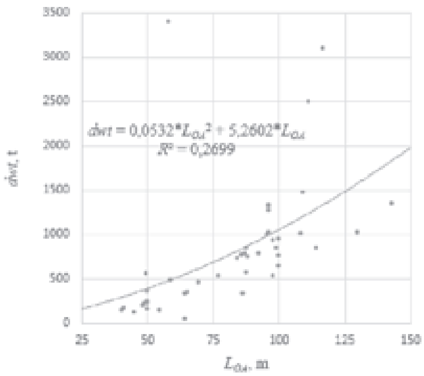


*Figure 23: Dwt as a function of $L_{OA}$*

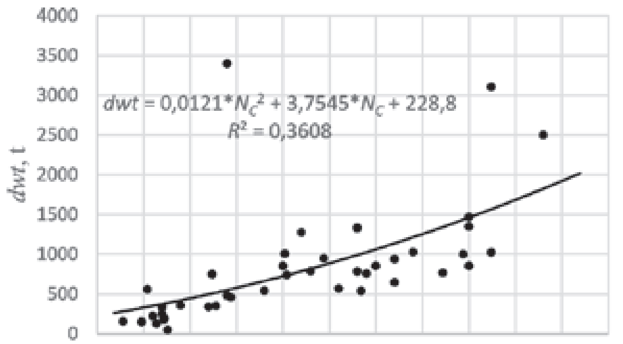


*Figure 24: Dwt as a function of number of cars*

The three double-ended ferries differ significantly from the group of others which were analyzed. Two of them with *dwt* over 2400 t have large car capacities, more than 220 cars, and one of them has the highest *dwt* (3397 t) with a very small car capacity (70). For the rest of the analyzed ferries, as shown in Figure 24., *dwt* and the car capacity are linked over the following formula:

$$Dwt = 0.0121 \cdot N_C^2 + 3.7545 \cdot N_C + 228.8. \qquad (9)$$

The value of the $R^2$ coefficient is 0.3608.

Most of double-ended ferries sail on short, local routes so their passenger and car capacities are determined by route needs and port capacities. Number of passenger decks varies from ferry to ferry, and within the database the ferries have from one to three passenger decks. The passenger capacity depends of number of decks and because of this the correlation between the number of passengers and $L_{OA}$ is lower, with higher dispersion of data, shown in Figure 25. Passenger capacities range from 86 to 1250 with an average value of 464. The number of passengers can be estimated using the formula:

$$N_P = 6.3359 \cdot L_{OA}^2 - 49.38. \quad (10)$$

The value of the $R^2$ coefficient is 0.3873.

The car capacity mostly depends on the area of decks where cars or other vehicles are parked. These ferries rarely have more than one deck intended for cars and in this manner car capacity is strongly correlated with LOA and B, as is shown in Figure 26.. Car capacities range from 14 to 240 vehicles, with an average value of 104 cars. The number of cars can be estimated using the formula:

$$N_C = 2.2216\ L_{OA} - 75.432. \quad (11)$$

The value of the $R^2$ coefficient is 0.7615.

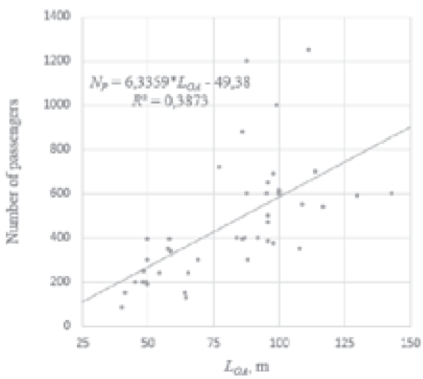


*Figure 25: Number of passengers as a function of $L_{OA}$*

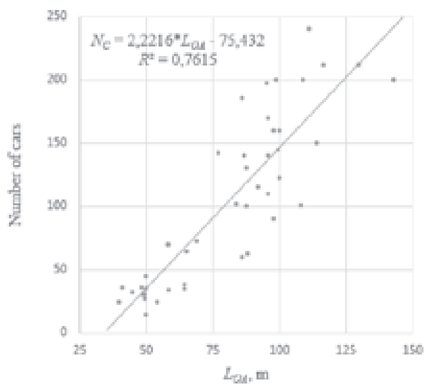


*Figure 26: Number of cars as a function of $L_{OA}$*

Figure 27. shows that $P$ is considerably correlated with $L_{OA}$, and ranges from 700 to 6000 kW. For one hybrid ferry $P$ reaches 7500 kW and the reason for this is that diesel engine power (3350 kW) and electric batteries power (4150 kW) were summed. The average $P$ is 2608.5 kW. $P$ can be estimated using the formula:

$$P = 0.2459\ L_{OA}^2 + 2{,}1519\ L_{OA} + 714{,}33. \quad (12)$$

The value of the $R^2$ coefficient is 0.415.

In Figure 28. it can be seen that there is a weak correlation between $V$ and $L_{OA}$. $V$ highly depends on service conditions, route lengths and passengers and vehicles transport needs. $V$ of double-ended ferries range from 5 to 16 knots, with an average value of 11.8 knots. $V$ can be estimated using the formula:

$$V = 0.0386\ L_{OA} + 8.7237. \tag{13}$$

The value of the $R^2$ coefficient is 0.1834.

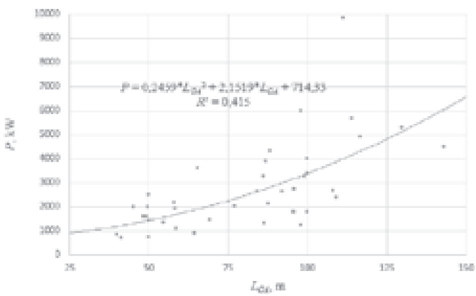


Figure 27: *P* as a function of $L_{OA}$

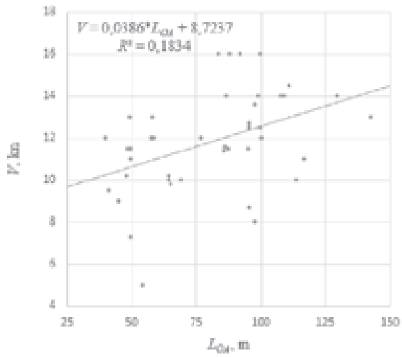


Figure 28: *V* as a function of $L_{OA}$

## 4. Guidelines for the concept design of hybrid ferries

Results obtained from the analysis of established databases were used for the estimation of basic parameters of hybrid Ro-Pax and double-ended ferry which were destined to be developed within the project METRO. These ferries are intended to operate on two different routes that were taken as relevant for the project METRO [11]. The longer route, with the length of about 130 nautical miles, should connect Croatia and Italy between ports of Split and Ancona, and the shorter one, with length of 2,7 nautical miles, should connect Istrian peninsula with the Island of Cres via local ports in Brestova and Porozina. Basic parameters for both new hybrid ferries were determined using the formulas and diagrams presented in this study, and are shown in Table 1. and Table 2. As the exact basic parameters of the new ferries are still unknown at this very early stage of the preliminary design, for both new ferries the basic parameters were estimated for four different ferry lengths, which fall within the expected range of ferry lengths. In both tables the basic parameters of existing ferries that sail on these routes are also shown. The estimated basic parameters are in good agreement with the basic parameters of the existing ferries. It can be pointed out that the existing ferries are not specifically optimized for the indicated routes.

*Table 1: Ro-Pax ferry – route Split and Ancona*

| Ro-Pax | | | | | | |
|---|---|---|---|---|---|---|
| **Basic parameters** | **M/V Aurelia** | **M/V Marco Polo** | **New design** | | | |
| $L_{OA}$, m | 147.97 | 128.13 | 120.00 | 125.00 | 130.00 | 135.00 |
| ***B***, **m** | 25.40 | 19.60 | 21.060 | 21.580 | 22.110 | 22.630 |
| ***T***, **m** | 5.80 | 6.20 | 4.850 | 4.990 | 5.120 | 5.260 |
| ***GT*** | 21518 | 10154 | 12780 | 14106 | 15474 | 16885 |
| ***dwt***, **t** | 3250 | 1132 | 2324 | 2565 | 2815 | 3074 |
| **IMO number** | 7602120 | 7230599 | - | - | - | - |
| **Build year** | 1980 | 1973 | - | - | - | - |
| **Passenger capacity** | 2280 | 1000 | 947 * | 984 * | 1021 * | 1057 * |
| **Car capacity** | 610 | 270 | 265 * | 281 * | 297 * | 313 * |
| ***P***, **kW** | 14120 | 15000 | 10898.3 | 11887.9 | 12919.1 | 13992.0 |
| ***V***, **kn** | 15.5 | 16.0 | 16.8 | 17.1 | 17.3 | 17.6 |

* - *To be taken with caution.*

*Table 2: Double-ended ferry – route Brestova-Porozina*

| Double-ended ferry | | | | | | |
|---|---|---|---|---|---|---|
| **Main particulars** | **M/V Bol** | **M/V Brestova** | **New design** | | | |
| $L_{OA}$, m | 95.4 | 58,17 | 60.0 | 70.0 | 80.0 | 90.0 |
| ***B***, **m** | 20.0 | 16,8 | 13.423 | 14,434 | 15,439 | 16.444 |
| ***T***, **m** | 2.30 | 2,70 | 3.094 | 3.242 | 3.390 | 3.538 |
| ***GT*** | 2330 | 2315 | 1481 | 2063 | 2698 | 3385 |
| ***dwt***, **t** | 1000 | 482 | 507.1 | 628.9 | 761.3 | 904.3 |
| **IMO number** | 8736344 | 8625090 | - | - | - | - |
| **Build year** | 2006 | 1985 | - | - | - | - |
| **Passenger capacity** | 600 | 338 | 331 * | 394 * | 457 * | 521 * |
| **Car capacity** | 176 | 70 | 58 * | 80 * | 102 * | 125 * |
| ***P***, **kW** | 1412 | 2200 | 1728,7 | 2069,9 | 2460,2 | 2899,8 |
| ***V***, **kn** | 12 | 12 | 11.04 | 11.42 | 11.81 | 12.19 |

* - *To be taken with caution.*

## 5. Conclusion

One of the main goals of the METRO project is the development of two new hybrid ferries, RoPax and double-ended, which may be suitable for the transportation of passengers and vehicles between ports in Italy and Croatia in the Northern Adriatic. In order to obtain guidelines for the selection of basic parameters of new ferries, two databases were formed, one for each ferry type.

The following data were gathered as basic parameters: length overall, breadth, draft, main engine power, speed, gross tonnage, deadweight as well as passenger and car capacity. In addition to these data, the databases partly contain some other data (for example route lengths, ferry lane meters, number of passenger and cargo decks, etc.), but these data were not analyzed due to their incompleteness or unreliability.

Given that a quite sufficient number of both types of ferries were gathered, the databases provide very good guidelines for new hybrid ferry designs. Based on the data analyzed and formulas developed within the study, the basic parameters of four ferries within the range of lengths that could fit well into the Northern Adriatic area were preliminary selected. The selection of these basic parameters represents the first step in the process of development of new hybrid Ro-Pax and double-ended ferries within the project METRO.


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