Extending the life of a ship by extending her length: Technical and economic assessment of lengthening of inland vessels

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ABSTRACT

The objective of MoVe IT! (Modernisation of vessels for inland waterway freight transport) project is to investigate cost-effective options for modernisation of the European inland fleet. One of the project tasks was to examine the feasibility of lengthening of existing small vessels (*LOA* < 86m) from both the technical and the economic point of view. With respect to that, the gradual lengthening (in several predefined steps) of two typical inland vessels of CEMT class II and III was examined. For each step, the ship structure scantlings were verified against the rules of classification societies, the manoeuvring features were simulated and the power necessary for attaining certain speed was calculated. Finally, the economic and environmental impacts of lengthening were assessed. The results of the analysis confirmed that lengthening can be viable, in particular for larger vessels (in this case, class III) where the payback periods were found to be relatively short. In addition, the lengthening proved to have a positive effect from the environmental point of view. The analysis also demonstrated that there are conditions related to waterway characteristics and economic environment under which the lengthening would not pay off, even though it would be technically feasible.

Keywords: MoVe IT!, Modernization of inland fleet, Retrofitting, Lengthening of inland vessels.

1. INTRODUCTION

The lengthening of ship hull as a measure aimed at increase of competitiveness of smaller vessels is hardly a novelty. In fact, it is a practice already present in both the new-building and the reconstruction of seagoing and inland ships. Nevertheless, rather than relying on shipbuilding practices only, the MoVe IT! project intended to offered a systematic analysis of lengthening, by taking a number of relevant aspects into account: strength of lengthened structure, manoeuvring capabilities and powering requirements of the retrofitted vessel. Technical analysis supplemented by an economic assessment should provide practical lengthening guidelines to ship-owners considering such retrofitting solution. Furthermore, the analysis should indicate the upper limit of lengthening for a given ship, in terms of technical and economic soundness. Therefore, one of the project tasks, carried out within the Work Package 6 (*New scales and services*) was to investigate possible costs and benefits of the lengthening of the typical small (*L* < 86m) inland cargo vessels, whereby the lengthening, as considered in the MoVe IT! project, represents the extension of mid-ship section, while beam and depth remain unchanged.

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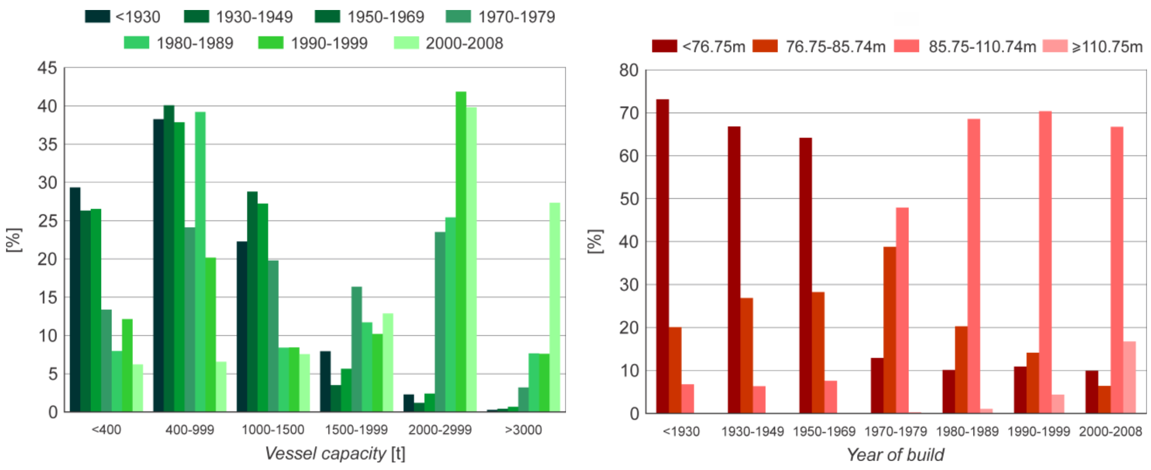
2. LENGTHENING SCENARIOS

First of all, it was necessary to establish which ship types and CEMT (Conference of European Ministers of Transport) classes were of particular interest for lengthening analysis. The development of the "lengthening scenarios" is described in Bačkalov (2014). It was decided that the investigation should focus on dry cargo self-propelled vessels, since existing single-hull tankers should comply with the double-hull requirements in the first place. This would make scale enlargement much more complex and possibly less attractive than finding the new market, or even scrapping the ship. (Adjustment of single-hull tankers to new market conditions was subject of another task performed within WP 6). Next, an attempt was made to identify the length spans that stand out either by number of vessels or by capacity utilization (or by any other criterion or combination of criteria) and therefore deserve particular attention. Subsequently, the evolution of (Western) European inland fleet was analysed in order to discover patterns and establish trends in the development of the vessels, with an aim to pinpoint a length that may be considered as "desirable" and, apparently, feasible. Two tendencies could have been noticed.

It is obvious that small inland fleet is gradually disappearing. Due to numerous reasons, thoroughly elaborated by van Hassel (2011), the existing small vessels are vanishing, while new orders of such vessels are becoming scarce. This is clearly shown in Figures 1a and 1b that were composed based on the data published by UNECE (2011) and show the evolution of the self-propelled vessels of the Rhine fleet since the 1930s to the present days. In Fig. 1a, self-propelled vessels of the Rhine fleet are organized by capacity and year of built. The decrease of share of the smaller vessels (< 1000t) and the share upsurge of the large vessels (> 2000t) are apparent and most pronounced at the ends of the range (for ships < 400t and > 3000t). The vessels in range 1000t ÷ 2000t (which approximately conforms to the lengths 80m ÷ 100m) appear to be equally attractive today as they used to be in the 1980s.

In Fig. 1b, vessels are organized by length and year of build. The statistics show sharp decrease of number of new-built vessels with $L < 85$m in the last five decades, whereby decline of new-building of vessels less than 77m started a decade earlier. Simultaneously, the share of vessels longer than 110m rapidly increased as of 1980s.



a) b)

Figure 1. Evolution of the self-propelled vessels on the Rhine: (a) by size and year of build and (b) by year of build and length

Another visible tendency was that scale enlargement has been taking place within the CEMT classes too. Brolsma (2011) points out that, as a consequence of scale enlargement, a vessel may have the class IV length while maintaining the class III width. This is confirmed by other studies as well (see, for instance, report by a&s management et al., 2003). Vessel categorization as laid out in CEMT (1992) is therefore partly out of date.

Finally, it was concluded that the lengthening of very small vessels, less than 400t and 50m (CEMT class I) should not be examined. Such vessels are either very old (and are about to be scrapped) or (if new) deliberately serve a particular niche market connected to specific waterways (e.g. a network of small canals) and therefore need not to be extended. Consequently, the analysis focused on CEMT II and III class vessels with the ultimate goal to reach the class IV length or even the lower boundary of class Va length span (as the basic CEMT classes already evolved). More precisely, the goal was to attain, as far as applicable, the length span 80m ÷ 100m.

Subsequently, it was decided to conduct the analysis by simulating the extension of the mid-ship of two “parent vessels” in equal lengthening steps, ΔL = 6m, which (roughly) corresponds to the space required for an additional TEU bay. The parent vessels should be typical representatives of their respective types, including structural, powering and propulsion arrangements and equipment. Vessels with particulars that fall out of class boundaries (for example, shallow draught) as well as vessels with atypical design solutions were deliberately left out, in order to preserve the applicability of results to as many vessels of an examined class, as it is possible. Finally, two existing vessels, Hendrik and Rheinland, which fulfilled the afore-mentioned conditions, were selected (Table 1). Interestingly, both vessels have actually been lengthened in “real life”: Hendrik by 10m and Rheinland by approximately 6m. Both vessels still operate.

Table 1. Parent vessels

Parent vessel	Hendrik	Rheinland
Length over all, *LOA* [m]	69.98	57.5
Beam over all, *BOA* [m]	8.6	6.34
Draught, *d* [m]	2.95	2.43
Depth, *D* [m]	3	2.5
Displacement, Δ [t]	1360	724
CEMT class	III / IV	II
Year of build	1975	1959
Construction	Single hull / double bottom	Single hull
Propulsion	Single propeller	Single propeller

3. STRENGTH OF LENGTHENED VESSEL STRUCTURE

From the structural point of view, the goal was to determine the required scantlings of structural elements of lengthened hulls, according to the current rules of classification societies, and consequently, to calculate the increase of cargo carrying capacity and corresponding retrofitting costs, for each lengthening step.

In the present analysis, only conventional shipbuilding materials (i.e. mild steel) were considered, as ship-owners tend to opt for mature and proven technologies. (Nevertheless, innovative structures involving composites and advanced construction solutions were subject of another MoVe IT! work package). The scantlings of structural elements of Hendrik and Rheinland were verified against the rules of Germanischer Lloyd (2011) and Bureau Veritas (2009) respectively. Detailed calculations are given in Wilcke et al. (2014).

Hull lengthening is not a straightforward procedure, but requires certain level of optimization. In some cases, due to the limitations imposed by the rules (e.g. maximum permissible cargo hold length), the exact position of inserted section is to be decided upon consideration of possible weight savings, complexity of the solution and man-hours required.

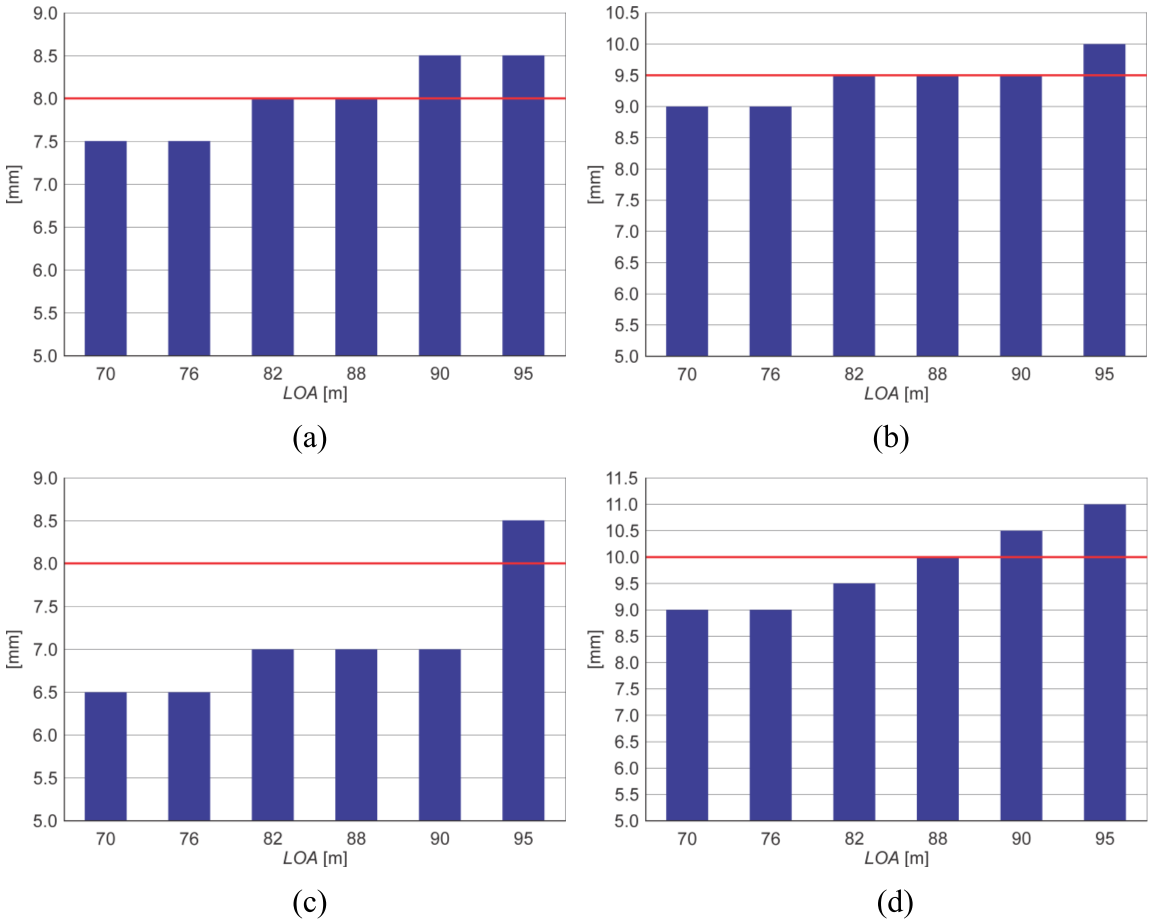
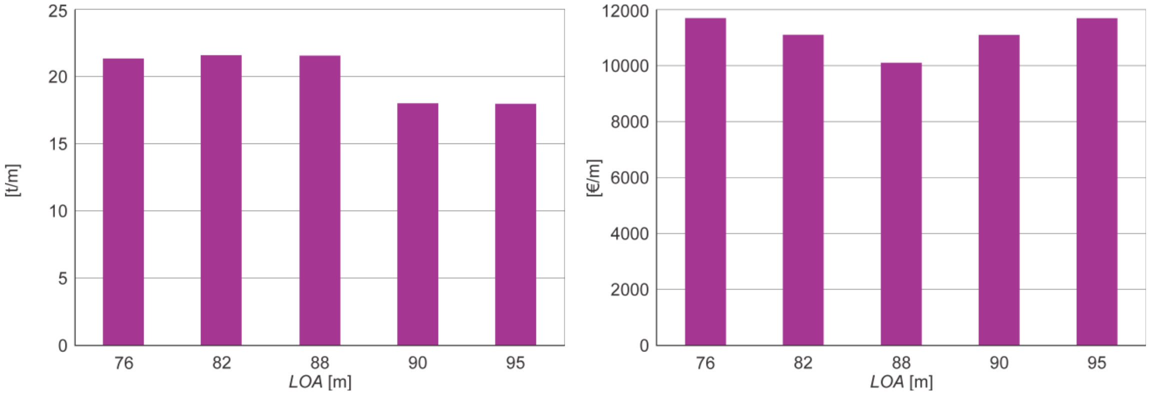


Figure 3. Thickness of (a) bottom plates, (b) chine radius, (c) side plates and (d) hatch coaming, for various lengths as required by Germanischer Lloyd. Red lines correspond to “as built” condition. (Hendrik)

The lengthening analysis of Hendrik was performed up to *LOA* = 94.99m. Exceeding this length would formally place the vessel in CEMT Va class with increased safety, equipment and crew requirements. The analysis indicated that the lengthening for more than 18m could be technically challenging and hence possibly not feasible. Namely, scantlings of stiffeners and plates that correspond to original, “as built” length (*LOA* = 70m) fulfil the requirements of Germanischer Lloyd up to *LOA* = 88m. Beyond this length, a number of structural elements would have to be upgraded or replaced by stronger ones, see Fig. 3a ÷ 3d. Obviously, the replacement of large steel panels such as bottom plates would drastically increase reconstruction costs. This could be overcome by introducing additional longitudinal stiffeners in order to comply with buckling (in case of side plates) or longitudinal strength requirements (in case of bottom, chine radius and hatch coaming). Either way, further lengthening of Hendrik would require considerable reconstruction (formally, the conversion of the vessel, which is regarded as new-building by Germanischer Lloyd). Furthermore, several special solutions that are normally out of scope of the classification rules would have to be applied.

Relative increase of cargo carrying capacity for each lengthening step is given in Fig. 4a. Up to *LOA* = 88m, additional mass of cargo generated per lengthening meter is around 21.5t/m, but it drops to 18t/m for the next two considered lengths. Finally, relative costs of hull lengthening (including material and labour costs of building of the new section and the upgrade of existing elements, hatch cover procurement and docking costs per lengthening meter) also indicate that 88m is the upper limit of lengthening of class III vessel (Fig. 4b).



(a) (b)

Figure 4. Hendrik: (a) additional mass of cargo per lengthening meter; (b) relative costs of hull lengthening

The lengthening analysis of Rheinland was carried out up to *LOA* = 69.5m, that is, in two lengthening steps only. Namely, assuming that the corrosion took place (due to the fact that the vessel was very old) the scantlings of some elements of the "as built" structure failed to satisfy the rules of Bureau Veritas even at the first lengthening step. Bottom plates could not fulfil the requirements regarding buckling; thickness of webs of main supporting structure was below the minimal value required by the rules, after the deduction of corrosion addition. The buckling issue could be solved with additional longitudinal stiffeners, but the insufficient web thickness of floors and web frames (4mm instead of required 4.94mm) would have to be approved by the classification society, probably based on the direct calculations of ship strength. Relative costs corresponding to lengthening of Rheinland's hull for 12m were estimated to 7100€/m, while additional mass of cargo attained 13t/m.

4. MANOEUVRABILITY OF LENGTHENED VESSELS

The manoeuvring capabilities of lengthened vessels were assessed in a series of simulations conducted using the state-of-the-art in-house software of MARIN based on works by Hooft (1994), Hooft & Nienhuis (1995) and Hooft & Quadvlieg (1996). The following manoeuvres were simulated: zig-zag manoeuvre, combined turning circle / pull out, evasive manoeuvre and crash stop tests. The simulations were carried out for two speeds, 10km/h and 13km/h, and three water depths: deep water, h_w = 5m and h_w = 3.5m. The complete results obtained through simulations are presented in Tonelli (2014).

The standards for manoeuvrability of sea-going ships are established by the IMO Resolution MSC.137(76), IMO (2002). Although it was not intended for inland vessels (and consequently may have only limited applicability in such cases) the IMO (2002) Resolution was still used in the present study. This was done in particular because the manoeuvrability criteria laid down in technical standards of the Rhine Commission are largely descriptive and qualitative rather than quantitative, see RVIR (2014). Some more precise requirements referring to performance in evasive manoeuvres are, however, contained in the so called "Administrative instructions to the Inspection Commissions", see CCNR (2011), and hence were used in this investigation as well.

It was found that the hull extension did not affect considerably the manoeuvring features of the examined vessels, except in shallow water. It should be noted that manoeuvrability worsens at approximately $h_w/d = 3.5$, see Robbins et al. (2013), which is satisfied for both ships at $h_w = 5$m and $h_w = 3.5$m.

The larger vessel, Hendrik, fails to comply with IMO (2002) criteria for turning circle and zig-zag manoeuvre in $h_w = 3.5$m for any of the considered lengths, including the original one. Nevertheless, these results are merely an indication as IMO (2002) standards apply in deep, unrestricted water only. In any case, it would be advisable to decrease the approach speed in order to improve the turning ability performance in shallow water. Furthermore, evasive manoeuvre tests carried out by mathematical model revealed that CCNR (2011) limits are breached at $LOA > 82$m and steering angle $\delta = 45°$, Fig. 5, as well as that vessel is not sufficiently steerable with $\delta = 20°$. As a solution, the replacement of the rudder was proposed.

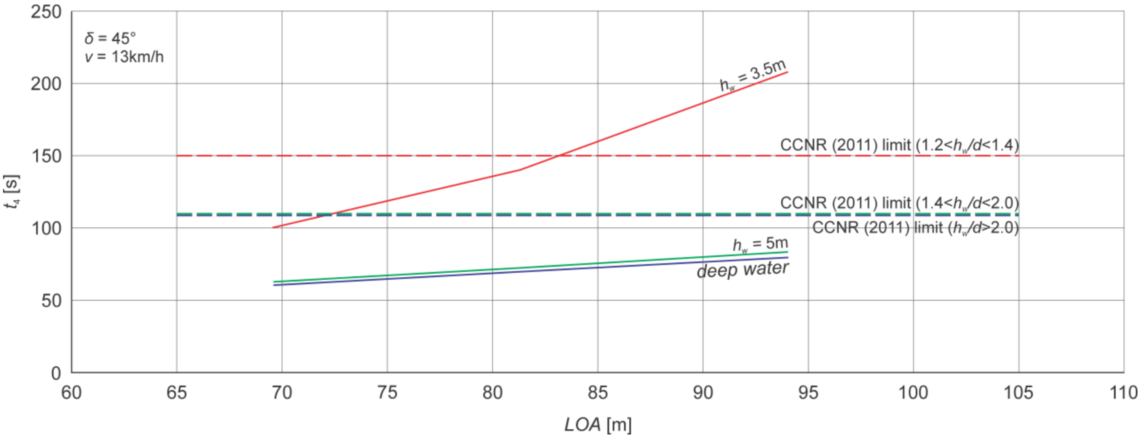
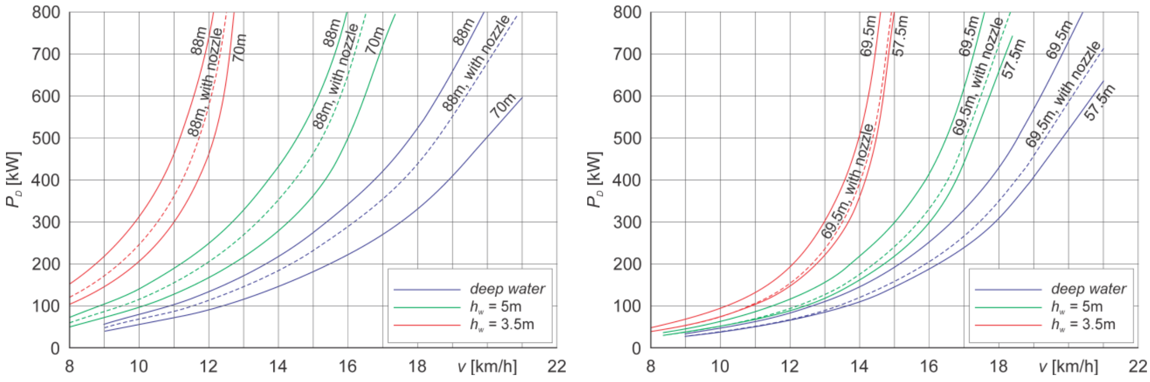


Figure 5. Evasive manoeuvre performance of Hendrik for a range of lengthening steps compared with CCNR (2011) limits corresponding to different water depths

5. (RE)POWERING OF LENGTHENED VESSELS

Given that the analysed retrofitting implies extension of length while the other main particulars remain the same, the propeller diameter could not have been changed. The "naked" propeller, however, could be replaced by a propeller in nozzle so as to increase the propulsive efficiency. The vessels could be also re-powered, that is, the older engines could be replaced by contemporary high-speed Diesel engines that are more efficient, cleaner, cheaper and lighter. Consequently, the effect of lengthening on powering was examined in case that the original power train (engine / gearbox / propeller) was retained, as well as in the case that the lengthened vessels were retrofitted with ducted propellers whereby the new power train was installed too (i.e. lengthened vessels were re-powered).

In each of the scenarios, all the calculations were carried out for three water depths: deep water and two shallow water depths $h_w = 5$m and $h_w = 3.5$m. The details of the calculations are given in Radojčić & Simić (2014). Fig. 6a and 6b show the estimate of delivered power P_D required for attaining a certain speed, v in analysed scenarios, for Hendrik and Rheinland, respectively. For the sake of clarity, only the curves corresponding to the original length and the maximal lengthening are given (whereas the curves matching the other lengthening steps would be in between these two). With the unchanged power train, the CEMT III class vessel lengthened by 18m would attain up to 2km/h less with the same engine power than the parent vessel (Fig. 6a). However, the speed reduction is less pronounced if the ducted propeller is installed instead of a "naked" one; this way, nearly 1km/h would be regained. Analogue conclusions could be drawn in case of navigation in shallow water. Similar findings are valid for the smaller vessel as well (Fig. 6b).



(a) (b)

Figure 6. Estimated required delivered power for different retrofit options:
(a) Hendrik; (b) Rheinland

Another "speed limit" that affects the vessel performance is related to the squat effect and wave wake in shallow water. The squat, however, is not significantly affected by the considered length variations.

6. ECONOMIC ASSESSMENT OF LENGTHENINGS

In order to derive an economic assessment of lengthening effects and associated environmental impacts, the operational profiles of the examined vessels had to be built. It was assumed that the vessels operate 48 weeks a year. Hendrik would complete one round trip on weekly basis on a 100km stretch of the Rhine. Rheinland was placed into completely different conditions: it was supposed that the vessel operates on a much longer section of the Danube, making approximately 15 round trips per year on a 1000km stretch. Given that Hendrik sails on a short route, it was supposed that the vessel was loaded on departure trip only. Unlike that, Rheinland would typically wait for cargo instead of sailing empty on the return trip; thus the vessel was loaded in both the upstream and the downstream direction. Further differences include the price of transported goods: though both vessels carry agricultural products in bulk, Hendrik could charge 24€/t, whereas Rheinland's freight rate would be smaller, 17€/t. In both cases, the analysis is carried out for two (average) sailing speeds. The number of round trips, however, was fixed, regardless of the speed considered. It should be emphasized that the outcome of the analysis strongly depends on the assumed operational scenario.

Three indicators are used to evaluate the economic feasibility of lengthening: net present value (NPV), internal rate of return (IRR) and payback period. IRR serves as a measure of the profitability of an investment, while NPV is used to assess the present value of the money in future, taking into account changes in economy such as inflation. The higher the IRR and NPV are, the more attractive the lengthening would be. Naturally, shorter payback periods would make this retrofit option more appealing. In inland navigation, it was found that the desirable payback period was considered to be four years at the most. Extensive report on the economy of the lengthening is given in Gille & de Swart (2014).

The results of economic assessment of class III vessel lengthening are given in Tables 2 and 3. Except for the first step (*LOA* = 76m), the examined lengthening options were found to be economically feasible. The change in average speed did not affect the results considerably.

Table 2. Economic assessment for average speed of 10km/h, Hendrik

LOA [m]	76		82		88	
Propeller	“naked”	ducted	“naked”	ducted	“naked”	ducted
NPV·1000 [€]	791	801	2073	2091	3355	3383
IRR [%]	23	21	53	48	93	83
Payback time [years]	6	6	3	3	2	2

Table 3. Economic assessment for average speed of 14.4km/h, Hendrik

LOA [m]	76		82		88	
Propeller	“naked”	ducted	“naked”	ducted	“naked”	ducted
NPV·1000 [€]	760	835	2011	2093	3264	3356
IRR [%]	22	22	51	48	89	82
Payback time [years]	6	6	3	3	2	2

The results obtained for the smaller vessel were quite dissimilar (Tables 4 and 5). The payback periods were found to be excessively long. This in particular applies to higher speed case, where enlarged payload is insufficient to outweigh increased fuel consumption.

Table 4. Economic assessment for average speed of 10.8km/h, Rheinland

LOA [m]	63.5		69.5	
Propeller	“naked”	ducted	“naked”	ducted
NPV·1000 [€]	70	71	298	385
IRR [%]	9	8	20	18
Payback time [years]	15	16	6	7

Table 5. Economic assessment for average speed of 14.8km/h, Rheinland

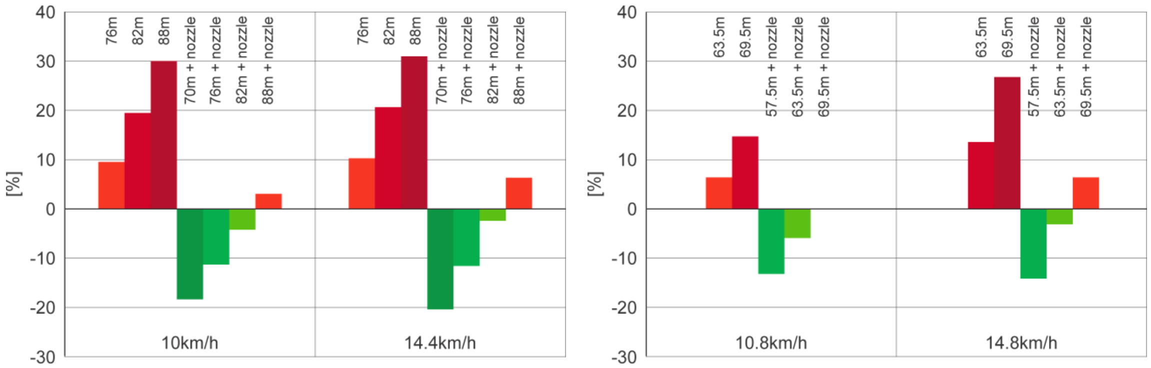
LOA [m]	63.5		69.5	
Propeller	“naked”	ducted	“naked”	ducted
NPV·1000 [€]	-27	75	190	325
IRR [%]	4	9	13	16
Payback time [years]	> 26	16	10	8

Additionally, a sensitivity analysis was carried out with an aim to establish the influence of specific assumptions on the analysis outcome. With respect to that, the investment costs, fuel price and freight rates were varied within the range of ±20%, ±10% and ±25% respectively. Regarding the larger vessel, the sensitivity analysis performed for the first lengthening step (*LOA* = 76m), revealed that the examined fuel price variation did not affect the outcome of the analysis (as the payback period remained six years in any case), whereas the changes in investment costs and transport prices were found to be more influential and could have prolonged the payback period up to eight years or shortened it down to five. Similar conclusions were drawn for the smaller vessel, Rheinland in the first lengthening step (*LOA* = 63.5m). In addition, it was interesting to check whether considerable improvement of economic climate in the Danube region, reflected in 25% higher transport prices, could make the second lengthening step (*LOA* = 69.5m) feasible. The analysis shown that, even under such favourable conditions, the payback period would be at least five years.

7. ENVIRONMENTAL IMPACT OF LENGTHENING

In order to evaluate the influence of lengthening on the pollution of the environment, the harmful emissions of ship engines: CO_2, NO_x, PM, CO, HC and SO_2 were assessed for each lengthening step for both, the vessel with the "naked" propeller and the vessel with the propeller in nozzle. The total annual emissions may be calculated by multiplying the total fuel consumption on a yearly basis with the fuel consumption-dependent emission factors. For the purpose of the present study, emission factors were retrieved from Van der Gon & Hulskotte (2010), and represent the values averaged over different power classes of engines. The details of the assessment of the lengthening from the environmental point of view are presented in Gille & de Swart (2014).

The influence of the average speed of sailing and the propeller arrangement ("naked" vs. ducted propeller) on the emissions levels was investigated for both vessels. Regarding the larger vessel Hendrik, it was found that emissions are increased by 30% on the annual level after lengthening by 18m, in case that vessel sails with the speed of 10km/h on the average, Fig 7a. However, if the vessel is retrofitted with a ducted propeller as well, total emissions are increased by 3% only, for the same additional length and speed. The results do not differ considerably if the vessel sails with the average speed of 14.4km/h.

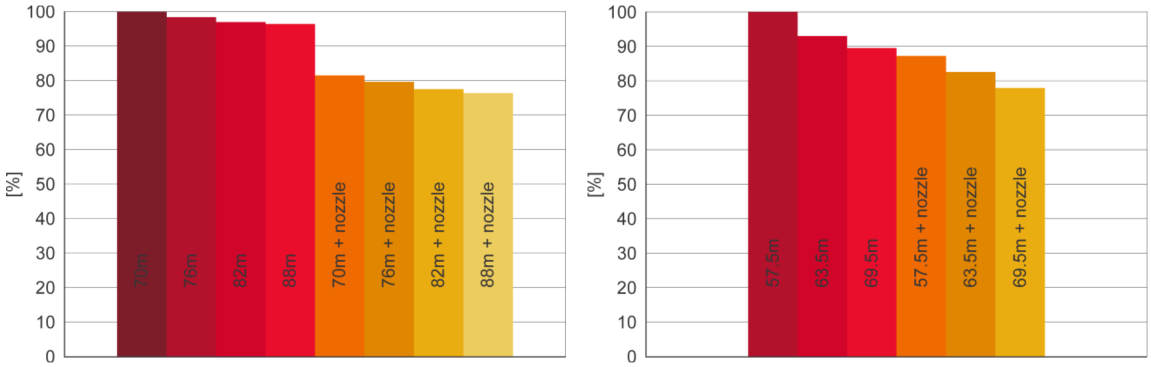


(a) (b)

Figure 7. Annual increase of total emissions for different retrofit options, relative to the original length: (a) Hendrik; (b) Rheinland

As for the Rheinland, the maximal hull extension from the technical point of view (ΔL = 12m), results in 15% higher emissions on the annual level, for the lower vessel speed considered. In case that the propeller in nozzle is also installed, the level of emissions remains practically unchanged in comparison to the base case (*LOA* = 63.5m). The situation is somewhat different if the speed is increased to 14.8km/h, Fig. 7b.

Clearly, in absolute terms, increase of the length is followed by the increase of emissions. Conversely, emissions are reduced relative to the transport work done. The decrease of emissions per tkm of transported goods is presented in Fig. 8. In case of Hendrik, considerable decrease of emissions per tkm is attained not by lengthening, but by installing the propeller in nozzle. Regarding Rheinland, however, the contribution of the hull extension is much more pronounced: the emissions are decreased by more than 10% only due to the lengthening of the hull by 12m.



(a) (b)

Figure 8. Decrease of emissions per tkm for different retrofit options, relative to the original length: (a) Hendrik; (b) Rheinland

8. CONCLUDING REMARKS

In shipbuilding practice, the lengthening of ship hull is a well-known method for increase of profitability. On the other hand, it is also known that, from the ship design point of view, the length is the “most expensive” ship dimension; see for instance Lamb (2003). Due to the longitudinal strength requirements, increased length (whereby other main particulars remain unchanged) results in the greatest relative increase of lightship. Indeed, in the present analysis, the deadweight coefficient has only marginally increased after lengthening. In case of Hendrik, hull extended by 25% of the original length resulted in less than 1% greater deadweight coefficient, η_{DWT} (defined as the ratio of mass of deadweight and displacement). Similarly, after the lengthening of Rheinland’s hull by some 20% η_{DWT} rose not more than 2%. Increased length, however, is expected to extend the life of the ship, thanks to the positive effects of the economy of scale. Furthermore, in inland navigation, increased length should allow for greater operational flexibility in low water periods, when sailing at lower draught would not mean major reduction in cargo carrying capacity.

Albeit having a relatively wide scope, the present investigation actually consists of two case studies, so it would be dangerous to “extrapolate” the results to all the vessels in the same class. It should be stressed that the results of the analysis heavily depend on the assumed operational scenario. Nevertheless, the following could be concluded.

- It was shown that it would be technically feasible to lengthen the CEMT class III/IV vessel Hendrik by as much as 18m (from LOA = 70m to LOA = 88m). Although the manoeuvrability of the vessel was not drastically affected by the lengthening, the evasive manoeuvre tests revealed that a new, improved rudder arrangement would be required. Replacement of engine by a modern, cleaner and lighter one was considered as well. Still, the payback periods were found to be relatively short, thus confirming the viability of this retrofit solution for vessels operating on a short distance route on the Rhine on a regular basis.

- The analysis also demonstrated that there are conditions related to waterway characteristics and economic environment under which the lengthening would not pay off, even though it would be technically feasible. Payback periods corresponding to the lengthening of the CEMT class II vessel Rheinland by 12m (from LOA = 57.5m to LOA = 69.5m), operating on a long distance route on the Danube in the less favourable economic conditions, were found to be too long. In fact, this result is in agreement with the operational experience on the Danube, where small self-propelled vessels are rarely used for such purposes. Although real Rheinland was indeed lengthened by 6m, the vessel sails on the Rhine, in much different conditions.
- Both examples have shown that greater benefits are achieved by a proper combination of retrofit options. By reducing the power demand of the lengthened ship, the propeller in nozzle had a considerable, positive impact on environmental performance of the vessels. Moreover, from the economy point of view, installing the propeller in nozzle in most of the cases did not extend the payback period.
- Evaluation of environmental impact of lengthening provided an additional perspective. Unless specified level of emissions is imposed by regulations or required by an economic initiative (such as e.g. Green Award), harmful emissions are normally out of focus of ship-owners and hence are not an integral part of a retrofit strategy. On the other hand, although lengthening of Rheinland proved to be unfeasible, it was also shown that a combination of retrofit measures (lengthening + nozzle) could result in 20% relative decrease of emissions per tkm. Therefore, a proper environmental policy could perhaps stimulate ship-owners to opt for retrofit options even when the return of investment otherwise could not be foreseen in short term.

As a final remark, it should be pointed out that the vessel retrofit is a multi-faceted problem. Without proper analysis taking into account both technical and economic implications of an operational profile, successful retrofit cannot be guaranteed of it is based on shipbuilding practice only.

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