Barging around London

by Henrik Utvik, B. Sc.

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1. Introduction

1.1 Aims

The Grand Union Canal in London has existed since the early 19th century. While well-utilized from the mid-

Figure 1: London canals (British Waterways).

2. Design philosophy and background

2.1 State of the art

(Hekkenberg, Tugt, Till, & Zanden, 2007) postulates that the rate of technological innovation in inland waterways (IWW) shipping is considered to be low. The main reasons for this are cited to be the following:

- 1. Inland waterways vessels are usually operated by small companies with little extra capital to bear the risks associated with new technologies.
- 2. Due to the nature of inland vessels being of relatively low value, the technology often needs to be proven to be considerably better than the already used alternatives for the investment to be worth it.
- 3. Researchers often consider problems in inland waterways to be of relatively low complexity, and thus not worth pursuing.
- 4. Brokers usually interested in selling standardised products instead of designs optimised for a specific role.

A number of design challenges are cited for IWW vessels in particular. One is restrictions on dimensions due to locks, bridges etc. This limits the payload of each vessel. Oted as more important is variety in water-depth that can be encountered. The limited depth and the potential great depth-variety ca4/1s tw9[1 11.04ees small companies with little extra cap432 84g0 G[(ca4/1s tw9[fac00008i)12(rs)-3(esuc 1)]

(Sperling, Overschie, Hekkenberg, & Mulder, 2007) builds on the idea of increasing innovation in the IWW sector. Several innovation types and technology types are analysed. A list of the most relevant and important technologies are listed. The technologies are categorised depending on the level of innovation; radical



2.2 Rules

For inland waterways vessels operating in the UK, the MGN 280 code applies for operations, structures, stability, and manning.

2.3 Public initiatives and plans

The EU in particular is pushing for increased usage of the inland waterways as a means to achieving more sustainable transport of goods around the continent, and regulations to incentivise and facilitate more inland waterways transport is continuously being investigated. The goal of these policies is to increase the share of inland waterways transport to 20 % of total goods transported in the EU by 2020 (UN, 2011).

There is currently not a comprehensive domestic plan in the UK for outmoding transport to the inland waterways. However, the potential of the rivers and canals system are repeatedly recognised. The previous government coalition proposed to create a public charity organization to operate and upgrade the canals, but no fixed proposition seem to have emerged.

The London government has assessed the potential for waterways transport at several occasions, but little has been done. A report in 2007 questioned the potential for the canals, which such barriers as investment costs and no enthusiasm in the public brought up as points against their usage (PBA, 2007).

2.4 Design methodology

Because of the high number of variables and uncertainties prevalent in the early stages of product design, engineering projects such as these are usually highly iterative. This is highly relevant for maritime engineering projects.

Because of the inherent uncertainties in such a process it is prudent to formalise as much of it as possible, and apply a rigorous design methodology. Since the project is both a research paper and a concept design, the author will be working on the fringe between those two disciplines, combining them where possible. Thus the following methodology will be applied:

Usually in a research paper the subject for research is outlined through one or several research questions. Since this is essentially a design task, this will be done through more concrete instead.

The main design problems should summarise what the design is supposed be about which needs it addresses and the main design features that should be achieved. Every step in the design process should be about answering these problems.

Design requirements.

Output:

Detailed knowledge on how to answer design requirements. Literature review document.

Tools:

UCL library services. Online academic services such as Google Scholar and Esevier. High-knowledge personnel if obtainable.

At this stage, the research knowledge and base concept can be applied to achieve a detailed design. This should consist of detailed recommendations and solutions on how to fulfil main design requirements. Once the concept has been more refined, detailed technical data such as load distributions, load cases, and structural data can be obtained.

Input:

Base concept. Research output.

Output:

Detailed technical concept: Load cases, refined hydrostatic data, and structural analysis. Solutions to main design requirements.

Tools:

Ship design and other software. Literature review document.

The economic sustainability and feasibility of the vessel must be emphasised and proven. A good estimate of the equipment and build costs will be useful to potential investors. However, in order to attract attention, a suitable business plan should also be presented, so that it can be shown the numerous ways the ship could bring in money for the owner, and the special features of the vessel that can be marketed to dients.

Input:

Some market analysis.

Structural data.

Output:

Procurement and through-life cost estimates.

Business-plan that captures main revenue streams from the ship, but also covers riskassessment and main challenges.

Tools:

Structural analysis. A business plan methodology. Industry data.

The results needs to be available to decision makers, researchers, investors, and the public in order for the concept to gain wind and actually be taken to a more concrete level. Thus communicating the results in a way that showcases the high technical knowledge achieved and applied, but is also understandable to laymen, is paramount. Visualisations are important, such as sketches showcasing the vessel interacting with the environment around the canals. Drafters and artists may be hired in order to make system sketches.

Input:

The complete concept design.

Output:

Technical report. Technical drawings. Concept sketches. Presentations.

Tools:

Drawing programs. Sketching tools. Presentation toolkits.

3 Concept design

3.1 Design problems

In engineering design, it is imperative to have a solid understanding of customer needs. While companies spend a lot of money on marketing, it is important not only to know what customers say, but also what they think. Thus empathising with and mapping the perspective of users can be an important design tool. This tool was applied in order to get a good grip on the relevant design problems. This was again important to set good vessel requirements, which is the framework for a good ship design.

In this case, the user-needs also reflect how the vessel has several direct and indirect user-groups, all with different perspectives and requirements.

Ship owner	Responsible for operations and maintenance. Responsible to customers.	Technological reliability. Low-cost operations. Marketable concept. Low down- time and maximising vessel usage.	A sustainable and profitable service.
Crew	Navigation. Loading/ unloading. Hands-on maintenance.	On-board safety. Smple operations. Low noise and vibrations.	Enjoying working at the vessels. The ability to perform vessel operations safely.
Qustomers	Buying the services the barges can provide.	Deliveries on time. Flexibility in service. Smple and fast cargo- handling.	High reliability. Competitive prices.
General public	For the general public, the barges can potentially have utilitarian qualities that contributes to the greater good of the city.	Noise and air pollution considered a big problem in the city. Traffic safety important, outmoding road transport considered beneficial.	Lower air pollution. Less road- traffic and noise around London.

- 1. How can emissions free navigation in London be made possible?
- 2. How can the vessel designs and fleet cope flexibly with changes in market conditions?
- 3. What is the most optimal loading system? How to design loading and cargo handling systems that are congruous with the operations both on land and from the ship?
- 4. How will the ships navigate as safely as possible?
- 5. How can the design most effectively reduce noise?
- 6. What kind of infrastructure investments are necessary to sustain the operation?

These questions provide a framework for a set of requirements that the design should meet, which are outlined in the next chapter.

3.2 Outline requirements

- 1. The hull dimensions will have to adhere to canal lock restrictions.
- 2. The vessel speed will adhere to the speed limit on London canals up to 3.5 kts service speed.
- 3. In order to create a truly environmentally sustainable alternative to road-based transport, the ship will be zero-emissions.

4.

While passenger vessels are most likely to require their own sets of vessels, it could be possible to combine the three first types of vessels into one. The main role is likely to be that of a general cargo vessel, transporting cargo through mediums such as:

Plastic containers Small plastic tanks Cardboard boxes Pallets ISO containers Orates Recycling storage units Other boxy cargo units

And, if allowable within existing rulesets, it could be easily converted into a bulk storage. This is likely to require some special structural considerations. Additionally, large portable tanks could be a potential cargo. This would combine the potential of several of the major

Servicing both the commercial sector, and possibly also domestic deliveries, the profile of the vessel could be a "water-born lorry-

trailers. If it becomes a success, it could certainly help achieve the goal of more environmentally friendly transport, and also reduce traffic around the main roads.

The mai

rules and regulations to also extend to large, portable tanks will be performed.

3.4 Vessel types

3.4.1 Dumb barge with tug boat

The most conventional configuration is t

propelling capabilities. While these are cheap to construct and has maximum carrying capacity, they also require tug boats to constantly tow them.

Advantages:	Drawbacks:
No requirement for prime mover in the barge maximises the vessels carrying potential. The dumb barges alone are simple and cheap to construct. Potential to carry several barges at one thus increasing carrying capacity	Hydrodynamic disadvantages when compared to other alternatives. Main practical problem is with the locks, since both the tug and the barge time. This makes navigation through the canals more complex, particularly if there are multiple barges on one tug. Increase in barges towed gives increase in required manpower, so it might not be more cost-effective in all cases. Mooring more complex.

3.4.2 Articulated and integrated tug-barge

In order to make dumb barges with tug boats more effective, the articulated and integrated tugbarge (AT-B/IT-B) were invented. These tugs pushes barges instead of towing them.

Advantages:	Drawbacks:
Higher cruising speed made possible in comparison to conventional tugs. Higher hydrodynamic efficiency in comparison to conventional tugs. Better steering. Smpler operations.	More expensive/ complex to build than conventional barges. No real power advantage in low-speed

- Racks. Racks could be convenient cargo mediums, as they would allow companies to lift off containers and pallets using forklifts. Additionally, as roro-units.

Due to the fact that there are currently few wharves along the canal, cranes were chosen as the best solution in the short term. The design would also accommodate installing racks if required. For a large-scale system it is highly likely that specialized roro

As observed, under this scenario, there will be far more trips to be exploited than the capacity of any potential vessel. This indicated that, unless the costs of building larger barges were prohibitive, that the best solution could be to design a vessel maximised in size. A model was made for hull-cost and maximum power for a range of vessel-sizes. The model was made by first varying dimensions and calculating an average resistance as the vessel increases in size. The expected hull-cost was estimated. The cost model of (Hekkenberg, 2014) was applied, which uses a cost model based on hull steel weight, and main dimensions. The weight fraction of the hull weight was estimated using empirical data from (Papanikoulao, 2014), which estimated it to be around 21% of the total displacement.

Payload [t] As observed from the data, there were gains of up to 2 kW Qq0.0r/aFnmpms

Displacement	92.	Т
Volume (displaced)	92.	m^3
Draft Amidships	1.06	Μ
GMt corrected	1.917	Μ
Wetted Area	138.724	m^2
Max sect. area	4.452	m^2
Waterpl. Area	92.19	m^2
LCB	-0.382	from zero pt. (+ve fwd)
LOF	-0.4	from zero pt. (+ve fwd)
Block coeff. (Cb)	0.95	

3.6.4 Squat

		Sq	uat
V		ß	
0.257	0.297	1.000	0.001
0.514	0.297	1.000	0.005
0.772	0.297	1.000	0.011
1.029	0.297	1.000	0.020
1.286	0.297	1.000	0.032
1.543	0.297	1.000	0.046
1.801	0.297	1.000	0.064

Comment: Squat is the increased displacement of the vessel as the effect of pressure differences when the hull goes through shallow water. The primary effect of squat, is the increase in draft that leads to increased resistance. While the effect is small in this case (because of the low speed of the vessel), it still needs to be taken into account for the power calculations.

Squat was calculated using the formula in (Molland, Turner, & Hudson, 2011) page 103.

A secondary effect of squat, is that it can in some cases lead to grounding. While the extra displacement did not directly lead to this problem in this case, the effect still had to be taken into account when choosing propellers and designing appendages.

3.6.5 Resistance calculations

As earlier, the powering analysis was performed using a numerical technique, KR Barge.

In addition to the effect of squat, in inland waterways there are also

Shallow water effects were accounted for with the method of Schlichting as rendered in (Molland, h8* nBTW* nBT/F1

A 2% increase due to appendages/ wind was assumed (little empirical data is available for inland waterways).

The squat was simulated by using the maximum displacement increase (6.4 cm) for the entire analysis. Since it was still early in the design process, this was an inconsequential simplification, and could be mitigated at a later stage.

The propulsion efficiency was assumed to be 60 % for all conditions.

		Shallow	SW		
Speed	KRpower	water	model	Canal width	
[kts]	[kW]	correction	error	correction	Wind/appendages

- Low-temperature (LTPEMFC)
- High-temperature (HTPEMFC)

The standard unit for various uses is a LTPEMFC. Because of the low tolerance for impurities in the fuel cell, the hydrogen has to be of exceptional quality so as not to cause reliability issues (Han, Charpentier, & Tang, 2012). However, HTPEM-units have higher CO-tolerance, thus theoretically enabling it to tolerate alcohols and gas, resulting in potentially higher fuel flexibility. HTPEM-units also have higher efficiency, and don -up time that is an issue for some of the other high-temperature fuel cells. The main disadvantage of a HT in comparison to an LT unit is accelerated fatigue on the cell due to higher operating temperature (Sharaf & Orhan, 2014) (Han, Charpentier, & Tang, 2012). PEM fuel-cells have already been fitted into land-based vehicles, yachts, and smaller craft. The ferry MFVågen runs on a 12 kW HTPEM unit [Prototech, 2010].

Alkaline fuel cells are among the most developed (available since the 60s). They have particularly high energy conversion efficiency (Kordesch & Ofrain, 2003). Other major advantages are that they are relatively cheap, and can operate under a wide range of temperature-conditions, thus making them highly efficient at various loads. The main disadvantage however, is that they are high-maintenance. This is partly because they need completely pure hydrogen in order to work, and partly because of the corrosive electrolyte, which is expensive to replace. Additionally, the power and energy density is considerably lower than the alternatives (Sharaf & Orhan, 2014)

Efficiency	60-70%
Fuel types	Hydrogen
Power density	100 W/kg
Lifetime	Uncertain, lower than
	competitors
Power range, existing units	Up to several MW
Temperature	

Discharge efficiency	50-90%
Lifetime	Variable
Weight density	42 Wh/kh
Volumetric density	60-110 wh/l
Power density	180 W/ kg
1	Powereenie 2014)

⁽Powersonic, 2014)

Variants of lithium-ion batteries are applied a range of purposes, including automotive. The main advantage of lithium-ion batteries is that they are able to discharge energy at an astounding rate, and is thus perfect for heavy and variable loads. The main disadvantages are reliability issues, and also that the energy density has potential to improve.

Discharge efficiency	~90%

-

Length





Figure 8 and figure 9 shows clear advantages for the fuel cell, while figure 7 shows a slight advantage for the battery. Although it must be stated that the operating costs are likely to be lower for the batteries, the upfront costs, not only for the units themselves but also for the charging system, are quite high. In addition, batteries take long to recharge. a PEM fuel cell would be flexible, without having to recharge for a long time after each trip. With this in mind, the fuel cell was chosen.

4.1.4 Conclusion

In the initial iteration it has been decided to equip the vessel with a high-temperature PEM fuel cell. The logistics of fuelling and operations are discussed more in-depth in chapter 5.1. Assuming 10% losses, the curve for installed power could be procured.

4.2 Propeller system

4.2.1 Defining user requirements

The most important factors in choosing propeller were considered the following:

- Very important to sell concept as previously discussed.
 - Thought to be no more than 1.5 meters, at least before dredging.
- in order to maximise life-span at limited depth.
- at slow and variable speed so that the operator can adjust operations and cost.

4.2.2 Design Process

4.2.2.1 Outboard vs inboard motor

Considering the user requirements, the following was deduced:

- Having an inboard motor takes space away from payload, and makes the hull slightly more expensive.
- Having an outboard motor allows the crew to easily access and clear the propeller/unit for debris. This could turn out to be important considering the large amount of garbage and unwanted objects floating around in the canals (at least before dredging and cleaning). This would help maintain the reliability of the service, and keep operations simple.
- Snce the propulsion is all-electric, no large mechanical transmission gear is needed anyway, and the el-motor will be connected to the prime mover through wire.

For the above reasons, an outboard configuration seemed most recommendable.

4.2.2.2 Propeller type

Due to the choice of outboard motor, the choice in propeller was mainly limited to conventional FP vs. CP-propeller.

1) Fixed-(b)tch propellers (FP) are simple, cheap and reliable, but inflexible due to being

While normally a CP-propeller would normally be chosen in cases where there are several possible operating conditions, in this case a case could be made for choosing FP.

Some research on company websites indicated that articulating cranes from 10-20 ton meters would be around 1.5-2.5 tonnes for the entire system w/ hydraulics (PM Granes Website) highly uncertain exactly how big the crane should be, an approximate value of 2 tonnes was chosen.

4.3.2 Sizing

Because of lack of data, sizes for such weights as accommodation, control systems, and safety

account for uncertainties.

The propeller w/ el-motor and system, was estimated from systems of similar characteristics.

Steel weight was estimated as a fraction of displacement using (Papanikoulao, 2014).

For the prime mover, it was decided to size it to the maximum of what the engine room could take, within the parameters specified in the DNVGL class rules for fuel cell machinery. Reference GA. This would give the barge a 60 km range before refuelling.

The

4.4 Structure

4.4.1 Modelling and assumptions

Table 25: Scantlings, example

As the iterations were performed, gradually better estimates of deadweight capacity, optimal cargo weight distribution

Suggested further work:

- Stiffener tripping analysis for flat bar stiffeners.
- 4.5 Stability and operations
- 4.5.1 Introduction

After the strength calculations, the new lightship wei

- Height

Thus an algorithm to take height restrictions into account was built into the stability calculations, to uncover maximum load height for each condition, and see which load-cases would be height or draft-restricted.

5 Finalised concept

5.1 Logistics

5.1.1 Fuelling

An important discussion is the logistics of the fuelling for the barges. In some applications such as submarines, hydrogen is continuously produced from alcohols, because they are less spacedemanding. However, this system could prove to increase UPC, and also likely weight significantly, due to alcohols being up to 24 times as heavy as hydrogen.

for required distance are actually too

high. However, a major limiting factor could be the physical capacity of the fuelling stations. A large number of barges need a lot of fuelling stations, which could contribute to clogging due to waiting and queuing. This indicates that batteries, although quite currently quite expensive, could be revisited as the main alternative for prime mover in a large system of barges, particularly if the battery price decreases as expected. Batteries could be charged for the entire duration up-front, although this would also require a large fuelling station along the canals, which could present its own logistical issues.

5.2 Economics

5.2.1 Procurement cost

A detailed cost estimate was created for the vessel. The full methodology with sources can be found in appendix F.

Unit	Cost	
Hull	14633.4	
Control systems	500	
Outboard motor	4000	
4 FP-propellers	700	
Prime mover	17500	
Orane	10000	
Misc	500	
TOTAL		
Table 33: Cost estimate		

The biggest uncertainty is regarding the crane. Depending on the chosen capability, the cost can vary widely, likely from £5-25,000. Thorough market research needs be done to make sure the barge has the right capacity. As previously shown in the stability analysis the potential of the vessel to perform crane operations is highly dependent on the height of the cargo units.

5.2.2 Through-life costs

A yearly cost projection for the barge could be calculated using the following assumptions:

- Fuel price for Hydrogen produced with renewable energy £6. This is the same as in the US
- Maintenance costs estimated from LTPEM-data (James & Spisak, Mass production cost estimation for H2 PEM fuel cell systems for transport applications, 2012) + margins for crane and vessel to be 50p per kilometre.
- 12 kWh use of crane pr day (loose estimate).

Without accounting for substituting the fuel cell (every 5-10 years, dependent on achievable lifetime), the yearly cost structure looks like the following:

|--|

A breakdown of the communications	A fail-safe that would automatically
between control and vessels could have	stop the individual barges, or the entire
extremely damaging effects.	system, dependent on how critical the
	breakdown is

Table 36: Risks with no-manning

entire

The low-manning concept needs to be verified on a small scale before it can be applied for the entire system. Thus a barge fleet and the logistics plan should from the beginning be designed for unmanned operations, and the relevant regulatory bodies should be involved from an early stage, so as to be able to benefit from this as soon as possible.

5.4 Business model

A tentative business model can be made using (Osterwalder, 2010). A simple overview of the key areas of the business can be used as a tool for more in-depth discussion about strengths and weaknesses of the venture. For this, the business model canvas can be applied.

	Manufacturing industry.
Our unique customer	Catering businesses.
groups whose needs	Domestic deliveries.
must be identified.	Recycling.
	Food producers.
	·
What we are offering to	A way for people and companies to be a part of reducing air and noise
our customers to make	pollution around the city.
them buy our product.	Safety: Taking traffic off the road in the city.
	marketing purposes.
	Setting up an internet page promoting the barges is a no-brainer (this
How we communicate	could be a future UQ-project).
with our customers.	Placing leaflets in bars, grocery stores. Other word of mouth-
	techniques.
	Social media strategies could be incorporated into the marketing plan.
	When the business is up and running, the webpage should have 3 basic
	functions: Tracking barges (in the style of the TfL-website), placing
	orders, and giving feedback on service.
	TBC.
	Usage fee for cargo freight.
How income is made.	Potential for leasing out to companies for larger missions.
	Potential for creating subscription revenues from domestic deliveries.
	Potential for brokering between supplier and purchaser of cargo.
	The vessel(s).
The main assets needed	Skilled operators (competencies in crane operations/ cargo handling
to make the business	and steering the vessel itself).
work	Fuelling system on land.
	Access to skilled maintenance personnel, either in-house or leased on-
	demand.
	Operations of vessels.
The main activities	Marketing to existing and potential customers.
required to make the	
business work	

Fuel supplier.
If leased, vessel maintenance supplier.
Fuel transport company.
Potential strategic alliance with National Rail and/or TfL, in order to exploit economies of scale to the fullest.
Since company is acting like an intermediary for supply; need to treat
customers as partners.
Fuel costs
Manning, vessel.
Manning, onshore (marketing, administration, technical, depending on organization structure).
Maintenance.
Procurement costs for new vessels.

Table 37: Business model canvas

-	CONTRIBUTES TO LOWER NOISE, CARBON AND AIR EMISSIONS	-
-	CHEAPER THAN ROAD TRAFFIC AT MEDIUM AND LOW SPEEDS	
-	CAN FREIGHT HIGH QUANTITIES	

Manufacturing cost analysis of stationary fuel cell systems, 2012) estimated that for stationary HT fuel cells at around 25 kw capacity, could be between \$700-1,100, depending on production rate. Data pointed to fuel cells for automotive/prime mover purposes being considerably cheaper than for stationary purposes. However, due to lack of specific data for automotive HTPEMFC, the cost was assumed to be \$900 (£600) per kW.

The price for li-ion batteries were taken to be in the range of \$350/kWh (values inferred from online sources predicting how the price may change, as there were no unified estimates).

Because of the inability to get any good industry data, it was resorted to estimate prices through Ebay (the online auction service). The price range for new articulating cranes were enormous, and in most cases they were mounted to large trucks, probably inflating the price.

Without the vehicles, it was estimated the price for 5-to-10-ton cranes could be down to £5-10,000, and a 25-ton-crane could be from £15-20,000 and even more. However, an estimate from a crane producer for a tailored crane should be procured when the required capacity is decided.

Estimated from similar motors (25-35 HP) at E-bay and company websites (\$3-5000 for new ones), and added margins to account for the tailoring of a duct.

Estimated from similar propellers on company websites.

Smple assumptions made to account for safety equipment etc, and wheel/electronic control systems.

APPENDIX C: STRUCTURES

Bending moment, sample:

Section	0	2	4	6	8	10	12	14	16	18	2
Point											
weight											
LSweight/m		0.80	0.70	0.70	0.70	2.70	0.70	0.70	0.70	0.70	0.7
Payload											
weight/m		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Section area	4.45	4.45	4.45	4.45	4.45	4.45	4.45	4.45	4.45	4.45	4.2
Buoyancy/m		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.8

-BM 0 -428 -3674 11701 - ((+)) (18)

Where L and t are plate length and thickness respectively.

A presentation of plate thicknesses and stiffener sizes follows.

FORE:

		Stiffener
Area no	t [m]	area
Top deck	0.0038	0.0001
Side shell 1	0.0038	0.0001
Side shell 2	0.0038	0.0001
Side shell 3	0.0038	0.0001
Bottom		
plate	0.0038	0.0001
Double		
plate	0.0038	0.0001

Table X1: Wheelhouse

MID:

Area no	t [m]	Stiffener area
Top side		0.00023
Upper side below		
waterline		0.00023
Lower side beow		
waterline		

 $\label{eq:stability} \texttt{Static stability} \ \texttt{data such as KB, BM, GM, LOF, LOB found through hydrostatic program.}$

=

Trim:

Where MTC

(20)

•

Where rho is water density, g is gravity and lyy is the second moment of inertia over the y-axis of the ship.

=

Parallell sinkage:

= ____ €(21)