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Update of the E³ Tug Development – Environmentally Friendly, Economically Viable, Efficient in Operation

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SYNOPSIS

The E^3 project, a joint effort of Smit, Damen Shipyards Gorinchem, Alewijnse Marine Technology and others, has the goal to not only develop a more environmentally friendly tug, but also to develop a methodology to make a realistic assessment of the environmental impact of a harbour tug on its environment. The Es stand for Environmentally friendly, Economically viable and Efficient in operation.

The project is divided into three stages. In the first, the environmental footprint and the operational profile of a Damen ASD Tug 2810 have been determined for operations in the Port of Rotterdam. The obtained information has been used as input and the benchmark for the following stages.

The second stage comprises designing and ultimately building a 'greener' tug with the best technology currently available. In this stage, a propulsion configuration will be determined which best matches the objectives of the E^3 project. In determining the best configuration, various options such as diesel electric, hybrid propulsion, the use of batteries and their charging methods and dual fuel/gas engines are evaluated. Measurements will be performed upon completion of the tug's construction to establish the new environmental footprint and to verify whether the E^3 objectives have been met.

In the third and final stage a design study will be performed based on emerging technologies, such as RIM drive thrusters, the latest generation fuel cells, solar cell decks, etc. The environmental footprint of this design will be determined through computer modelling.

The E^3 project is currently at Stage 2. To be able to determine the optimal propulsion configuration for a tug working in the Port of Rotterdam, several tools and methodologies have been developed. These will be discussed in this paper:

1. An evaluation method has been defined to assess a shortlist of design alternatives with the E^3 criteria. The shortlist was established following a review of available technology.
2. An emission impact analysis methodology has been developed by IMARES (Institute for Marine Resources and Ecosystem Studies). As one of the main criteria in the evaluation is the environmental impact of the different design alternatives.
3. A Dynamic Propulsion Simulation Model has been developed to provide the input per design alternative for these impact analyses.

1. A RETROSPECTIVE ON THE BENCHMARK MEASUREMENTS

At *Tugnology '09* in Amsterdam, the operational profile and emission measurements of the benchmark, ***Smit Elbe*** – a Damen ASD Tug 2810 *(Figure 1)* – were presented[1].

These measurements have proven to be of significant importance for the progress made within the project and have helped further the understanding of the operational profile.

Figure 1: **Smit Elbe** *– Damen ASD Tug 2810.*

A short summary: the operational profile was measured by logging over 80 parameters, at 1Hz, over a four-week period. In this period, 27 towing jobs were performed and three different crews operated the vessel. The emission profile was measured, in a single day, by taking 18 relevant operating modes (eg engine idle in transit, bollard pull condition at 25 per cent, 50 per cent 75 per cent, 100 per cent power, etc).

These measurements proved that the propulsion system is being used very inefficiently. It was also found that by looking at the actual time traces of the operational profile, and using standard statistical analysis, some very important operational requirements could be deduced.

An example involves the time along shore to charge batteries. It became apparent through additional GPS data linked into the dataset, that time available for charging batteries at the berth was less then initially assumed. The dataset showed that the tug often shut down its main engines (indicating it being along shore), whilst not being at its regular berth. The crews simply often decided not to return to their regular berth between jobs, but rather stay deep inside the harbour, as their next job was already around the corner. This kind of information would not be available if only the standard engine logs were looked at.

2. DESIGNING THE E³ TUG WITH THE BEST AVAILABLE TECHNOLOGY

The second stage of the E³ Tug project is divided into several steps to ensure that all available technology is properly evaluated and the right choices will be made. First, an inventory of the available technology was made without directly judging anything on its merit. After the inventory was made, the technology was compared to the functional requirements of a tug.

In parallel to the inventory of technology, the requirements for the E³ Tug were determined. This was done by not only analysing the operational profile, as mentioned before, but also by re-evaluating the requirements for a standard ASD Tug 2810. Some of these design requirements are, for instance, the lowest acceptable continuous bollard pull required and the lowest acceptable endurance of the vessel.

The combination of the operational requirements and the evaluated technology led to a shortlist of 'high potential' configurations. The main goal of all design alternatives was to minimise the inefficient use of power sources by creating flexible propulsion systems: flexible in the sense that the power can be drawn from different sources, ensuring that those sources can be utilised as efficiently as possible, both in modes of low power demand (eg transit) and high power demand (bollard pull).

The shortlist of design alternatives reads as follows:

A: Two main engines connected to electric motor/ generator and CPP thrusters with shafts combined with a relatively large battery pack;

B: Two main engines connected to electric motor/ generator and CPP thrusters with shafts combined with a relatively large battery pack and one generator set;

C: Two main engines connected to electric motor/ generator and CPP thrusters with shafts combined with a relatively large battery pack and two generator sets;

D: Three generator sets and FPP thrusters with L-drive electric motors combined with a large battery pack.

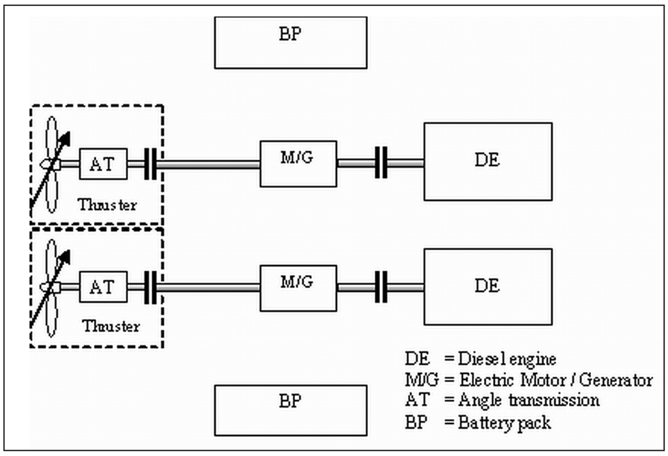

Figure 2: Design Alternative A.

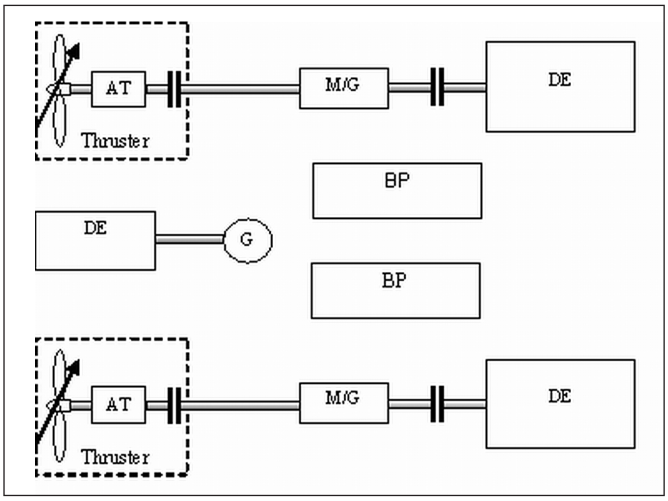

Figure 3: Design Alternative B.

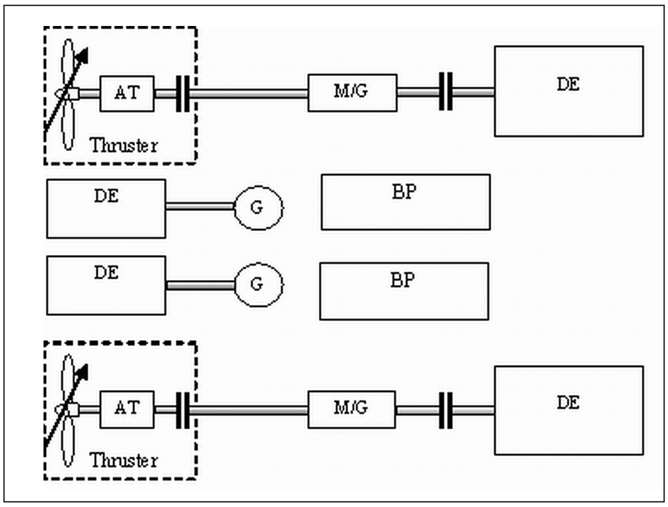

Figure 4: Design Alternative C.

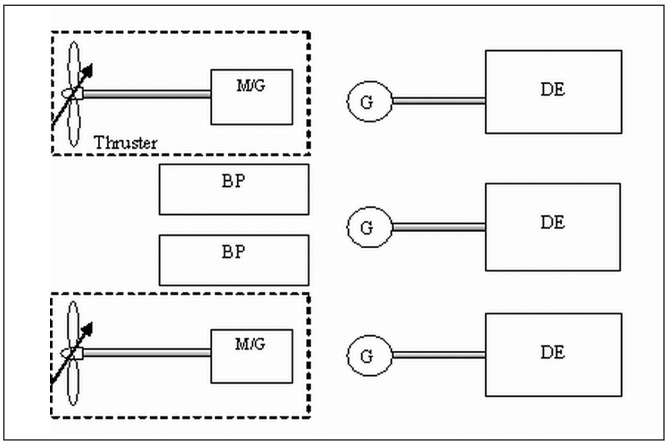

Figure 5: Design Alternative D.

3. EVALUATION METHOD

The shortlisted concepts need to be evaluated according to the three 'E' criteria as set out at the project initiation. This evaluation can be described as a multi-criteria problem wherein both qualitative (Efficient in operation) and quantitative (Environmentally friendly and Economically viable) criteria need to be compared. Next to the qualification, 'qualitative' and 'quantitative', the three 'Es' can also be divided into costs (Economically viable) and benefits (Environmentally friendly, Efficient in operation).

The evaluation of the design alternatives compared in the E^3 project focuses solely on the operational part of the life cycle. The environmental impact due to construction or end of life of the vessel is not considered. How the three criteria will be evaluated, is described below.

Environmentally friendly

The design alternatives considered in the E^3 project are focused on decreasing the impact of (exhaust) emissions to the environment. These calculated values will be compared using the method developed by IMARES. This method is described in detail in Section 5, *Impact Analysis*, and results in an (exhaust) emission impact reduction index. Reductions are calculated relative to the benchmark.

Economically viable

The criterion Economically viable will be described in terms of a cost index. The capital expenditure and operational expenditure per design alternative will be related to the benchmark design. The cost index will describe the difference in cost of operation for a fixed period (eg a year). Regardless of the period selected, fixed costs such as depreciation of the asset and scheduled maintenance (eg battery replacement) as well as financing costs, will be included.

For example, the cost index will include expected differences in maintenance costs and fuel costs related to the operational profile. Estimates of these costs for the design alternatives will be made with the use of the dynamic propulsion simulation model.

Efficient in operation

After review of the four alternatives against the criterion Efficient in operation, it was concluded that the expected differentiation between the design alternatives and the benchmark will be minimal. The design alternatives and the benchmark have the same hull, deck equipment and performance relative to the operational profile. Including a criterion with very little differentiation between the alternatives under consideration, does not add to the evaluation itself.

Therefore the choice was made to not rate the criterion Efficient in operation, but rather to set as a requirement that the design alternatives will be at least as efficient or exceedingly efficient in operation as the benchmark for the operational profile under consideration. This requirement was taken into account while shortlisting the design alternatives.

The design alternatives shall thus be rated by the criteria Environmentally friendly and Economically viable under the condition of no loss of efficiency in the subject operation. Per design alternative both criteria will be rated relative to the benchmark design. Dividing the cost index with the emission impact reduction index will thus create a cost-benefit index with which the design alternatives under consideration can be rated. Graphically this cost-benefit can be represented as shown in *Figure 6*.

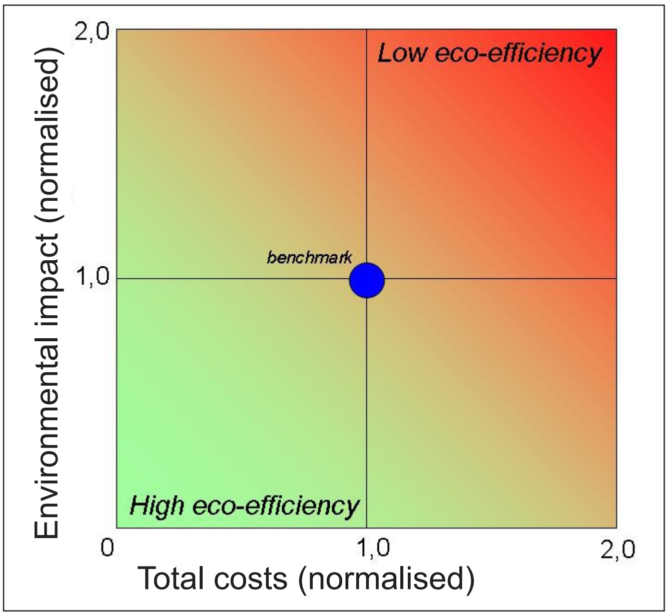

Figure 6: Eco efficiency representation[2].

4. DYNAMIC PROPULSION SIMULATION MODEL

To calculate the fuel consumption and the emission output of the design alternatives, a dynamic propulsion simulation model was made for every design alternative. With dynamic modelling, a towing job can be simulated (in the time domain). In this way, the jobs measured for the benchmark (ie thruster handle positions), could be used as an input for the design alternatives *(Figure 2)*. This enabled easy comparison between the alternatives and the benchmark.

The simulation model was validated with the power and fuel consumption measurements taken in Stage 1. This is a very important step in proving the validity of the simulation model and justifying its use for comparing the design alternatives *(Figure 3)*.

One of the main advantages of using such an elaborate dynamic modelling technique (versus static modelling) is that the simulation uses the actual time traces of the operational profile. The time trace involves all operating conditions including transient behaviour (increasing or decreasing power). This results in more accurate predictions of fuel consumption, consequent emissions and operating costs than when one uses a static model. When using a static model the operational profile needs to be split up into a finite number of modes and consequently data is lost.

Another advantage is the possibility to assess engineering challenges beforehand. The utilisation of different mechanical and electrical components to deliver power simultaneously can lead to interaction problems. By dynamic simulation, the component control can be analysed and optimised beforehand.

The dynamic propulsion simulation models were created using the computer program Matlab/Simulink. All the major components in the alternative designs were modelled using mathematically accepted models like Seilliger for the diesel engines.

The model incorporates a two-dimensional hydrodynamic model of the tug (x and y direction) so it is possible to calculate the effective tow force of the tug on the assisted vessel. This was necessary to take the effect of different propulsion types into account. Thrusters with controllable pitch propellers are used differently than thrusters with fixed pitch propellers when small amounts of thrust are required. Thrusters with fixed pitch propellers need to be turned outward, essentially destroying power, while thrusters with controllable pitch propellers simply reduce pitch demanding less power from the power source.

In future, the simulation models can be used to further develop and test the energy management system of the E^3 design and evaluate performance of the design relative to other operational profiles.

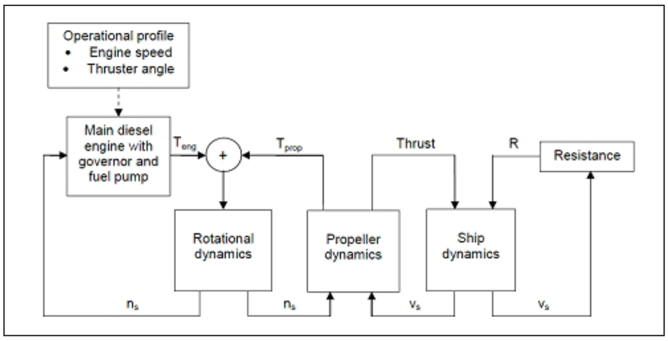

Figure 7: Dynamic Propulsion Simulation Model.

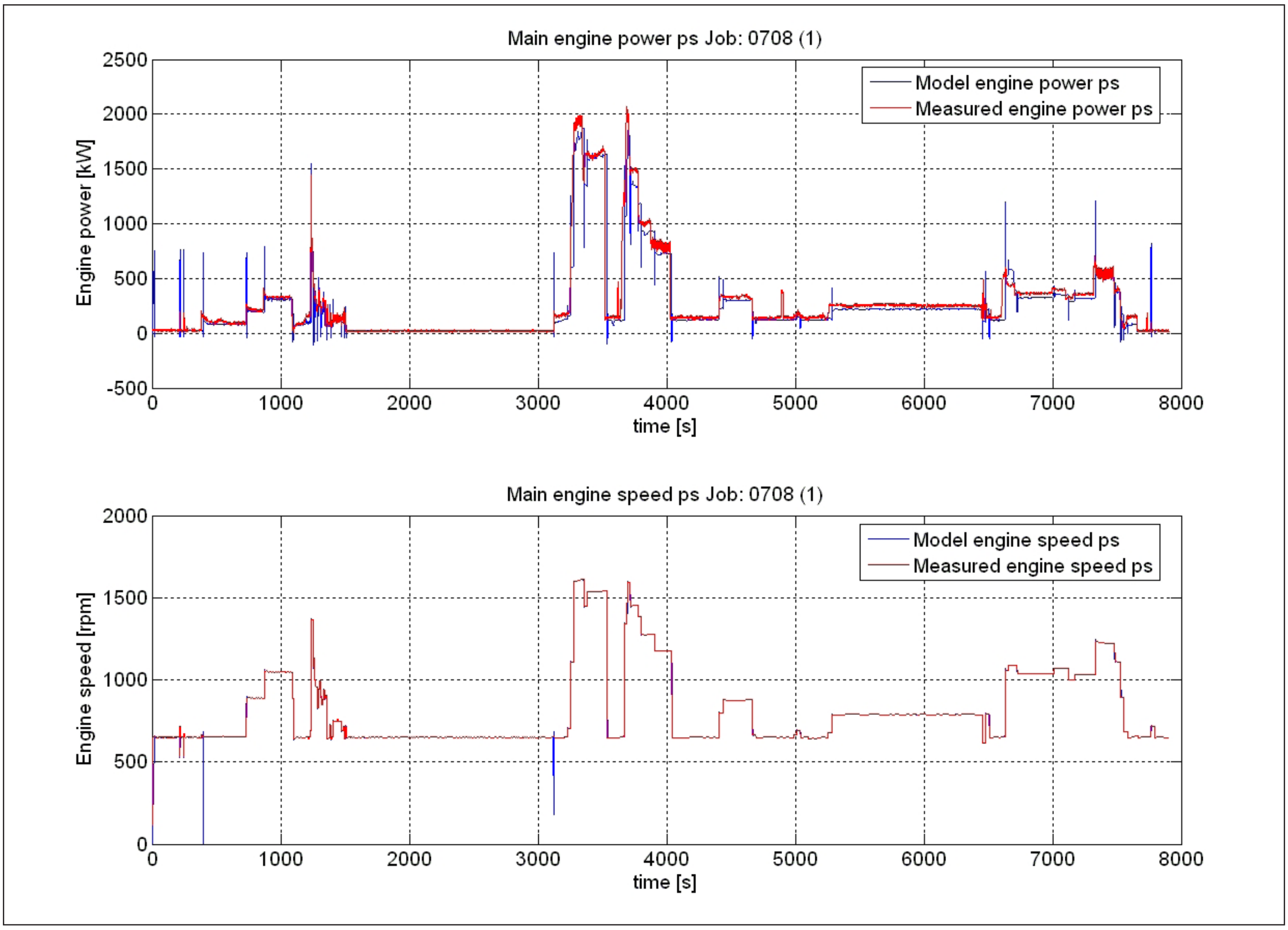

Figure 8: Model vs Measured Engine Power.

5. IMPACT ANALYSIS

The impact of the different design alternatives on the environment is considered as one of the main criteria within this project. It was decided to not only consider one pollutant, such as CO2 or NOX, as prescribed by IMO, MARPOL, Annex VI. Rather a methodology was developed which takes into consideration the most significant air pollutants in the ship's exhaust, and determines their impact on the environment in which the tug operates.

To this end, the possibility of applying the Environmental Impact Factor Air (EIFAIR), as commonly used in the Norwegian Oil and Gas industry, was investigated. Although initially the methodology looked promising, it was abandoned. One of the requirements of the methodology is that it can be easily adopted by the community with minimal cost. The EIFAIR incorporates complex dispersion modelling with multiple emission sources which requires considerable expertise. A less complex method was selected which will be described below.

Emissions affect the environment at different spatial scales. They can cause adverse effects to the local environment, but can also affect the climate on a global scale. Although these effects are very different (and measured in different units), the aim is to express both of them in a single indicator to evaluate and compare the different design alternatives. This is done by expressing the impacts on a scale relative to the benchmark *(Figure 9)*. As both indicators are now expressed as a percentage relative to the benchmark, they can now be combined into a single indicator. An optional weighing factor between the two indicators can be introduced to reflect their relative importance as experienced by the different stakeholders in the project.

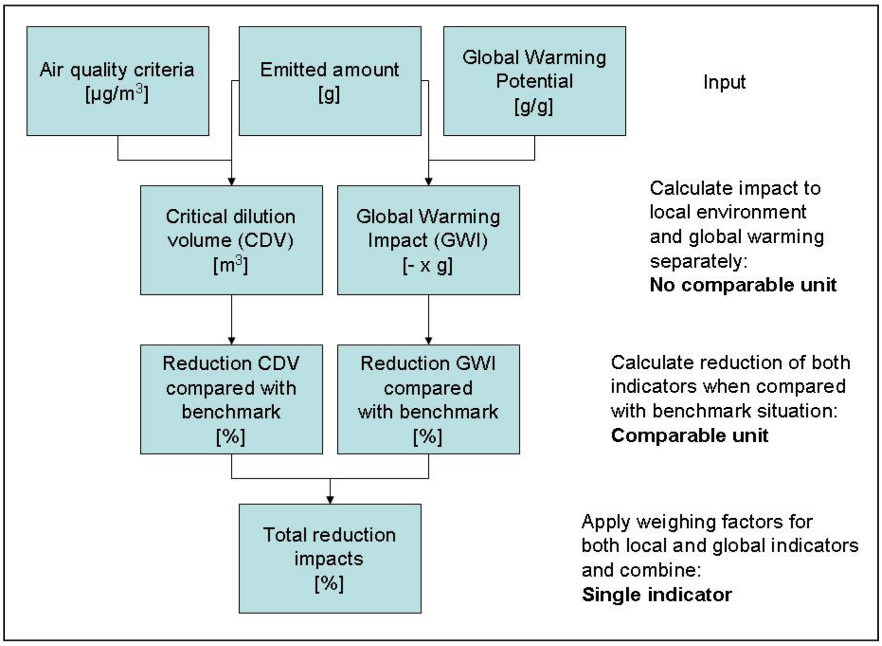

Figure 9: Strategy used to combine local and global effects in one indicator.

The global and local indicators have different definitions. For the local impact the Critical Dilution Volume definition (CDV) is used and for the global impact the Global Warming Impact (GWI) is used.

The CDV is defined as the amount discharged (μg) divided by the environmental quality criterion (μg/m^3) of the component. The resulting indicator has volume as quantity (m^3) and should be seen as the (air) volume required to dilute the emitted amount to satisfy the environmental quality criterion. Although this approach does not involve complex dispersion modelling (describing processes such as diffusion and deposition), it gives an indication of the impact of the components.

In order to calculate the CDV, environmental quality criteria are required for each of the components. For the Rotterdam situation, air quality criteria are set by the European Union[3/4] for a large number of the contaminants in the tug's exhaust. These are implemented by the Dutch authorities in the Environmental Law[5]. For some of the components no environmental criteria are set. For these components either the Occupational Health & Safety Law, or otherwise reported threshold values without legal status, were reverted to.

The Global Warming Impact (GWI) is defined as the emitted amount of greenhouse gases in grams of CO2 equivalents. The amount of CO2 equivalents is calculated for each greenhouse gas using the Global Warming Potentials (GWP) as set by the Intergovernmental Panel on Climate Change (IPCC)[6].

Under the Kyoto protocol, the Conference of Parties decided[7] that the GWP values calculated by the IPCC are to be used for converting the various greenhouse gas emissions into comparable CO2 equivalents. Therefore it is a good basis for the impact assessment of the gases emitted by tugs. It is assumed that the separate components in the tug exhaust can be added to determine total impact on the climate.

As both global and local impacts of the tug's exhaust are expressed on a relative scale, the simplest way to aggregate them into a single indicator is to use the unweighted average of the two relative impacts. However this would imply that both impacts are of equal importance, while in reality this is probably not the case. There is no strict objective way to determine the importance of the two impacts, as the importance also depends on specific perspectives. The procedure for weighting local and global effects is not yet set at the time of writing this paper.

The weighing factors for local impact could basically be a system which assigns a penalty to substances that are already present at high levels (compared to the quality criterion) such as NOx. This can be achieved by using Risk Characterisation Ratios (RCR) of each of the contaminants in the area under consideration to weigh the CDV. The RCR in this case has been defined as the ratio between the environmental background concentration and the environmental quality criterion for each specific contaminant.

Background levels, however, are not constant (in time and space), especially when effort is made to improve the air quality. A risk of using RCRs is that the tug's environmental performance is optimised for the current time frame, which might not be the optimum performance in the future. Therefore, the project team will have to decide whether to include these local background levels in their assessment and, if so, how to implement the weighing precisely. This decision is yet to be made at the time of writing this paper. Involvement of local government would be beneficial in this consideration.

The considered design alternatives incorporate significantly more batteries than the benchmark design. It is expected that these batteries need to be replaced at least once during the operational lifetime of the vessel. Therefore it was decided to include the impact on the environment of recycling the batteries.

6. PROJECT STATUS

The project is currently in the stage of evaluating the shortlisted design alternatives. Once this has been completed, the selected design alternative will undergo a thorough review. In particular the design of the control system will be worked out in more detail. Once this has been completed, a Go/No Go decision will be made as to whether or not to build the E³ tug.

Simultaneously, Stage 3 will be started. Through computer modelling, emerging technologies will be evaluated on their environmental merits.

7. SUMMARY

The development of the E³ Tug has thus far proven to be a valuable experience. The involved parties have gained a deeper insight in the operational profile of the tug through measurement of the operational profile and exhaust emissions.

Stage 2 of the project involves the design and evaluation of several design alternatives. A methodology is presented with which the design alternatives are evaluated in relation to the three Es of the E³ project. The methodology involves dynamic simulation models and a comprehensive environmental impact analyses.

The newly proposed methodology will enable the industry to make fair comparisons between designs for a given location and corresponding operational profile. The full methodology will be published upon completion.

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