Summary

From shallow to deep water, from the well to the ship, from the offshore field to shore or between countries, many kilometres of offshore pipelines for transportation of hydrocarbons (oil and gas) have been installed over the last decades. Allseas' *Tog Mor* is a shallow water pipelay barge capable of laying pipes up to a water depth of 25 meters. Currently, Tog Mor is more than forty years old and is due for replacement. Therefore, Allseas has considered to replace Tog Mor with a new shallow water pipelay barge. However, it is unclear whether the current barge is optimised for pipelaying since it is designed for crane supported purposes. The aim of this research is to give insight into vessel properties which determine the pipelaying performances and to define a set of design requirements for the new shallow water pipelay barge, Tog Mor 2.0. To define the requirements of Tog Mor 2.0, the principles of Systems Engineering are followed.

Based on the operational analysis, the performances of Tog Mor can be improved by a reduction of the theoretical peak cycle time, optimisations of the pipelaying process and a reduction of downtime. The output of the operational analysis in combination with the principles of pipelaying creates insight into performances of the current Tog Mor and results in potential bottlenecks. Those performances and potential bottlenecks were the input of the functional definition of Systems Engineering. The aim of this functional definition is to allocate functions and systems and to define the input to the Quality Function Deployment (QFD) tool. This tool helped to prioritise the design focus point in terms of functions which were the firm basis of the physical definition. Physical definition is the translation of the functional design elements into hardware components and the integration of these components into the total design. As individual functions and systems depend on each other, the dependency of those elements were considered. The objective of this methodology was to identify and focus on the critical functions which add the most significant implications on the vessel and use decision making process to optimise the performance of the pipelay barge.

The last thirteen years, the variance in pipeline diameter is narrowed down and the demand for larger diameters is increased. In order to compete within this market and to align the operational profile of Tog Mor 2.0 within the scope of the fleet of Allseas, the new barge should be able to lay pipes up to an outer diameter of 60 inch. To support the selection of the implementation which best balances the desired characteristics of the new design and contributes to a reduction in cycles times, a functional analysis is performed. Based on the functional definition and the Quality Function Deployment tool, the most important functions are defined. More specifically, the functions stability & motions, station keeping, cargo transportation, pre-work pipelaying and assembling have a direct and indirect relation to the cycle time.

Due to the inversely proportional relationship of the number of production days and corresponding production costs, an increased number of stations and lay speed do not have an advantage in terms of costs. Based on the operational criteria, the firing-line of Tog Mor 2.0 consist five stations (three welding stations, one NDT & GB station and one FJC station). This firing-line is located off-centre at a distance of 5.9 meter from starboard. Within this distance, containers and davits can be stored or installed depending on the phase of the pipelaying process. Due to pipes which are getting heavier, the tension capacity of the tensioner should be upgraded to hold the pipe in suspension without buoyancy modules. The strapping procedure of buoyancy modules is time consuming, requires additional crew, deck space and could be a potential bottleneck in terms of peak cycle times. Therefore, those buoyancy modules are preferred to be avoided in the pipelaying process. The inner stinger is applied in the new design to reduce the impact of the limited design criteria (overbend strain). In order to transform the single point failure focus of Tog Mor to a more redundant ship design, two tensioners of 100 ton each will be installed on Tog Mor 2.0. However, even with an inner stinger, experiments showed tensions above the limit of 200 ton. Consequently, still buoyancy modules are required in case of larger pipe diameters. Those tensioners could have a maximum length of 12.0 meter. The first tensioner is installed at a distance of 13.1 meter from the stern. In order to make a pull of a new joint, the tensioner and anchor mooring system have to work as one system in shallow water areas. To withstand external loads (even if one of the anchor lines fails) and be able to make a pull, a ten anchor mooring system is selected (six forward, four aft lines). Based on the external loads, anchor patterns and the

design criteria of DNV-OS-E301, the rated pull capacity of the winch systems should be equal to 110 ton. The maximum breaking load of the mooring lines are equal to 275 ton which results in a 2.5 inch wire.

To increase safety, improve the efficiency and design a redundant shallow water pipelay barge, two bevel machines are integrated in the new design. Furthermore, the A&R winch is replaced by a storage wheel, compensator and traction wheel and the bare joint and head are stored in a vertical rack closer to the first station. Since the lay speed of Tog Mor 2.0 is above the limit of the lay speed of one construction crane, an additional pipe transfer crane (PMC4800-40) is installed on deck. This crane is responsible for all pipe movements, is installed at a distance of 41.9 meter from the stern and 13.8 meter out of the centerline (port side). This pipe transfer crane loads pipes with a 60 inch outer diameter at a distance of 45 meter. As a result of the increased size of the helicopter deck, the gains expressed in deck space and the area which can be reached by the special purpose crane are limited. Those limited gains versus the increase in investment costs, crane capacities, dimensions and hull structures result in the decision of three fixed davits at the front end of the ship. Based on this decision, the maximum radius of the special purpose crane (which is responsible for all pipelay supported movements) is equal to 66.6 meter. This radius can be reached by the current Liebherr crane of Tog Mor and will be installed on Tog Mor 2.0 to reduce the investment costs. This crane is installed mid ship to reduce heel angles. In the bead stall, two overhead cranes of 20 ton (which are able to operate in series or parallel) are required.

Based on those individual functions, systems and interactions, the length of Tog Mor 2.0 is fixated. The depth is chosen such that it is sufficient to store the anchor winches, storage wheel, compensator and traction wheel below main deck. Those systems lowered to the base line results in more free deck space at main deck and a more operational efficient pipelaying procedure. The service draught is based on the internal requirement of the minimal amount of pipe joints stored on deck for a total period of 36 hours. Those pipe joints are stored in four pipe stacks. Based on the moment of inertia, center of gravity, transverse moment of inertia and volume displacement, the metacentric height is equal to 19.1 meter. As a result of a positive GM value, Tog Mor 2.0 will stay upright. In terms of roll motion and vertical motion at the stinger tip, Tog Mor 2.0 has an improved workability of 12% and 8% respectively. There should be noted those numbers are based on specifications of Sur de Texas project. An increased water depth results in less operational gains in terms of workability percentages. An increase of the moulded breadth results in an improved workability in terms of roll motions and vertical motions at the stinger tip.

As a result of an improvement of each individual function and the interactions among those functions, an improvement of 30% in terms of theoretical minimum peak cycle is achieved by an optimisation of the pipelaying process and potential bottlenecks. A reduction of the peak cycle time, an optimised pipelaying process and a reduction of downtime percentages results in an improved overall performance of Tog Mor 2.0 compared to the current Tog Mor.

In further analysis, the impact of different stinger configurations in terms of tension levels and need of buoyancy modules should be analysed. Furthermore, the workability of Tog Mor 2.0 should be validated by different projects and a more in-depth analysis of the weight and center of gravity of the machinery foundations, deck equipment and stores are required. Finally, all functions, systems and interactions among those elements should be investigated in a next design design iteration.