A Pragmatic Approach to Ergonomics in the Amphibious Lift Ship Design

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1. ABSTRACT

The Royal Netherlands Navy is continously aiming at increasing the quality of the ship design process. Until now the process was not always well defined. Personnel involved and the intuitive approach of the designer was an important factor. Nowadays the rapid change of the threat and related operational requirements in automation and manning reduction may influence the design of the vessel. Therefore, in co-operation with the TNO Institute for Perception, analytical methods based on human engineering activities were used in the design of a new Amphibious Lift Ship. Given the human and technological capabilities and limitations, it is possible within certain constraints, to establish the preliminary ship design and the future manning requirements in the conceptual design stage.

This paper describes the basic design process in which the hierarchical functional structure of the ship was determined based on staff requirements and mission descriptions. Therefore functional decomposition techniques were used while ship system performance parameters were determined. Then the function allocation process is performed for a number of typical and critical functions using scenario descriptions. Verification of the function allocation process by means of task analysis and in a more quantitative way by performance prediction techniques are being carried out at present time. Future developments are discussed.

2. INTRODUCTION

In the last decade the design of naval ships for the Royal Netherlands Navy (RNN) has been influenced by the rapid change in threat and related operational demands. In particular staff requirements are mainly focused on multi-functionality, automation and manning reduction. Until recently the design process was not always well defined and was dependent on the personnel involved and the intuitive approach of the designer. Up to the Project Definition Phase the design work was mainly carried out by internal RNN organizations, in particular the design of the ship itself, of the platform systems, the architecture of the weapon systems and the software for weapon and platform control. This may have advantages because the requirements can be defined in close cooperation with operators, maintainers, naval staff, laboratories and other institutes before initiating the design process. This synergy is even enhanced by the short communication lines in our small country. Then in the Project Definition Phase the preliminary design specifications are matched with the available industrial technology and know-how.

The design process can be defined as a transformation of the requirements into functional specifications, while minimizing the total life cycle costs and maximizing the quality and performance. Two decades ago the design of new manned systems was governed by physical sciences and engineering disciplines but over the years there has been a tendency to improve the design process. In particular the interest grew to take into account the human element and systems engineering was combined with system ergonomics.
Nowadays manned systems become more and more sophisticated and there is a risk that human and technological capabilities and limitations may directly influence, and in unbalanced situations even degrade system performance. Therefore the search to improve the design methods and techniques has led to a growing interest to include human factors (human engineering, manpower, personnel, training, system safety and health hazard) in the design concept of new Navy ships. Especially when dealing with innovative ship design or with new requirement and functions, new design methods based on system ergonomics may significantly increase the quality of the design.

This paper describes the design process used in co-operation with the TNO Institute for Perception in the design phase of a new Amphibious Lift Ship (ALS). This new type of vessel is foreseen to conduct both military and civilian missions. Based on the staff requirements a mission and function analysis is performed. The goal of these techniques is to describe in a structured way what the system should do and which performance criteria should be met. In a next phase function allocation is performed assigning human and/or machines to typical functions like flight operations, dock operations, embarkation of personnel and vehicles, damage control, propulsion control, etc. Verification of the function allocation is carried out at present time.

An important advantage of the stepwise ship design method as described above is the fact that the design process is governed by function analysis. In traditional design processes technical solutions are often applied before a profound analysis of the requirements and functions has been performed. By careful function allocation a rational balance between manning and level of automation is obtained. This is one of the most important aspects of the ship design process. Then, in an early stage knowledge is obtained about how the system will be used and how the system will perform. Many design errors can be avoided resulting in cost reduction lateron.

3. METHOD

For the design of the ALS a top-down approach is followed. This means that a series of steps are followed to transform the operational needs into a system description [1]:

1 *mission and scenario analysis*
Based on operational staff requirements mission and (worst case) scenario descriptions are generated and analyzed in order to identify the overall requirements and those factors that could influence the performance requirements of the man/machine system [2].

2 *function analysis*
Based on mission and scenario descriptions the functions of the system are identified using decomposition techniques. Starting at the mission level each function is decomposed into subfunctions through successive levels of detail to the point that these subfunctions can be allo-

cated to resources (human, hardware and/or software components).

3 *function allocation*
Function allocation is a crucial activity in system design and assigns human and/or machines to the identified subfunctions. A review is performed of the human system component identifying the potential capabilities and limitations of the human operator and of the hardware and/or software components. Careful allocation will lead to optimal system design in which different levels of automation can be distinguished.

4 *task analysis*
Task analysis is the first step in verifying the function allocation. Task analysis focuses on the interaction between human operators and hardware/software components of the system. In this analysis detailed scenario descriptions are used resulting in time lines and information flow diagrams. Results could indicate operator overload situations or system malfunctioning. In that case reallocation of the subfunctions has to be performed.

5 *system performance prediction*
System performance prediction analysis is based on computer models predicting how man-machine systems as defined in the previous steps perform. These stochastic models are obtained using special purpose modelling techniques (SAINT, SIMWAM, Petri Nets, etc).[3],[4],[5]. By repeated model calculations statistics of the system performance variables are obtained within reasonable confidence intervals. By comparing these results with the system performance criteria it can be verified if the function allocation has been correct.

6 *interface and workspace design*
Interface and workspace design applies the human factors knowledge resulting from the sequences as mentioned above to the design of systems, equipment, interfaces, workspace and environment. The workspaces can be evaluated using anthropometric models [6]. For the ALS design this step is not yet relevant.

The first three steps have been performed. Both task analysis and system performance prediction are more quantitative analyses using computer modelling techniques. These techniques put a demand on specialists. However, these analyses are of vital importance, especially when dealing with complex man-machine systems in a dynamic environment. Repetitive function allocation is sometimes needed.

4. RESULTS

Starting with the RNN staff requirements the basic mission requirements were determined, indicating in general terms what the system is supposed to accomplish. In order to provide comprehensive mission requirements the basic ALS requirements were described in more details in three hierarchical levels. These levels are named mission categories, missions and mission segments. For presentation of the hierarchical structure a software tool Structured Design Workbench (SDW) [7] was used. Also (worst case) scenario descriptions are generated covering the sequence and timing of major events, threat situations, communication, environmental conditions, etc. Figure 1 shows an SDW hierarchical mission description of the mission category PERFORM OPERATIONAL TASKS. It should be noticed that at both upper levels missions are still presented in general terms. Only at the third level mission segments are presented as time related activities (plan a mission, perform mission, debrief mission). Here points of beginning and ending of the segments can be distinguished and presented in such a way that the upper level mission is covered during its execution.

The ALS function analysis consists of further decomposi tion of the mission segments. Specialists of the RNN were consulted and invited to successively decompose the mission segments into subsequent subfunctions at a lower level. Therefore, based on existing systems functions and on the new mission requirements, new concepts for future subfunctions, subsystems and components were defined. The subfunctions were presented as hierarchical trees (Function Flow Diagrams) using SDW. The lower level subfunctions describe the different phases of a function on a higher level as it is performed. This process continues until a level is obtained on which function allocation can be performed based on the new defined subsystems and components. For the ALS decomposition at maxi-

mum three hierarchical function levels are used.
Figure 2 shows the function decomposition of mission segment PERFORM AMPHIBIOUS WAREFARE (AMW). It should be noticed that STILL GENERAL functions are distinguished. Figure 3 AND 4 show the lower level decomposition of subfunctions PERFORM PLANNED AMW MISSION and PERFORM EMBARKATION FOR PLANNED AMW. This lowest function level is further described by means of scenarios, describing the activities in one or more (worst case) situations. Implementation was effected by the Detailed Process Schemes (DPS) option of SDW. These scenarios, of which an example is shown in Figure 5, are primarily used for function allocation.

For the function allocation an iterative concept is chosen. The group of specialists involved had to fill in so-called "function allocation forms". Each form is assigned to one subfunction and focuses on the activities to be performed during the execution of the related subfunction. The order in which the activities are presented is in accordance with the related scenario description. On the forms the available equipment and the information needs are registered. Therefore profound knowledge of the state-of-the-art of automation techniques (hardware/software speed, accuracy, load, reliability, etc.) is needed. Also the performance criteria, one of the most crucial elements of the list, are fixed. After consulting future ALS operators and officers in charge, considering the level of automation and available resources and using Fitt's List [2], emphasizing the capabilities that are unique to humans while checking the performance criteria, function allocation was effected and noted down in the list. At that point subfunction elements became task elements.
In Figure 6 the function allocation form is presented of the subfunction EMBARK VEHICLES FOR PLANNED AMW. It is clear that the criteria are not always defined as this appeared to be one of the most difficult items.
After inventory it also appeared that certain operators were simultaneously involved in several task elements. By creating a matrix representation it is possible to classify and judge if these operators still have a reasonable degree of availability. If not, reallocation of the subfunction elements is needed. At the end a manning list was formed.

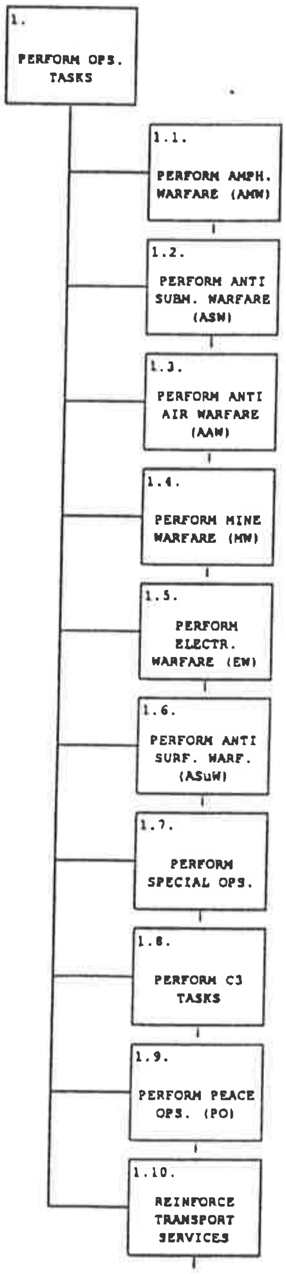

Figure 1. Hierarchical mission description of the mission category PERFORM OPERATIONAL TASKS using SDW.

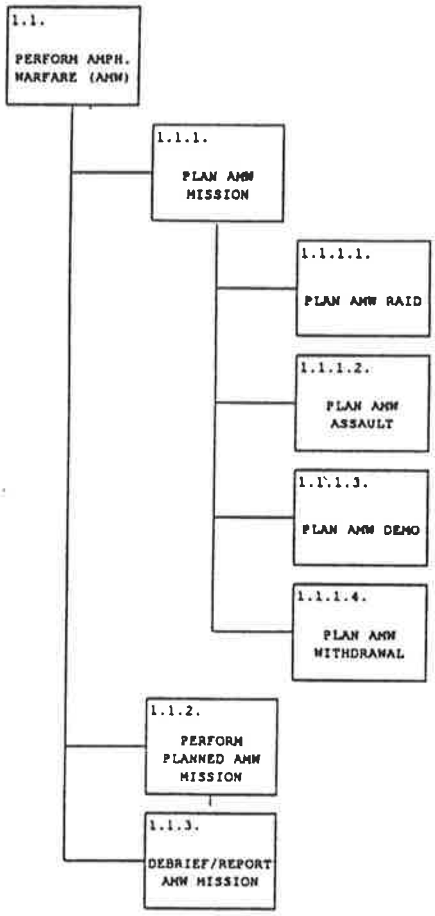

Figure 2. Function decomposition of mission segment PERFORM AMPHIBIOUS WARFARE (AMW) using SDW.

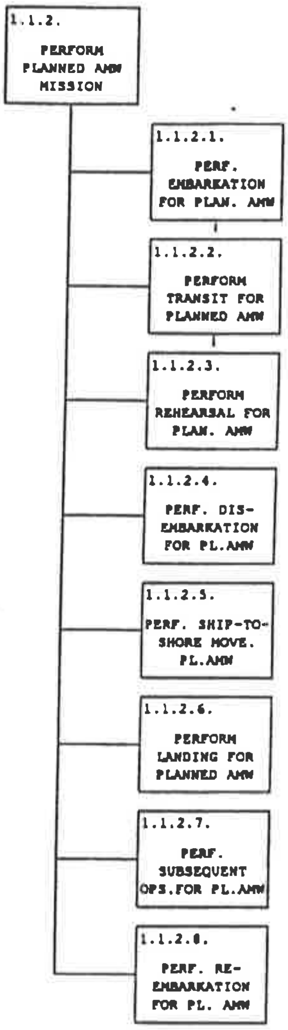

Figure 3. Function decomposition of subfunction PERFORM PLANNED AMW MISSION using SDW.

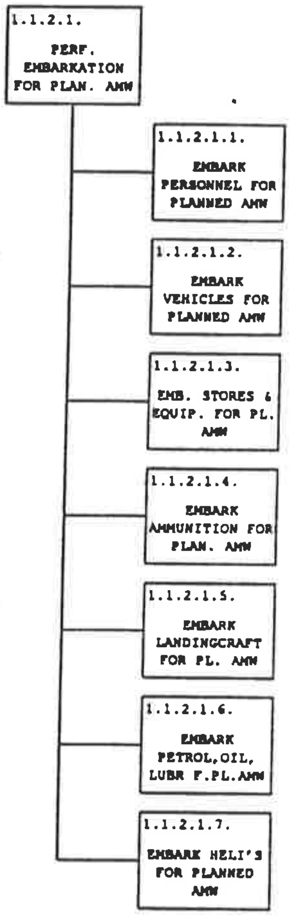

Figure 4. Lower level decomposition of subfunction PERFORM EMBARCATION FOR PLANNED AMW using SDW.

ATS FUNCTION ANALYSIS		Pagina : 7
Systeem	: ATS	Versie : IZF
Type	: Detail Proces Schema	Auteur : TACT/MARNS
Naam	: EMBARK VEHICLES FOR PLANNED AMW	FUNCTIE ANALYSE ATS
		Datum : 02-07-1992

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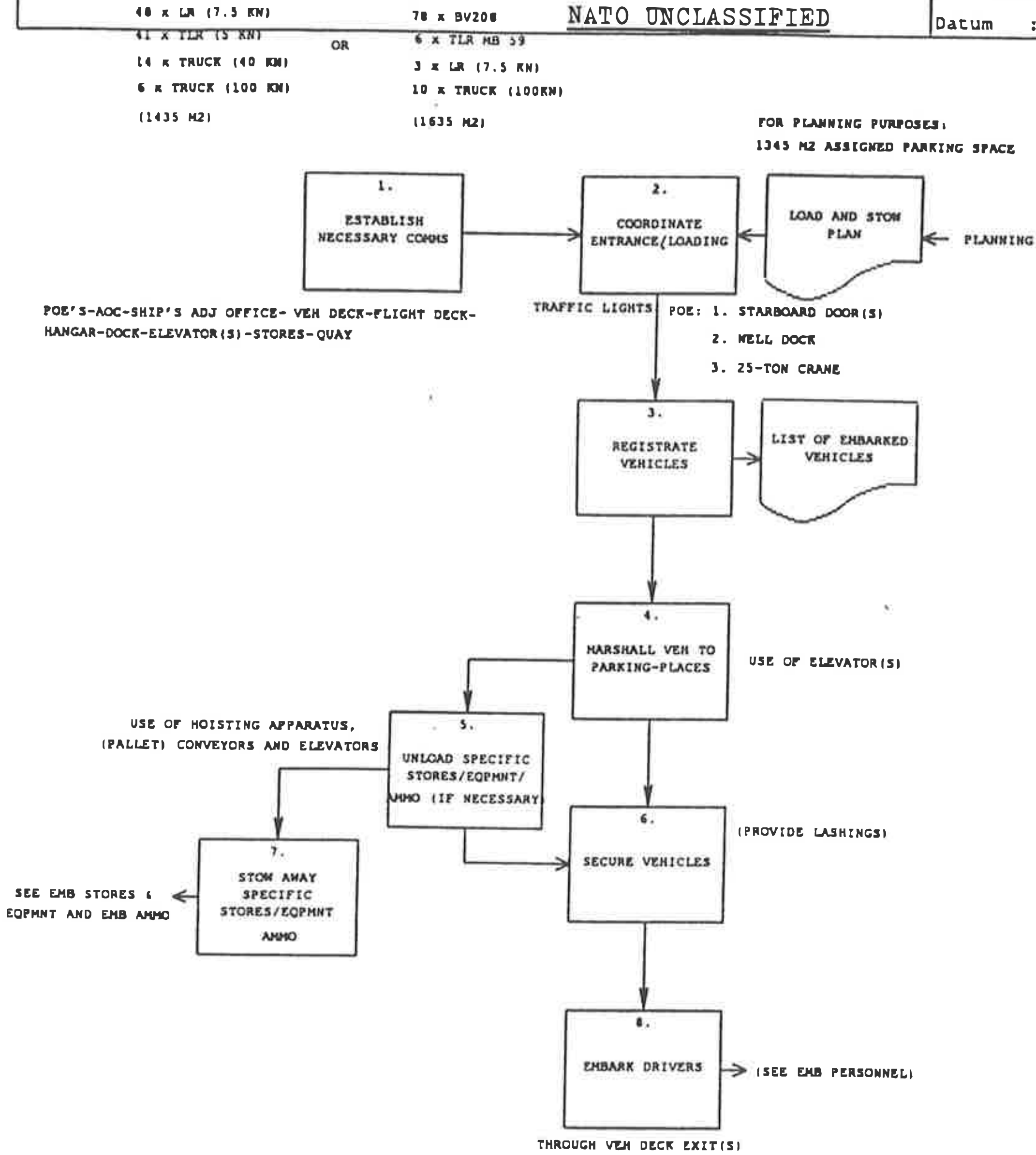

Fiure 5. Scenario description subfunction
EMBARK VEHICLES FOR PLANNED AMW using DPS.

SUBFUNCTION 1.1.1.2.2.2.2 EMBARK VEHICLES		INFORMATION		ALLOCATION			LOCATION	REMARKS
		NEEDED	MEANS	REQUIREMENTS/ CRITERIA	OPERATOR	EQUIPMENT		
.1	ESTABLISH NECESSARY COMMS	points of entry (POE's) amount of marshallers embarcation routes	embarcation plan ship loading plan	unsecure voice comms	ship's combat cargo officer amphibious ops officer ship's adjudant unit motor transport officer vehicle deck officer marshallers	telephone portable radio's public announcement system	quay, POE's, veh. deck, AOC, flight deck, hangar, 12-ton elevator, ship's adjudant office, secveral stores	
.2	COORDINATE ENTRANCE/LOADING	list of vehicles to be embarked sequence of embarcation	embarcation plan ship loading plan (load and stow plan)	embarcation within 18 hours in a tidal harbour amount of vehicles depending on tasking	vehicle deck officer unit motor transport officer	see above + traffic lights CCTV	vehicle deck flight deck quay dock control	
.3	REGISTRATE VEHICLES	table of vehicles to be embarked	ship loading plan	as soon as possible (ASAP)	marshallers	tables and/or PC (lightpen)	vehicle deck (POE's) flight deck	
.4	MARSHALL VEHICLES TO PARKINGPLACES	POE's embarcation routes allocation of parking places	ship loading plan (load and stow plan	ASAP	vehicle deck officer marshallers 12-ton elevator operator	portable radio's 12-ton elevator jackets + lightsticks	vehicle deck flight deck hangar 12-ton elevator	
.5	LOAD VEHICLES	POE's	ship loading plan	ASAP	drivers of vehicles crane drivers assisting personnel	crane	vehicle deck flight deck	
.6	UNLOAD SPECIFIC CARGO	info about vehicle loads	ship loading plan	ASAP	advance ply ship's crew	hoisting apparatus pallet conveyors elevators	quay flight deck vehicle deck's stores	
.7	STOW AWAY SPECIFIC CARGO							SEE EMBARK STORES AND EQUIPMENT
.8	SECURE VEHICLES			"zeevast" tracked veh. must be ????? ASAP	drivers ship's crew	lashings wooden blocks	vehicle deck flight deck hangar	
.9	EMBARK DRIVERS							SEE EMBARK PERSONNEL

Figure 6. Functoin allocation form of subfunctions EMBARK VEHICLES FOR PLANNED AMW.

5. CONCLUSIONS

In the design of a new Amphibious Lift Ship for the Royal Netherlands Navy new design methods are used based on a system ergonomic approach following a number of steps.

First the staff requirements are transformed into mission/scenario requirements and presented in a structured way using SDW software. Then, in the function analysis phase, the lower level mission segments are hierarchically decomposed into functions and subfunctions. This appears to be a very important and effective phase of the design process as the specialists involved are united and forced to share their viewpoints. Careful selection of the automation level form a solid basis for effective function allocation. Finally the function allocation was performed on the basis of Fitt's List and detailed worst case scenarios. By filling in forms RNN specialists had to describe working conditions and performance criteria for future resources. This appeared to be a considerable problem and major decisions had to be made about workplace layout and location. For instance whether the engine room surveillance is to be performed on the bridge or not, fixing the degree of maintenance on board and ashore, fixing the automation level for embarkation, etc. Function allocation will directly influence the manning list and should therefore be performed in a careful way.

The design phases as described above differ from previous concepts in warship design. Although a number of steps in the design process were taken and task elements were determined by allocating human and/or machines, the design process in this phase may still be considered as an observed guess. Apart from some timeliness and rough impression of operator availability no real quantified confirmation is obtained whether the allocation was correct. Especially when dealing with complex man-machine systems functioning in a dynamic environment, more quantitative analysis is needed. Therefore simulation techniques will be used to achieve a more profound task analysis.

6. FUTURE DEVELOPMENTS

Verification of the function allocation is being carried out at present time starting with the function DISEMBARCATION PERSONNEL AND VERHICLES as this appeared to be one of the most critical ALS functions. For the task analysis detailed scenarios are generated in which sequential and simultaneous activities of the system components are described. These activities are presented as network diagrams, indicating their relationship and characteristics. For performance prediction these networks are implemented using the Simulation for Workload Assessment and Modelling (SIMWAM) in IDEA/MANPRINT [8]. Stochastic model variables like task execution time, the probability of successfully completing tasks, setpoint accuracy of operators, etc. are implemented by predefined distribution sets (Monte Carlo approach). By repeating the model calculation many times (iterations) the statistics of the system variables can be obtained. These variables may concern operator busy/idle time, time history of state variables, scenario execution time, resource utilization, etc. By comparing the model calculation results with the system performance criteria it can be verified if the function allocation was correct.

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