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# Optimal Staffing for Future Military Operations

Implications for the Maritime Domain

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# Optimal Staffing for Future Military Operations

## Implications for the Maritime Domain



### Problem area

When armed forces are acquiring new materiel, such as a new weapon platform, a more-or-less standardized procedure will be followed to support the acquisition and sustainment of the new materiel throughout its lifecycle. Generally, the armed forces will formulate their requirements, candidate systems will be evaluated and compared, the acquisition will be prepared, the new system will be phased-in, will be operated and maintained, and will be phased-out at the end of its lifecycle. For a specific weapon platform, the personnel requirements and associated costs for operation, maintenance and other functions of the user organization must be substantiated. The projection of the personnel requirements of the future user organization is notably difficult. This paper shows how these personnel requirements for operation and sustainment of a weapon platform can be mapped out at the unit level.

Operation at night or around the clock are commonplace in the maritime environment, requiring even more efficient scheduling to make the most from the limited number of crew members available.

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## Description of work

The development of a man power planning is part of a 'lean' approach that has been adopted by NLR to develop new services. Such development project follows five phases (DMADV) in which a manpower planning will be gradually developed. These phases are: (1) Define, (2) Measure, (3) Analyse, (4) Design, and (5) Verify. DMADV is a lean methodology used to design new services while ensuring the end product is correctly delivered to the stakeholders. The goal of the DMADV methodology is to create a high-quality service while keeping the stakeholders' requirements in mind during every phase of the project.

## Results and conclusions

The methodology yields the following results:

1. Determination of the number and types of personnel required for military operations with given weapon platforms;
2. Determining the operational capability of a manning/platform, given the number of personnel;
3. Optimization of the function table when constraints or personnel requirements need to be adapted;
4. Optimized planning with allocation of personnel to tasks;
5. Qualitative and quantitative comparison of different manning concepts.

Some of the bottlenecks that were identified were only recognizable after rigorous analysis. Knowing these bottlenecks at an early stage allows the planner/commander to work around these bottlenecks and avoids irregularities in the required workforce. Such bottlenecks occur when tasks need to be handled simultaneously by one group of personnel, for example, when one unmanned aircraft needs to take-off and another needs to be landed by one launch and recovery crew.

## Applicability

Although the paper focuses on air/maritime domain, application can be based on operational ambitions of any military organization, for example, 24/7 surveillance of an area of operations. The methodology takes into account operational constraints, personnel constraints, and training requirements.

### GENERAL NOTE

This report is based on a presentation held at the Maritime/Air Systems & Technologies conference (MAST 2016), Amsterdam, the Netherlands, June, 21st, 2016.

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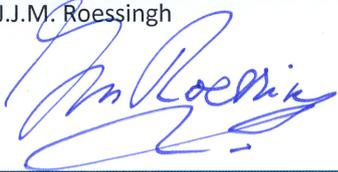
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## Summary

Staffing is a key issue when planning operations with new systems. The Netherlands Aerospace Centre (NLR) has developed and proved a methodology for estimating personnel numbers and is able to indicate where gains could be made.

The methodology and application are based on operational ambitions, for example, 24/7 surveillance of an area of operations. The methodology takes into account operational constraints, for example, the number of available weapon platforms to complete this task, and personnel constraints, for example, regulations concerning shift work for personnel and training requirements. The methodology results in an organization chart for units operating a weapon platform, a function table, and an optimized planning with allocation of personnel to tasks.

The methodology is based on 'Lean Design' consisting of five phases: Definition-Measure-Analyse-Design-Verify (DMADV). Each phase has its own tools for activities such as requirements capturing and cause-and-effect analysis. Using the methodology, an example application to determine the staffing of an Unmanned Aerial System (UAS) will be demonstrated. NLR proposes a number of ideas for deploying personnel as efficiently as possible without excessive task load. The deployment of air crew is optimised within flight and duty time limitations. Complex timing issues related to the operational concept of the UAS can be optimally resolved. Calculations included schemes of what can be achieved when the desired number of personnel is not available.

This paper will explain the methodology for optimal staffing and discuss application to the maritime domain.



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# Abbreviations

ACRONYM	DESCRIPTION
ATM	Air Traffic Management
CAP	Combat Air Patrol
CONOPS	Concept Of Operations
Det	Detectability
DMADV	Define-Measure-Analyse-Design-Verify
DNW	German-Dutch Wind Tunnels
FMEA	Failure Mode and Effects Analysis
FTE	Full-Time Equivalent
HRM	Human Resource Management
IR	Infra-Red
LRE	Launch and Recovery Element
MALE	Medium Altitude Long Endurance
MCE	Mission Control Element
NATO	North Atlantic Treaty Organization
NLR	Netherlands Aerospace Centre
Occ	Occurrence (Frequency of ..)
OPS	Operations
RPAS	Remotely Piloted Aircraft System
RPN	Risk Priority Number
SAA	Sense And Avoid
Sev	Severity
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
US	United States (of America)
USV	Unmanned Subsurface Vehicle

# 1 Introduction

## 1.1 Problem Area

When armed forces are acquiring new materiel, such as a new weapon platform, a more-or-less standardized procedure will be followed to support the acquisition and sustainment of the new materiel throughout its lifecycle. Generally, the armed forces will formulate their requirements, candidate systems will be evaluated and compared, the acquisition will be prepared, the new system will be phased-in, will be operated and maintained, and will be phased-out at the end of its lifecycle.

For a specific weapon platform, the personnel requirements and associated costs for operation, maintenance and other functions of the user organization must be substantiated. This paper shows how these personnel requirements for operation and sustainment of weapon platform can be mapped out at the unit level.

Operation at night or around the clock are commonplace in the maritime environment, requiring even more efficient scheduling to make the most from the limited number of crewmembers available.

## 1.2 Approach

The development of a man power planning is part of a 'lean' approach [2] that has been adopted by NLR to develop new services. Such development project follows five phases (DMADV) in which a manpower planning will be gradually developed. These phases are: (1) Define, (2) Measure, (3) Analyse, (4) Design, and (5) Verify.

DMADV is a lean methodology used to design new services while ensuring the end product is correctly delivered to the stakeholders. The goal of the DMADV methodology is to create a high-quality service while keeping the stakeholders' requirements in mind during every phase of the project.

## 1.3 Scope

The proposed method provides insight in the required personnel organization, when the operating unit is partially or fully deployed. The structure and size, the latter expressed in Full Time Equivalents (FTE), of the organization will depend on what will be considered a 'healthy' organization. A healthy organization may be defined in terms of deployment duration, shift duration and acceptable levels of short-term and long-term fatigue of personnel. A healthy organization also implies flexibility to absorb variations in personnel availability due to sick leave, vacation, education and training, while, at the same time, neither compromising the attainment of mission goals nor safety standards. There are also situations in the armed forces in which the size of the unit (in FTEs) to operate and maintain a new weapon platform is a given, due to e.g. cost constraints. In such case, the armed forces would like to know which mission goals can be practically realised with this given number of personnel and for what deployment duration. In other words, the question is: what continuity with such unit can be guaranteed, for what period and how must the given number of FTEs be subdivided over the functional groups within the unit? In such case, we have to resolve an optimization problem, rather than determining the required numbers based on operational requirements. Our method is suitable to look at the problem from both the required staff for full operation as well as capability of short term and long term operation with a given number of staff.

## 1.4 Structure of this paper

This paper describes a DMADV process for approaching and resolving staffing issues.

1. Definition of the workforce to be developed. Main tools during this phase are the Use Case, the Kano analysis and the Initial Business Case
2. Measuring aims at getting the operational requirements in focus. Part of the operational requirements will translate into personnel requirements. Subsequently, known personnel constraints must be applied to these personnel requirements. This allows us to separate function groups that can be summarized in an organization chart.
3. Analysis of staffing bottlenecks. Main tools are the Cause-and-Effect diagram, Failure Mode and Effects Analysis, and the Pugh Matrix, resulting in the main design parameters for a manning scheme.
4. Designing the organization, drafting the timeline for mission deployment and designing personnel assignment rules and resource allocation, eventually resulting in a function table.
5. Verification of the manning scheme and consolidating the Business Case

Examples are given from the work of the Netherlands Aerospace Centre for various customers in the air domain. The paper concludes with a discussion of implications for use of the recommended method in the maritime domain.

## 2 Definition of the workforce to be developed

### 2.1 Use Case

In the recommended methodology, development of a manning scheme starts with the development of a Use Case [2]. A Use Case is basically a set of short scenario descriptions (successful and failure scenarios). These scenarios are an important first step to fuel the discussion with the stakeholders of the weapon platform and to reach a common understanding about the actors and their tasks in the system. The Concept of Operation (CONOPS) for the weapon platform (when available) may provide input for the use case.

More formally, Use Cases are a technique for capturing the functional requirements of a system, including the involved personnel. Properly written, they accurately detail what the system must do: functions of the system and tasks of the staff. Use cases contain a number of scenarios in which a user of the system (e.g. a unit commander, squadron commander, captain of a ship) is the central actor. Moreover, the scenarios in a Use Case are tied together by a common user goal. The primary scenario is the 'main success scenario' which describes a successful work flow.

**Example.** A use case for mission control of a large (Medium Altitude, Long Endurance, MALE) UAS is taken as an example. The UAS is involved in a Combat Air Patrol (CAP) mission over theatre. The use case, describing a flight controlled from a Mission Control Centre, should first identify the primary actor and all secondary actors. In this case, the primary actor is the flight commander. Secondary actors may include the mission control flight crew (pilot and sensor operator), launch-and-recovery crew, technicians, Air Traffic Controllers, etc.

For each scenario in the use case, pre-conditions may be listed, specifying the state of the system (manning) before the flight scenario starts and including important system functions that impact the manning scheme. Furthermore, post-conditions specify the state of the system after the flight. One may, for example, see the following sequence of tasks for the flight:

- Start preparation of the ground control station by technicians for the mission
- Validate the mission planning and provide briefing
- Load the flight planning into the system
- Configure the ground control station for acceptance of the unmanned aircraft from the launch-and-recovery unit
- Accept the hand-over of the aircraft from the launch-and-recovery unit
- Fly the ingress route
- Take over surveillance tasks in the CAP pattern from departing aircraft during some overlap time, until arrival on target.
- Perform single flight in CAP (and perform surveillance tasks). This phase may take many hours, depending on the endurance of the platform, hence may include shift hand-overs.
- Hand-over surveillance tasks in the CAP pattern to arriving aircraft during some overlap time, until relieved on target.
- Fly egress route
- Hand-over aircraft to launch-and-recovery unit
- Configure ground control station for idle time
- Deactivate ground control station
- Perform debrief and administration
- Flight completed

A use case scenario would provide slightly more detail than just a list of tasks. It would specify the activities of specific persons and the durations of the different tasks. Where possible, task times, interactions between actors and relevant crew-states (workload, fatigue levels, etc.) may be described.

## 2.2 Kano analysis to prioritize workforce capabilities

From the Use Case, functional requirements for manning capabilities can be inferred. Care should be taken that the scenarios are specified at the appropriate level, starting with the highest level<sup>1</sup> use case. Subsequently, armed forces stakeholders can be asked to prioritize these required capabilities. Expectedly, different stakeholders will prioritize capabilities differently. Purchasers of the platform, Human Resource specialists, planners, commanders, maintainers and operators will all give different priority to functional requirements, for example, concerning the lead time of an actual deployment. Short lead times obviously provide expeditionary flexibility, but put personal preparation of to-be-deployed personnel under pressure.

A thorough and often-used method of prioritization of required capabilities is based on Kano analysis, named for its inventor, Dr Noriaki Kano. Kano defined three main categories into which each requirement can be classified [3]

- Basic capabilities: Not fulfilling these requirements is a functional barrier to entry—without the capabilities that these requirements provide, the armed services cannot use the weapon platform, for example, a complete crew, consisting of a Pilot and a Sensor Operator, is required to operate a UAS.
- Performance capabilities: Provide increasing utility when the capability is increased: the more the better. For example, a longer mission endurance and a longer range increase the utility of surveillance platforms. Higher maximum speed increases the utility of a fighter.
- Attractive capabilities. The requirement provides capabilities that differentiate one manning concept from its alternatives. For example, certain work-and-rest time schedules for crew may provide a significant healthier work force than others.

In addition there are low priority requirements, for which the added value is unclear or about which stakeholders do not care.

Kano devised a specific questionnaire in which two closed questions are posed about each capability to stakeholders. One question concerns the ‘functional’ capability, and one question concerns the dysfunctional capability, e.g.:

- What is your opinion about having forward-rotating shifts<sup>2</sup> for UAS operators involved in 24/7 operations from a mission centre at their home base?
- What is your opinion about not having forward rotating shifts for UAS operators involved in 24/7 operations from a mission centre at their home base?

For both questions, the answer categories are:

- I would like that very much
- I expect that

<sup>1</sup> From the viewpoint of the user, Use Cases can be constructed at different abstraction levels. In use case terms these are ‘cloud’, ‘kite’, ‘sea’, ‘fish’ and ‘clam’ level. For example, in UAS terms, taken the pilot as the user, the ‘cloud’ level may be the ATM-level, the ‘kite’ level is the mission level, and possibly addressing multiple flights simultaneously. The ‘sea’ level is at the level of the individual flight, addressing the interaction of the pilot with the air vehicle through the RPS. The ‘fish’ level is addressing subsystems such as a UAS Sense And Avoid (SAA) system. Finally, at the clam level you can zoom in at specific components of an SAA system, such as the utilization of an IR sensor [4].

<sup>2</sup> Changing from morning shifts to afternoon shifts, and then from afternoons to nights

- I don't care
- I can live with that
- I find that annoying

By combining the answers from a stakeholder to the two questions, it becomes readily clear whether the capability for this stakeholder is a basic-, performance-, attractive-, or low-priority-requirement (see [5]). Different stakeholders, such as planners, commanders, Human Resource Management (HRM) representatives, and platform operators, may prioritize the different capabilities differently. This should be taken into account in drafting the resulting list of stakeholder requirements. Once the required capabilities are prioritized, an initial business case can be drafted. Figure 1 provides an example of the outcomes of a Kano Analysis.

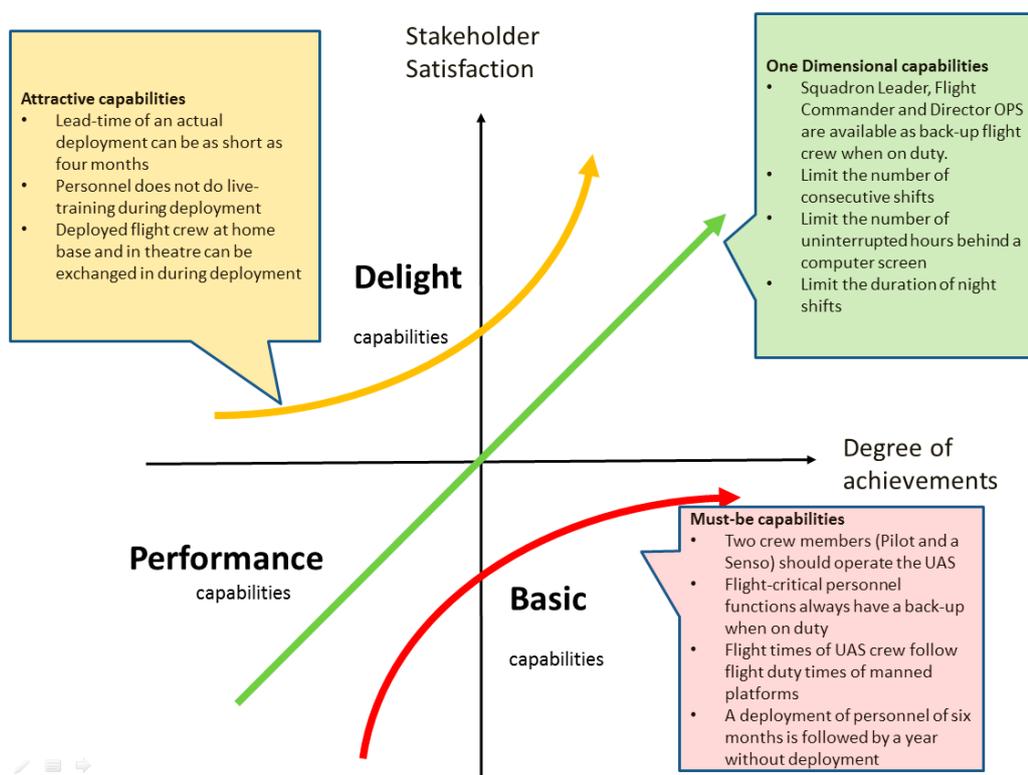


Figure 1: Outcomes of a Kano analysis. Example requirements for staffing a MALE UAS platform

## 2.3 Initial Business Case

Whether designing a staffing for a new system or improving the staffing for an existing system, it is worthwhile to constitute the associated costs and the hard and soft benefits that are expected. Hard benefits can be expressed in hard, monetary terms. For soft benefits, this is less straightforward. An increase in general well-being of staff, due to improved shift rotation, may not be directly quantifiable. Overall, the business case for an improvement in staffing, i.e. the benefits minus the costs, must be positive.

Costs may include payroll costs of personnel, and, costs for personal equipment may be calculated. Hard benefits can be cost savings, increase in operation endurance (e.g. flight hours) and the like. Soft benefits may range from safety benefits, reduction in personnel attrition, better career perspectives, less boredom, less work related-stress, healthier shift-work, etc.

**Example.** MQ-1 Predator UAS are used for 24/7 surveillance (Combat Air Patrol, CAP). To realise one 24/7 CAP, the US Air Force used to man a squadron with a total of 168 personnel (see Figure 2). As a hypothetical example, it is assumed that, currently, Mission Control personnel stationed at the home base has to fulfil ten consecutive night shifts and subsequently gets four days off-duty before rotating to morning shifts.

One could constitute a Business Case for healthier shift-work with a maximum of six consecutive shifts, with three days off-duty before rotating to the morning shift. The soft benefit is assumed to be healthier shift-work. However, to make a convincing Business Case, this should be realised without increasing payroll costs for the total of 168 personnel of the squadron. This means that tasks should be organised smarter, since the effective working hours of personnel on night shifts will be slightly shorter (10/14 days versus 6/9 days, the latter is around 5% less) for the improved scheme.

Mission Control		Launch & Recovery		Processing Exploitation Dissemination (PED)	
<b>Aircraft</b>	<b>0</b>	<b>Aircraft</b>	<b>4</b>		
<b>Personnel</b>	<b>43</b>	<b>Personnel</b>	<b>59</b>	<b>Personnel</b>	<b>66</b>
<i>Pilots</i>	<i>7 †</i>	<i>Pilots</i>	<i>3</i>	<i>FMV Crew</i>	<i>34 ‡</i>
<i>Sensors</i>	<i>7 †</i>	<i>Sensors</i>	<i>3</i>	<i>SIGINT</i>	<i>18</i>
<i>Maintenance</i>	<i>8</i>	<i>Maintenance</i>	<i>53</i>	<i>Maintenance</i>	<i>14</i>
<i>Msn Coordinator</i>	<i>5</i>				
<i>Leadership</i>	<i>2</i>				
<i>Admin/Overhead</i>	<i>14</i>				
<b>Other Equip</b>	<b>1</b>	<b>Other Equip</b>	<b>3</b>		
<i>Ground Station</i>	<i>1</i>	<i>Ground Station</i>	<i>1</i>		
		<i>Satellite Link</i>	<i>1</i>		
		<i>Data Terminal</i>	<i>1</i>		

Figure 2: Baseline situation for an initial Business Case, data taken from [6]

## 3 Measuring: getting the operational requirements in focus

### 3.1 From operational requirements to personnel requirements

In addition to the cases, requirements concerning personnel may be derived from a Concept of Operations (CONOPS) for the concerned platform. The CONOPS explains how the system will be operated and possibly how the system will be maintained and supplied. It may also provide the concept for initial training, qualification training, recurrent training, and requirements for keeping the crew current for their duties. Additional sources of information at this stage may be information from (NATO) partners that operate a similar platform in a similar manner. The manufacturer of the platform may also provide relevant information concerning for instance the crew concept and the maintenance concept. However, one cannot expect that the CONOPS provides exhaustive input for a manpower analysis. For platforms that are yet to be acquired, the CONOPS will still be under development. Therefore, the manpower analysis must be done in parallel, eventually providing input for the CONOPS.

### 3.2 From personnel requirements to an organization chart

Personnel requirements derived from use cases or other sources do not necessarily indicate the need for certain types or numbers of personnel. Although the CONOPS may, for example, dictate that the UAS ground control station must be inhabited by a complete crew (pilot and sensor operator) when controlling an aircraft, personnel constraints need to be taken into account, such as:

- Constraints resulting from the CONOPS. For example Predator UAS operations are based on ‘remote split operations’ in which the aircraft are launched and recovered from an airbase near the theatre of operations, while actual mission control (by far the largest part of the mission) is done from a home base. This dictates that aircraft maintainers and launch and recovery personnel must be deployed to theatre, while the remainder of the personnel remains in the home land.
- Differences in competencies between personnel: personnel have specialized in one or more functions through a process of recruitment, selection, education, training and experience, partly driven by personal preference. Generally, individuals are not directly employable in other functions. The operation and maintenance of a new weapon platform may require new competencies, not readily available in the organization.
- Constraints resulting from the legal status of the personnel, for instance depending on employing organization, national law, and applicable regulations.
- General constraints in human performance, for example: people can generally only do one task at a time, have limitations in information processing, handling speed, etc.
- Constraints related to training and currency. Manning schemes need to take into account currency of its personnel, for example, when a fully qualified UAS pilot on a MQ-9 is assigned to a so called Mission Control Element for a long duration, this person may lose his/her currency on so called Launch and Recovery tasks.

To map the various constraints on function groups is probably the most difficult part of the job. For example, UAS flight crew is constrained by (among other things) crew concept, deployment location and procedures, shift work regulations, flight time limitations, and back-up procedures.

This stage is finalized when the different types of personnel are detailed and summarized in an organization chart. On the basis of this chart and the constraints, the next stages will provide different function tables, i.e. personnel from the chart listed in a table with required personnel numbers.

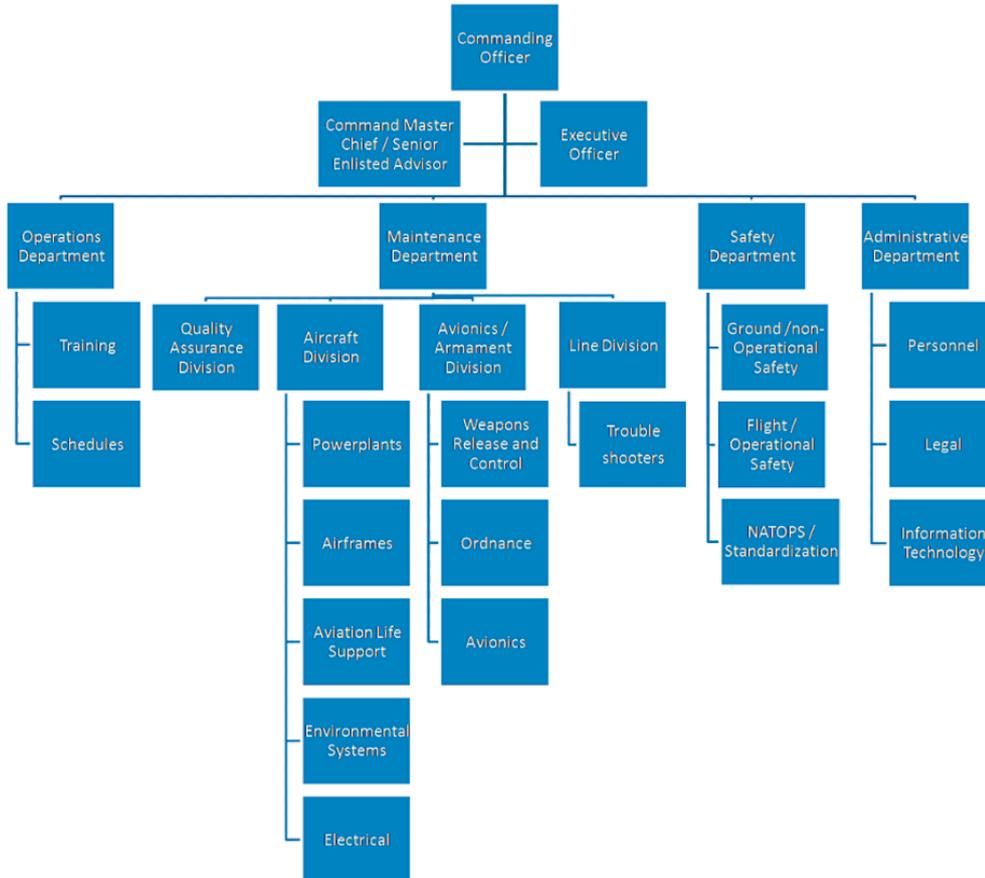


Figure 3: Example organization chart, taken from [7]

## 4 Analysis of Manpower - bottlenecks

### 4.1 Cause-and-effect diagram

The cause-and-effect diagram [8] is a tool to identify which factors affect the performance of a system (in this case focusing on the personnel organization). To find the factors we will assemble a list with possible causes of shortcomings. The cause-and-effect diagram (or fishbone diagram) as indicated in Figure 4, is used to brainstorm with stakeholders. The central question is thus to find shortcomings in the personnel organization. After coming-up individually with as much causes as possible for the delay and failure to deliver, the stakeholders classify these causes in the following six categories (6 times M):



Figure 4: Results of a Cause and Effect analysis on a flip over

1. Measures, for example, presence of personnel is not properly measured or recorded.
2. Mother Nature, for example, natural obstacles along the route, weather causing delays.
3. Methods, for example, inappropriate shift rosters.
4. Man, for example, lack of qualified personnel for a certain function.
5. Material, for example, poor communications infrastructure at the deployed base.
6. Machine, for example, inappropriate working positions.

### 4.2 Failure Mode and Effects Analysis (FMEA)

The most prominent shortcomings ('failure modes') identified with the cause-and-effect diagram in the previous section may be further analysed using a FMEA. Table 1 below shows the scale of the concept of the Risk Priority Number (RPN), which is the product of Occurrence (Occ), Detectability (Det) and Severity (Sev). These factors are expressed on a scale of 1-10. Consequently, the Risk Priority Number is expressed on a scale of 1-1000.

Table 1: The FMEA Risk Priority Number (RPN) scale

Severity		Occurrence		Detection	
Hazardous without warning	10	10 Very high: Failure is almost inevitable	10	Cannot detect	
Hazardous with warning	9		9	Very remote chance of detection	
Loss of primary function	8	8 High: Repeated failures	8	Remote chance of detection	
Reduced primary function performance	7		7	Very low chance of detection	
Loss of secondary function	6	5 Moderate: Occasional failures	6	Low chance of detection	
Reduced secondary function performance	5		5	Moderate chance of detection	
Minor defect noticed by most customers	4		4	Moderately high chance of detection	
Minor defect noticed by some customers	3	3 Low: Relatively few failures	3	High chance of detection	
Minor defect noticed by discriminating customers	2		2	Very high chance of detection	
No effect	1	1 Remote: Failure is unlikely	1	Almost certain detection	

An example FMEA (taken from [11]) is summarized in Table 2 below.

Table 2: Example FMEA quantifying the risks, Analysis of function failure modes, failure mode effects, and failure mode causes, with risk score, (pre-intervention)

Sub-topic	Failure mode	Failure mode effects	Failure mode causes	Occ.	Det.	Sev.	RPN
<b>Organizational climate</b>	Culture	Changes in engagement behaviour (decisions) due to moral stress (altered norms and rules)	Lack of physiological involvement due to unique nature of UAS CONOPS	9	3	9	243
<b>Organizational process</b>	Operations	High workload and fatigue	Continuous operations (24/7)	9	2	8	144
<b>Resource management</b>	Training	Excessive CAP demand that exceeds supply of trained personnel	Drop-out during career (three times higher compared to manned airframe programs)	7	8	8	448
<b>Resource management</b>	Staffing / manning	Fatigue, reduced flight safety	Operational tempo, low crew ratio	7	4	8	224
<b>Personnel factors</b>	Failure to obtain adequate rest	Insufficient rest resulting in various performance problems (lack of alertness, lack of concentration, increased reaction time, bad CRM, etc.)	High task load and surge shifts to meet CAP demands resulting in low number of off-duty days	5	5	7	175

## 4.3 Solutions for preventing failure modes and mitigating the consequences

For each failure cause and each risk factor (occurrence, detection probability and severity), the stakeholders should brainstorm about solutions to prevent the cause and/or mitigate the consequences. The results of these sessions can be summarized in a table similar to that of Table 2.

## 4.4 Quantified solutions with the FMEA (post)

Subsequently, the stakeholders can again estimate the Occurrence (score on a scale of 1-10), Detectability (id.), Severity (id.), but now with the proposed solutions in place. This is reflected in a new RPN. A reduction in RPN (absolute or expressed as a percentage) can be readily calculated.

## 4.5 Evaluating solutions measures against a baseline (datum)

To investigate what manning concept/scheme is needed for a weapon platform/ operation, a Pugh Matrix [9] may be devised. The set of criteria based on the stakeholder requirements are used and each of the requirements is categorized according to its importance: High (H=3), Medium (M=2) or Low (L=1). Example criteria are:

1. Lead-time of an actual deployment can be as short as four months (L)
2. Personnel does not do live-training during deployment (H)
3. Deployed flight crew at home base and in theatre can be exchanged in during deployment (M)
4. Squadron Leader, Flight Commander and Director OPS are available as back-up flight crew when on duty (M)
5. Limit the number of consecutive night shifts (H)
6. Limit the number of uninterrupted hours behind a computer screen (M)
7. Limited the duration of night shifts (H)
8. Two crew members (Pilot and a Sensor operator) should operate the UAS (H)
9. Flight-critical personnel functions always have a back-up when on duty (H)
10. Flight times of UAS crew follow guidelines for flight duty times of manned platforms (H)
11. A deployment of personnel of six months is followed by a year without deployment (H)

The group of manning concepts that are aimed at satisfying above criteria are, by means of example, (1) Manning Concept B, (2) Manning Concept C and (3) a hybrid variant, Manning Concept D. The baseline ('datum') with which all other concepts are to be compared is Manning Concept A, that is commonly used as manning concept for UAS at NATO partners. This results in the Pugh Matrix that is provided in Table 3.

When comparing the new concepts with the baseline (Manning Concept A), it becomes apparent that Manning Concept D scores the most positive points relative to the baseline. It combines some advantages of B and C. However, it has more negative points than Manning Concept C, mainly because stakeholders consider it important that a deployment of personnel of six months is followed by a year without deployment. If the latter requirement is decisive, Manning Concept C is preferable. If a short lead time is required, which is considered less important by stakeholders, than Manning Concept D is preferable.

Table 3: Pugh Matrix to compare three manning concepts against a baseline. Each requirement is scored with +, -, or Same when fulfilled better, worse, or Same as in the baseline. The scores (+=+1, -=-1, Same=0) are then weighted by Importance (H=3, M=2, L=1), resulting in a weighted score (W-score) for each requirement

Requirement	Importance	Manning Concepts (baseline = Manning Concept A)											
		Manning Concept B		Manning Concept C		Manning Concept D							
		Score	W-Score	Score	W-Score	Score	W-Score						
Lead-time of an actual deployment can be as short as four months	L	+	+1	-	-1	+	+1						
Personnel does not do live-training during deployment	H	-	-3	+	+3	+	+3						
Deployed flight crew at home base and in theatre can be exchanged in during deployment	M	+	+2	+	+2	+	+2						
Squadron Leader, Flight Commander and Director OPS are available as back-up flight crew when on duty	M	+	+2	+	+2	+	+2						
Limit the number of consecutive night shifts	H	+	+3	+	+3	+	+3						
Limit the number of uninterrupted hours behind a computer screen	M	-	-2	-	-2	-	-2						
Limited the duration of night shifts	H	+	+3	+	+3	+	+3						
Two crew members (Pilot and a Senso) should operate the UAS	H	+	+3	+	+3	+	+3						
Flight-critical personnel functions always have a back-up when on duty	H	Same	0	+	+3	+	+3						
Flight times of UAS crew follow guidelines for flight duty times of manned platforms	H	+	+3	Same	0	+	+3						
A deployment of personnel of six months is followed by a year without deployment	H	-	-3	+	+3	-	-3						
	Σ+		7		+17		8		+22		9		+23
	Σ-		3		-8		2		-3		2		-5
	ΣS		1		0		1		0		0		0

## 5 Designing the organization

### 5.1 Timeline for missions during deployment

During deployment, different processes take place at the deployed unit. A MALE UAS squadron which has to realise a 24/7 surveillance task, has, for example, the following processes:

- Launch and Recovery process,
- Mission Control process,
- First-line data analysis process,

Although these processes take place at different organizational sections and at different locations, these need to be closely coordinated. On the basis of task completion times, ordering of tasks, correspondence with other processes, and taking into account the personnel requirements, timelines can be drafted (for example using project planning software). An example of such deployment timeline for the launch and recovery process is provided in Figure 5.

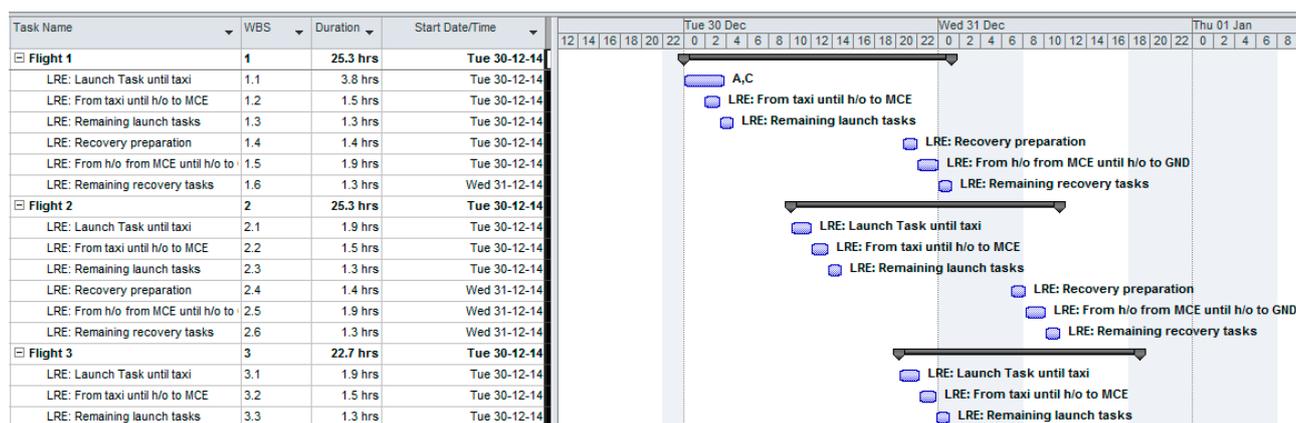


Figure 5: Snapshot of a deployment timeline in planning software package

Subsequently, the timelines of the different subsections need to be combined in order to identify bottlenecks in the processes. In the example for the mission of the UAS, a timeline was determined for the worst case operation for personnel requirements. In Figure 6 a sample can be seen of subsequent sorties of several unmanned aircraft, taking into account the transit to the area of operations (orange), the launch and recovery by the Launch and Recovery crew in the area (purple) and the actual operation over the area of operation in (light blue).

Some of the bottlenecks that were identified were not readily recognizable, given the long duration of each flight. In the example in Figure 6 most of the time two aircraft are airborne, and the majority of time controlled by crew located a long distance from the area of operations. In the figure, the purple areas of the timelines do not overlap, so a single launch and recovery crew, located near the area of operations, can perform take-off and landing sequentially. However, if transit time is longer, the purple areas will overlap, so three aircraft will be airborne at the same time. Two of those aircraft need to be controlled by the local launch and recovery crew. This would result in a number of extra aircrews needed for launch and recovery for 24/7 operations. Recognizing these bottlenecks at an early stage allow the planners /commanders to work around these bottlenecks. This saves a large number of personnel that would be active for a relative short time period per day.

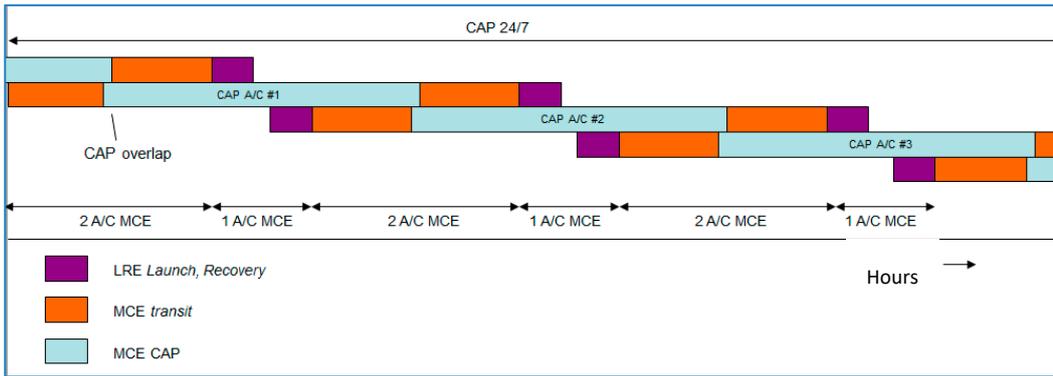


Figure 6: Representation of subsequent flights with a UAS for full coverage of an area of operation

## 5.2 Designing personnel assignment rules and resource allocation

The assignment of personnel to tasks in the above timeline can be rather complicated, depending on the complexity of the constraints. This could be sorted out manually, but will turn out to be painstaking. Specialized software that deals with resource allocation can be helpful. Personnel requirements include:

- Available working hours for individuals per shift,
- Number of consecutive shifts,
- Shift rotation scheme including days-off duty,
- Available working hours during a working year, including estimates of training hours, sick leave,
- The effect of the shift system for prolonged operation,
- Number of hours behind a computer screen, which requires breaks within a shift,
- Back-up crew, especially flight crew.

Also, with respect to availability of equipment a number of constraints may exist. For the example UAS operations, the number of available aircraft and ground control stations are obviously limited. Given all these schedules, timelines, constraints, the number of people that are required for operation can be determined. This assessment includes optimization to plan for the smallest number of personnel in the organization to allow safe operation that can be sustained practically and from a human capability perspective. The number that is required for a short term deployment can also be determined.

## 6 Verification

### 6.1 Verification of the manning scheme

During the optimization of the UAS example, schedules for shift workers were derived by the Netherlands Aerospace Centre that resulted in a lower number of personnel required for the analysis process, and a lower number of flight crew for the mission control process. This was achieved by different solutions: (1) varying start- and end-time of the shift for individuals, (2) allowing on-duty personnel and their back-ups to alternate between tasks, and (3) optimizing the scheduling of breaks, herewith satisfying the requirement to include breaks after every two hours of computer work.

It is worthwhile noting that each operational function that can be saved in an organization that operates in 24/7 continuous shifts, results in a reduction of five to seven persons in the work force (depending on, for example, organizational factors and differences between nations).

An additional optimization was performed to determine how the example UAS operation would be affected when personnel numbers and equipment would be available as initially planned. In this study both the number of attainable flight hours and their most efficient use (many shorter flights versus longer flights at certain time slots) were calculated. The solutions clearly showed the effects of a schedule on the crew. It may however be anticipated that tactical requirements will override these optimal schedules in some cases.

The long term effects of UAS operations with a shortage of staff were shown to have a detrimental impact on organizational health. From open literature [11] there are examples from intensive UAS operations, with accumulated, leading to attrition of personnel, resulting in an even higher burden to the remaining personnel.

### 6.2 Consolidating the Business Case

This step includes verification of the assumptions of the Initial Business Case. If a new organizational chart has been designed and/or personnel numbers have been adjusted, then total payroll costs of personnel for different deployment scenarios may need to be recalculated and compared against a baseline.

Specialists need to verify whether operational benefits, safety benefits, and improved Human System Integration (HSI) perspective can indeed be realized, possibly based on model-based simulation.

# 7 Conclusions and Discussion

## 7.1 General

A methodology for manpower planning was presented in line with Lean methodology, following the DMADV phasing. The methodology yields the following results:

1. Determination of the number and types of personnel required for military operations with given weapon platforms, summarized in organization chart and function table;
2. Determining the operational capability of a manning/platform, given the number of personnel;
3. Optimization of the function table when constraints or personnel requirements need to be adapted;
4. Optimized planning with allocation of personnel to tasks;
5. Qualitative and quantitative comparison of different manning concepts.

Some of the bottlenecks that were identified were not readily recognizable without rigorous analysis. Knowing these bottlenecks at an early stage allows the planner/commander to work around these bottlenecks and avoids irregularities in the required workforce. Such bottlenecks occur when tasks need to be handled simultaneously by one group of personnel, for example, when one aircraft needs to take-off and another needs to land by one launch and recovery unit.

Among the solutions emerging from projects examples are:

- Flight crew that take a break after being a few hours on the job can be used as a back-up (reserve) crew, or can provide assistance in other tasks such as planning;
- Hours during which no active flying is required (picket duty) can be used by flight crew to do currency training;
- Different crews can be given different start-times for shifts to avoid all crew being ready for a break at the same time;
- Manning schemes for longer term deployments may be implemented in which only part of the personnel starts the deployment at the same time. This avoids shortage of personnel for homeland defence task during preparation of the deployment, during leave, and following the return of personnel;
- Before implementing a mission planning for UAS surveillance (24/7 CAP), the maximum length of a mission should be determined as to avoid overlap between departing and arriving aircraft. In such case, two aircraft require control by the launch-and-recovery unit simultaneously, requiring the number of flight crew to be doubled;
- Combine an operation with a partner nation, to reduce the number of required personnel.
- Pooling of personnel by different units/weapon platforms, to reduce the number of required personnel. For example, during deployment personnel may be employed for weapon system A, and between deployments personnel may be employed for weapon system B.

Although not all solutions have been used practically, they may serve to avoid bottlenecks when needed.

## 7.2 Staffing for the maritime environment

With a trend of increased use of unmanned vehicles operating from ships, both in the air (UAVs) as subsurface (USVs), comparable staffing issues are expected to emerge. Until recently, most UAVs for naval use were relatively short endurance, such that operators could remain on task from take-off to landing. When the range and endurance of the maritime UAVs will be comparable to the ones operating from land bases, the issues with fatigue, reserve crews, total flying time per crew member are also issues that need to be addressed. This is particularly useful for night- or around the clock operations that are common in the maritime environment.

In general, a Navy attempts to work with smaller numbers of crew. Automation and better guided weaponry allow a trend towards the bare minimum 'skeleton' crew. However, with lower numbers of crew, one has fewer opportunities to optimize schedules and to prepare for incomplete crew. Illness, incapacitation and other reasons for requiring another crew member to perform the task of the absentee, can be more easily resolved if total number of crew is high relative to tasks to be performed. However, the trend towards less crew implies that any gap is harder to fill. In a combat situation with casualties, this effect is likely to be even stronger. The lessons learned from research of, particularly, the manning of UAS is applicable to these problems as well.

An assessment that shows how to do more with smaller numbers of personnel, will allow ships to become smaller and therefore cheaper to produce, to operate, and to constitute a smaller target for the enemy. This requires combining of tasks that may be performed by the same person or team, as well as more efficient scheduling

If the required crew for a mission leads to exceeding the allowable crew capacity of the ship, the duration of the cruise may be compromised. When a smaller number of crew is used, full 24/7 operation for some tasks may not be sustainable without compromising the health of the organization in the long run. Symptoms may be fatigued and demoralized crew, resulting in a less efficient operation. Optimization of staffing may be the difference between full coverage and constantly improvising to cover all tasks required.

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