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Fixed Interval Scheduling as a method for resource allocation at NOV

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This thesis is written with the purpose to find better solutions for resource allocation at NOV Molde. We send therefore a special thanks to the employees there for sharing their time to help us. The information provided by them has been essential for us to be able to conduct the thesis.

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Molde, 24.05.2011

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Abstract

The topic of the thesis is to look to National Oilwell Varco's need to revise their current planning and scheduling routines when it comes to resource allocation of service engineers in the company's aftermarket.

This master thesis deals with a special variant of Fixed Interval Scheduling Problem where jobs are to be assigned workers. Though this type of scheduling problem is well known, little (if any) research has been performed with the primary focus on utilization. In most industries scheduling is performed manually without the help of much computerized models.

After giving an introductory to the situation at NOV AM Molde, the thesis will set the problems into a theoretical context, and a mathematical model for the problem is given. The model is tested, discussed and shown with improved results compared to the original solutions from NOV. At last recommendations discuss factors that can lead to further improvements, and in what way NOV can further develop this tool.

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1. Introduction

In this master thesis we consider methods for resource allocation at NOV's Aftermarket in Molde. Top management in NOV AM Molde expressed a concern about today's practice with regards to this area and that it has not been in focus in recent years. There are several elements that affect their resource allocation, and our goal is to find a better method that takes these elements into consideration.

Focusing on this area is important for the Aftermarket in NOV as it has to deal with their core business of sending workers out to customers on various projects. Because NOV employs a large number of workers these constitute a large amount of the company's resources. NOV therefore wanted to see if there were any ways of using these resources more efficiently.

In this master thesis we wanted to apply the knowledge we have gained from our study to give recommendations and suggestions to help NOV in the field of resource allocation. We both have specialized ourselves in industrial logistics during the master's program. Because of our background in operational management and NOVs position in the oil industry, it became natural for us to choose a company like NOV for our master's thesis.

2. Organizing thesis

Chapter 1: The first chapter will give a short introduction to NOV and the business they operate.

Chapter 2: Statement of problems will give an introduction to how NOV operates, which rules they go by and which factors they consider when handling the allocation of workers.

Chapter 3: Literature review gives a brief introduction to the theoretical basis mainly with regards to project management and scheduling theory.

Chapter 4: Describes the method chosen and used to solve this thesis.

Chapter 5: Presents the mathematical formulation of the thesis and further go into details and specifications.

Chapter 6: Data collection describes short how we gathered the data needed for this thesis.

Chapter 7: Gives a short analysis about the results and compares the original solution provided by NOV with the model solutions.

Chapter 8: The chapter discusses the degree to which evidence support the interpretations of the results provided by the model.

Chapter 9: This chapter will discuss the results and limitations of the thesis.

Chapter 10: Recommendations for improving both the model and policies in NOV are discussed in this chapter.

Chapter 11: Contribution to thesis will short state the contribution of this thesis.

Chapter 12: Gives the conclusion for the thesis.

3. About NOV

National Oilwell Varco (NOV) is a worldwide engineering company providing products and services to the oil drilling business. With over 700 production, sales and service locations around the world, NOV is a huge actor in the business. Their regional office in Molde, Norway, specializes in engineering and has competence in producing cranes, winches, winch systems and hose stations for offshore installations, in addition to the service department. They have today 332 employees (NOV, 2011. Appendix D). Since the oil drilling business is constantly developing, the requirements from the customers are shifting as well. To fulfill the requirements from the customers, NOV Molde has a high focus on product development with a project oriented production strategy.

The Aftermarket department (AM) is a huge part of the office in Molde with 140 employees whereof approximately 60 service engineers (NOV, 2011. Appendix D). This department is performing repairs, maintenance, modifications and upgrades of equipment on both onshore and offshore installations. The locations of these sites could be anywhere from the coasts along Brazil and Angola, to small workshops in the Molde region. Maintenance jobs, installations, modifications and upgrades are activities that are easy to predict because of regular service times, and makes them easy to plan. Repairs on the other hand are unpredictable, for instance because of unexpected breakdowns, and therefore require the company to be flexible enough to finish all the jobs in a respectable time. All of these are known as service jobs.

Turnover 2008	Turnover 2009	Turnover 2010
36 651' USD	43 322' USD	45 330' USD

Table 1 – Turnover (Self-made, with numbers from NOV, 2011 – Appendix D)

In recent years, NOV has increased their activity and turnover. This is confirmed in table 1, which shows the turnover for the years 2008-2010. Especially from 2008 to 2009 the turnover increased significantly. In spite of this, NOV reports of a decline in their part of the industry where they operate. This has led to a reduction in sales of new cranes. As a result the backlogs have decreased as there are fewer installation jobs for AM.

Despite the decline of installation jobs, the amount other service jobs has increased in the same period. Service jobs are usually corrective maintenance, which are unscheduled maintenance jobs arriving unforeseen. These are short trips which have to be planned within a few days.

Today the AM has eight employees to handle the co-ordination of the service jobs arriving. They are organized with three Personnel Coordinators (PC), each have three Single Point of Contact (SPOC) below them. The teams' task is partially to assign jobs to service engineers that are available in the given time period, that he has the right experience and qualifications to perform the job, and to make sure that the required tools are available in the off-shore installation at the beginning of the job (NOV, 2010).

4. Statement of problems

The chapter will give an introduction to how NOV processes a job, from the job request and till the after-work conversations are completed. Further on, the chapter will discuss the issues NOV, and more specifically the Personnel Coordinators, have to consider when handling the allocation of service engineers.

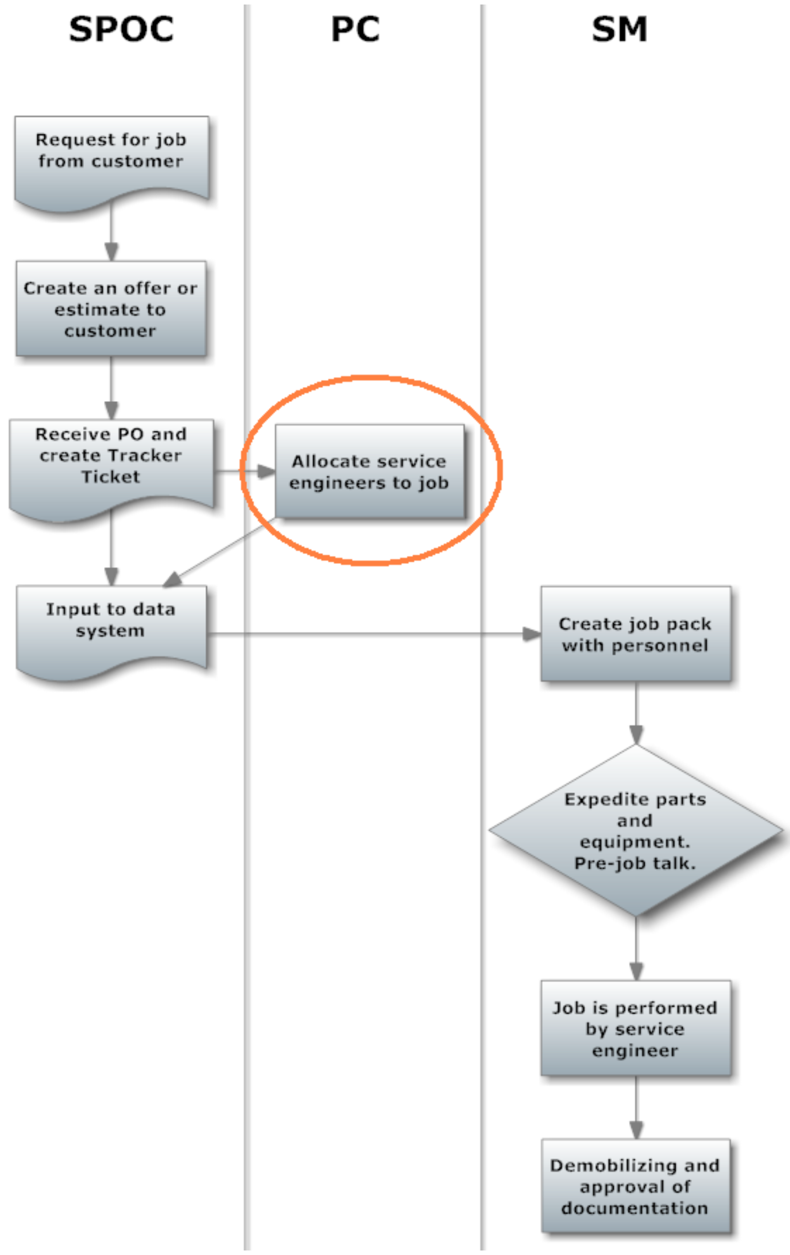


Figure 1 – Flowchart (Self-made, 2011)

a) Processing jobs

Processing of a job starts when a customer contacts an appointed SPOC with a requested job. When the customer and SPOC communicate with each other, the SPOC has to respond the customer concerning the job within 48 hours after their first contact. The SPOC then has to perform an internal cost calculation with estimated hours and equipment needed for the job. Normally they only get technical information about the job in advance, but for some standard jobs they also get details about the Purchase Order (PO) which contains more information.

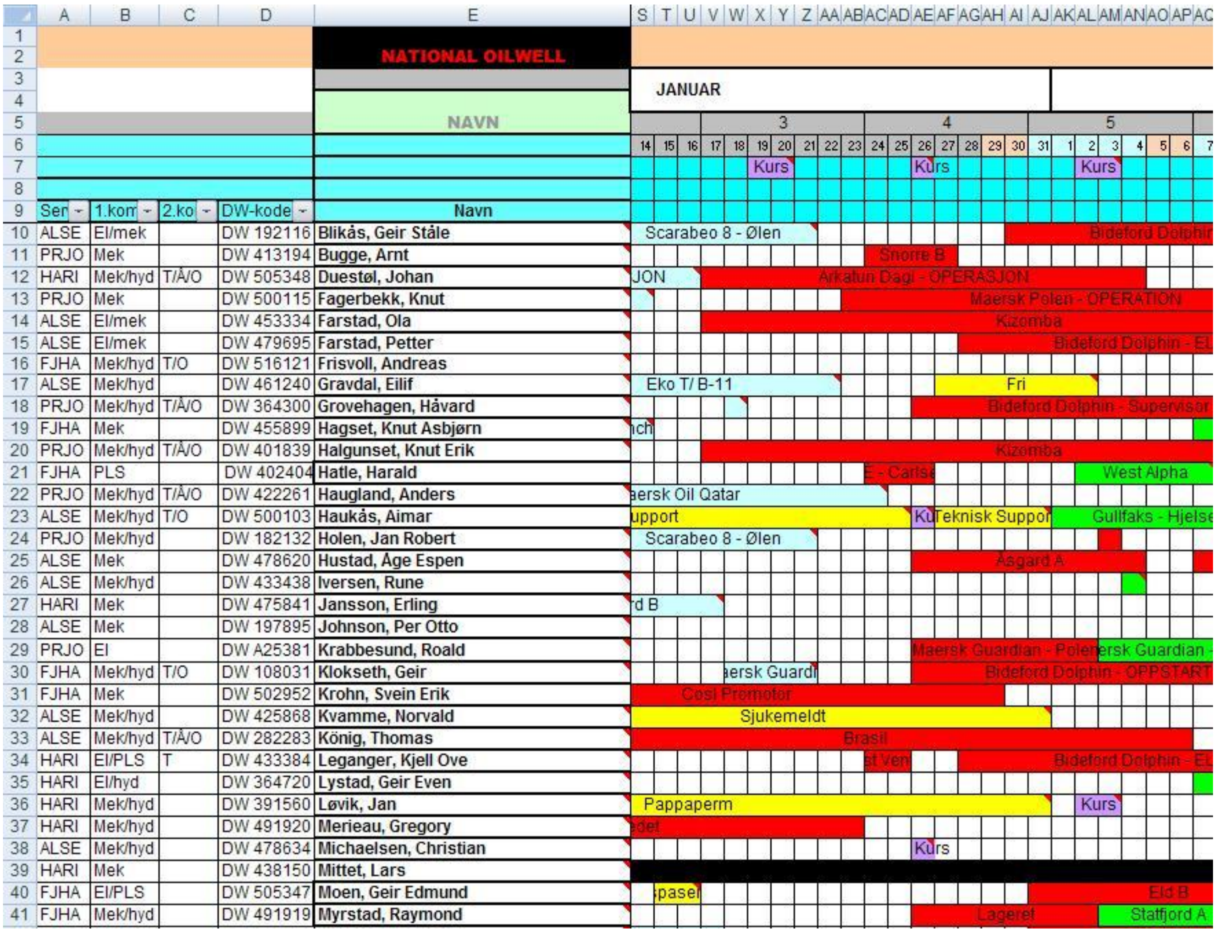
The SPOC uses NOV AM's global support system 'Tracker' to plan jobs. In this support system, information about all customers, products, employees and jobs are stored. The SPOC then creates a ticket for a particular job with a description, name of the SPOC and Service Manager (SM), start and due date, location, flight times etc. Further on the SPOC has to consider which resources the job requires. If equipment is needed to be ordered, the SPOC considers the lead time for these when planning the time horizon of the job. If the job does not require any parts, the SPOC contacts the Personnel Coordinators immediately to check the availability of service engineers.

The Service Manager's task is to plan the job for the service engineers. To document all the details about the job, they create a job pack. This pack contains estimated time frames for executing the job and the required level of competence and personnel. If there is any deviation from the ticket with regards to the time needed, the deviation has to be reported to the SPOC and updated immediately. The SM also orders equipment if needed for the job.

PCs are the ones whom assign service engineers to new and ongoing jobs, and are the only contacts when it comes to allocation of these for the AM department. The SPOCs contact the PCs when it comes to preparation of quotes and confirmed jobs. Today there are currently three employees in the position of PCs to handle the coordination of service engineers for the AM.

Upon receiving a job request, or a PO from the SPOC, the PC processes it, and provides feedback with regards to the resources available. The main part of the PC's job deals with the allocation of service engineers to specific jobs planned in conjunction with the customers and NOV. When a job is confirmed the PC locks the worker and reserves him for that time period to the specific job.

The following illustration is a snapshot of the current Excel spreadsheet that is the basis for planning the allocation of personnel:



Ser	1.kom	2.ko	DW-kode	Navn
ALSE	El/mek		DW 192116	Blikås, Geir Ståle
PRJO	Mek		DW 413194	Bugge, Arnt
HARI	Mek/hyd	T/Å/O	DW 505348	Duestøl, Johan
PRJO	Mek		DW 500115	Fagerbekk, Knut
ALSE	El/mek		DW 453334	Farstad, Ola
ALSE	El/mek		DW 479695	Farstad, Petter
FJHA	Mek/hyd	T/O	DW 516121	Frisvoll, Andreas
ALSE	Mek/hyd		DW 461240	Gravdal, Eilif
PRJO	Mek/hyd	T/Å/O	DW 364300	Grovehagen, Håvard
FJHA	Mek		DW 455899	Hagset, Knut Asbjørn
PRJO	Mek/hyd	T/Å/O	DW 401839	Halgunset, Knut Erik
FJHA	PLS		DW 402404	Hatle, Harald
PRJO	Mek/hyd	T/Å/O	DW 422261	Haugland, Anders
ALSE	Mek/hyd	T/O	DW 500103	Haukås, Aimar
PRJO	Mek/hyd		DW 182132	Holen, Jan Robert
ALSE	Mek		DW 478620	Hustad, Åge Espen
ALSE	Mek/hyd		DW 433438	Iversen, Rune
HARI	Mek		DW 475841	Jansson, Erling
ALSE	Mek		DW 197895	Johnson, Per Otto
PRJO	El		DW A25381	Krabbesund, Roald
FJHA	Mek/hyd	T/O	DW 108031	Klokseth, Geir
FJHA	Mek		DW 502952	Krohn, Svein Erik
ALSE	Mek/hyd		DW 425868	Kvamme, Norvald
ALSE	Mek/hyd	T/Å/O	DW 282283	König, Thomas
HARI	El/PLS	T	DW 433384	Leganger, Kjell Ove
HARI	El/hyd		DW 364720	Lystad, Geir Even
HARI	Mek/hyd		DW 391560	Løvik, Jan
HARI	Mek/hyd		DW 491920	Merieau, Gregory
ALSE	Mek/hyd		DW 478634	Michaelsen, Christian
HARI	Mek		DW 438150	Mittet, Lars
FJHA	El/PLS		DW 505347	Moen, Geir Edmund
FJHA	Mek/hyd		DW 491919	Myrstad, Raymond

Figure 2 - Sample of Excel sheet (Source: NOV, 2011)

The columns ‘Navn’ and ‘DW-kode’ are the list of service engineers that NOV employs. From the left side, the first column shows the SM that is appointed to each of the service engineers. Next, the basic competence is selected together with the indicators of T/Å/O, which will be explained further under ‘Competence and work experience’. On the right, dates together with the name and duration of each job are shown in a Gantt chart. Most of the jobs have comments with information about ticket number and basic description on them. Copying and pasting jobs and aligning them in Microsoft Excel is their only aid.

The color codes indicate in which stage the jobs are at or the engineers' personal status:

Yellow	Vacation, sick leave, flexi-time (VSF)
Blue	Completed jobs
Red	Unconfirmed jobs
Green	Confirmed jobs, but not yet completed
Purple	Optional course participation
Black	Not yet hired

b) Job characteristics

In NOVs daily operations they have challenges with regards to handling resource allocation. Given customer requirements the jobs they receive have fixed starting and duration times, and requires different job skills and job experiences. When a worker first is allocated to a job it is not possible to split the job into separate intervals, but requires the job to be viewed as a whole. NOV has a pool of workers with different skills and experience. Because of this, NOV matches these workers with the same requirements the jobs have.

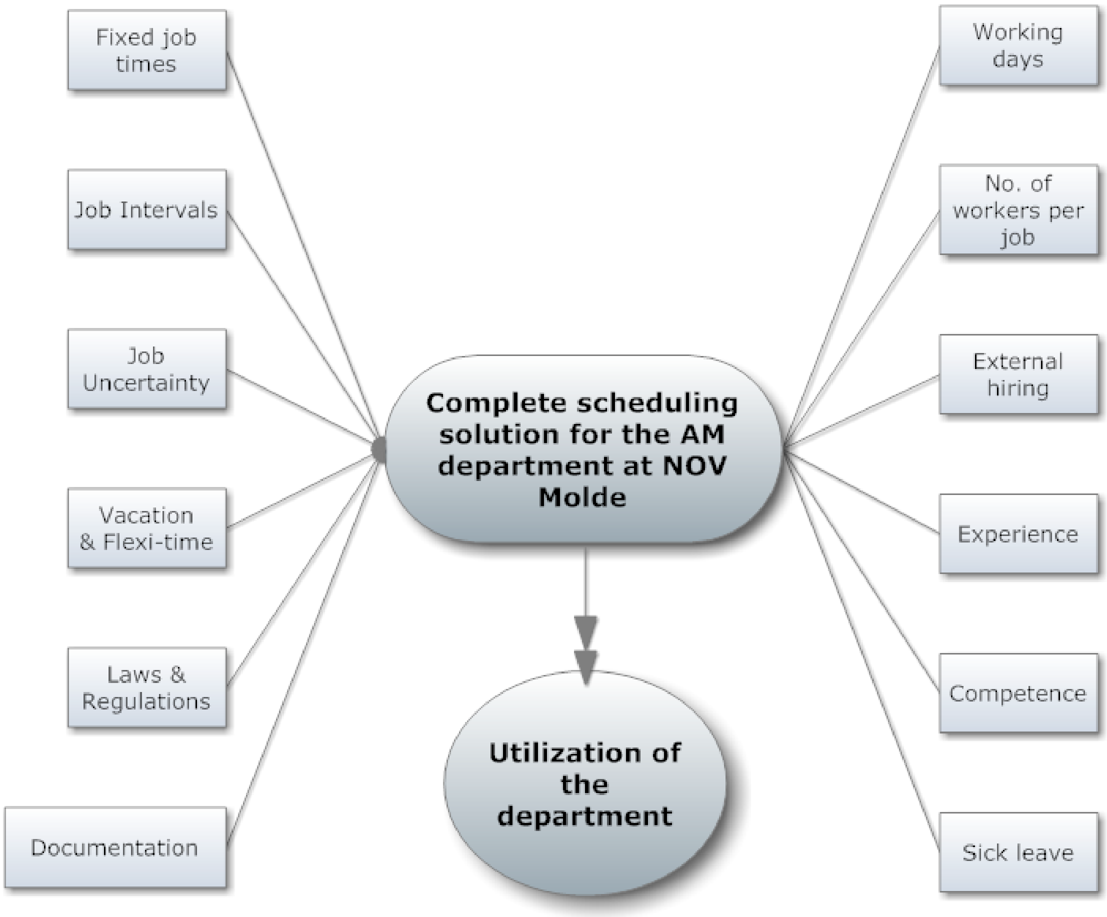


Figure 3 - Utilization elements (Self-made, 2011)

c) Vacation and flexi-time

Each year every employee is required to take some weeks of vacation. Though most workers have some periods during the summer reserved for holidays, because of the job situation vacations are often spread throughout the year. Another sort of vacation is the use of flexi-time. After working more than regular working hours, workers can take some time off at their own disposal.

d) Uncertainty

Scheduling jobs and personnel is a continuous process with changes occurring at any stage of the process. Early indications show that there is a high uncertainty involved concerning all requested jobs as they are very often either changed or delayed, while after receiving a PO the uncertainty decreases considerably. The level of uncertainty makes planning and scheduling for longer periods a challenge. Reasons for these changes are many. Because of many customers are operators of oil platforms in the North Sea, the weather may be highly unpredictable and cause unforeseen delays for all projects involved with the concerning platforms. Helicopters are not able to fly or land during harsh conditions, resulting in personnel being stationary either on- or offshore for a given time period.

The number of available sleeping barracks also may limit operations. Because of a restricted number of beds on each platform, the available space goes to the jobs and workers with the highest priorities.

At any given time there are multiple projects in process on these platforms. NOV alongside with other companies have to wait until they are given a time window for their jobs. In some cases NOV has ended up rescheduling and reserving service engineers for several weeks due to these circumstances. This decreases utilization and results in the worker missing other job opportunities.

e) Laws and regulations

When it comes to each country's laws and regulations NOV is of course obligated to follow these, and has to have the paperwork in order to be able to have access to these countries and sites. Some jobs need careful and precise planning with a time horizon of several months before the job is ready to commence. In cases, such as for Angola, Brazil and countries where NOV is doing business for the first time, this is a labor intensive process where several institutions have to be contacted to get the necessary approvals. The approvals could be of various purposes, for instance health certificates and visa.

When allocating workers to jobs NOV has certain restrictions for how much a worker is allowed to work. Even though some workers want as much work as possible, setting a certain limit for the workers is necessary for NOV. Though not exceeding such a limit, the amount of work should preferably be as close to a desired level as possible.

Especially as NOV's primary customers are within the Norwegian offshore sector, it is vital to keep track of each worker's movement and work schedule. In general each worker has a limit of 14 days to perform a job on Norwegian offshore installation. Though this restriction could in some cases be extended a few days, NOV does not have the opportunity to schedule for longer periods. After visiting an installation offshore regulations deny the worker from going offshore again until he has had a required number of days on land, also known as required rest periods. The required number of days is calculated to be ⅓ of the total number of days spent on the rig, rounded up to the nearest integer. For instance, for a job completed in 10 days a rest period of a minimum 4 days is set before the worker could perform another job.

If NOV were to try to send workers with excess amount of working hours to Norwegian offshore installations, these people would be stopped at the heliport by an external third party company and denied access to the helicopter and platform. This is done by each worker having their own unique DW-code (DaWinci), which is controlled and monitored by a company called Tieto Norway AS at each of the six heliport locations in Norway. If there are several jobs at different offshore locations the service engineers do have the ability to be moved from one rig to another without having to take the time off in between, given they do not exceed the 14 day limit.

Because of these strong and necessary regulations all documents and certificates have to be up to date. Controlling and updating these is a labor intensive and manual job where the PC has to check and locate the different documents in several sources and databases. For the Norwegian offshore sector documents referred to here are that of health certificates, OLF and competence confirmation, and international VISA and work permits.

f) Competence and work experience

With the information provided by SPOC about the jobs, the level of competence and work experience needed is known and given to the PC. The PC has to evaluate whether there are any available personnel to use matching the criteria needed for the jobs.

Service engineers at NOV are hired with different skill sets. These skills are divided into four competence categories, namely mechanics, hydraulics, electrics and automation (PLS). Most of the workers have either a combination of mechanics and hydraulics, or electrics and automation as these fields of work are most tightly connected. The documentation about the workers education and skills are stored in different places across various databases in somewhat of an unstructured way.

After filtering out employees based on their experience, NOV generally groups them into two categories, experienced and less experienced. If a worker posses a skill of either one or both start-up or yearly (O - oppstart/start-up and Å - årlig/yearly), he is classified as experienced. There is also a group called T for testing, but is not as much used. This means that for the most demanding and complex job these workers are selected. Usually there are more jobs with a higher requirement of competence available than there are people to fill these positions, which sometimes make it a challenge to NOV. On the other hand, less experienced engineers on average have fewer jobs assigned to them, because of the priority going to the more skilled personnel.

There is always a chance, when being out on a job, that engineers could face unforeseen issues which are not explained in the job description given by the customer. Through troubleshooting they may find other problems that make the job even more difficult to solve. Because of this the risk of having an inexperienced service engineer on site may result in being unable to resolve the issue within respectable time.

Though the main categories give an indication of a service engineer's work profile, much of the information regarding the decisions the PC creates are based on other factors, that are of a more personal and informal kind. The level of enthusiasm and commitment towards receiving and accepting new jobs varies highly between the service engineers, which the PC gets an idea of when communicating with each individual. Even though a service engineer has a specific skill set and experience on paper, it does not necessarily mean that he or she is able to perform the job at hand. The PC calls every one of these workers and receives a confirmation whether the person is suitable for the task at hand. Also, there are those who have all the necessary experience to handle complex jobs, but in some cases would distance themselves from those jobs that expect them to take some sort of leadership role.

There is also the issue of how much one can or wishes to work. In some cases the service manager (SM) expresses his or the personnel's concern if they are over- or under worked, given their preferences towards flexi-time. Also if a worker needs “time off” or has a vacation requests, the PC then takes this to account and tries to comply with the request.

g) External workforce

The general policy which NOV operates with is a so called “peak shaver”. Though there have been no calculations made in this area, NOV would like to have most of their engineers working continuously, and hire extras from external companies during times where demand is higher than the work force available. In these cases the PC first looks to their production site in Molde, Hjelset for experienced service engineers, before looking to external contractors. The result of hiring external contractors is then lower profit margins, but possibly lowers quality on the work being performed as these do not have the significant knowledge about the jobs as NOV employees do.

h) Factors that affect utilization at NOV

BusinessDictionary.com (2011) defines utilization as “The proportion of the available time (expressed usually as a percentage) that a piece of equipment or a system is operating”. In NOVs case it is measured by the portion of working hours performed and the works hours available. Today NOV Molde has a lower overall worker utilization than desired, especially compared to other NOV departments in Norway. Their goal is therefore to allocate the workers in such a way that the utilization of the workers is satisfying. Because of this, it is important to find the main factors that affect utilization at NOV.

To be able to confirm an increased utilization of the resources, we need a measurable indicator. Today NOV measures their utilization on a weekly basis. The service personnel’s regular working hours during a week consists of seven shifts à 6 hours, regardless of whether they work or not. To get 100 % utilization, NOV has to get paid 42 hours per week from the customer. So if in a week where a service worker does not work at all, the utilization will be zero. The utilization can actually be over 100 % for a period of time, in that sense that a worker often works seven 12-hours shifts for one or several weeks.

It is important to separate between indirect variables, which the company does not have any control over, and the direct ones. In NOVs case, there are mainly three indirect variables and two direct variables that affect the utilization. Starting with the indirect variables the issue regarding sick leave is of personal matters. Self-certification and short period medical certification are delicate matters which are difficult to deal with without going into deeper research in this area, yet they affect utilization.

Another indirect variable is that when a customer decides to reschedule or postpone jobs for various reasons. When a job is confirmed and a service engineer is selected, they avoid changing the person to another job because of the formalities they would go through again. As a consequence the job can be postponed the service engineer has to wait. Then the worker must wait until this job starts without being able to take any other jobs, which leads to idleness and the utilization negatively affected.

As mentioned in 'Laws and Regulations', after a work period at an offshore platform located in the Norwegian continental shelf, the service engineer are imposed a rest period. This quarantine is in effect as soon as the workers put their feet onshore, and the length of the quarantine is a third of the work periods total duration. Since the quarantine only is current after offshore work in Norway, the workers can work onshore in Norway and both onshore and offshore abroad during the quarantine. Because of these rest periods a worker cannot be allocated to an offshore installation and may reduce the utilization.

When it comes to the direct variables that NOV to some degree has control over, the first factor is the number of jobs coming in. Numbers of jobs coming in is dependent of requests from the customers and NOVs ability to sell services. As mentioned in 'About NOV', the demand for service jobs has increased stable during the last years, and NOV expects the growth to continue. This means that they need to increase their resources or become more efficient with what they already have. But similar to many industries there are some fluctuations in demand during the year. This is a very common situation, but is still difficult to deal with. Low demand leads to idleness for the workers and further decreases the utilization.

An element that may be essential for the utilization is the quality of resources, which also is a direct variable. If the company has a group of workers who have a lot of qualifications and experience, it is easier to allocate these workers to most jobs that commence. In the periods when demand is low, it is seldom difficult to allocate workers to jobs, but is far more difficult when the scheduling is complex.

Because of the factors mentioned earlier in the statement of problems, the allocation problem becomes highly complex with a large number of variables and constraints to consider. In NOVs dynamic and rapid changing business environment, it becomes a problem to both schedule jobs and to assign personnel to them in a satisfying way. This makes scheduling highly important as it considers all of these factors, and affects utilization to a large degree. As it is the PCs responsibility to actually control, monitor and deal with the main factors that affect utilization, the best way to improve utilization is through better scheduling.

5. Literature review

Based on the previous chapter regarding statement of problems, the literature review will put the company's situation into a theoretical context with focus on project management and scheduling theory.

a) Project management

The root of this thesis deals with the area of project management. Project management encompasses a range of literature regarding the three main parts; project planning, project scheduling, and project controlling (Heizer and Render, 2006).

1) Project planning

For a project to commence the project with it's' goals have to be defined. Defining a project includes stating which task to be done. This is usually done by work breakdown structure (WBS). This method breaks down the tasks into sub-components and even more detailed components. Then it's possible to identity all the activities that has to be finished and the related costs. To set the goals for the project, the output in forms of time, cost usage and performance have to be defined. Since these parameters are dependent of each other, choosing one or two to focus on is the best method (Heizer and Render, 2006).

2) Project scheduling

When the project has been defined and the resources selected, the project management has to schedule the project. The project management estimates how long time each activity will take, how many employees the activity needs and what equipment is needed. Then they have to sequence all the activities so they are sure that all the activities are taken into account, that the time usage for each activity is estimated, the performing order of the activities is correct and that the overall due date for the project is within its limits.

In addition to this, the management has to schedule the deliveries so that the right amount is delivered to the right time and location (Heizer and Render, 2006).

3) Project control

The project management has to control the progress of the project and monitor the resources, cost and quality of the activities. Since the project sequence and the allocated resources are estimated before project start, there is a large probability for errors in the real progress and the estimated progress. This means that the management has to make some changes in the current plan to make the project succeed. The changes to be performed might be to add more resources, and change or revise the sequencing schedule (Heizer and Render, 2006).

b) Time cost analysis

In time cost analysis, cost, time and scope are important elements.

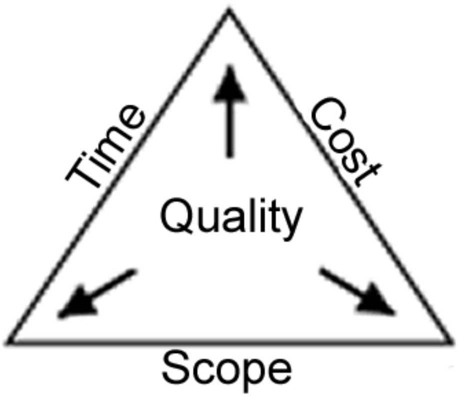


Figure 4 - The project management triangle (Source: tempdev.net, 2011)

Every project has some form of cost, time or scope constraints which can come in various forms. In terms of cost, money is usually not the only issue to consider. Also resources such as people, equipment and materials vary in importance and are to be seen as part of a budget. The time constraint deals in most cases with deadlines and completion dates, based on other factors in relation to projects. The third is known as the scope or the amount of work that has to be done. Work specification regarding activities and tasks fall under the project scope.

The project management triangle is of relevance as it balances between the three constraints and may determine the quality of the work being performed. In cases where the duration of a project has to be decreased (time), may result in higher costs or a reduction in the scope. If nothing is done to the two other elements than time, the quality may suffer. Also, if the budget decreases the results may be to reduce the scope or increase duration (time). Even though the complexity surrounding project management may be of larger dimensions the model is nevertheless relevant (Chatfield, C. 2010). The goal of using this type of analysis is to reach a cost-optimal plan by for instance allocating more resources to an activity (i.e., a higher cost input) and reducing its processing time (Brucker et al. 1999).

Because NOV is highly demand oriented, they have very little control over all of these three elements for each single job. The customer and NOV usually determine the duration, scope and the cost of each job based on previous experience and contracts, and are in many ways standardized. When looking at all of the jobs, together with the results of better scheduling, this may free up more resources and time for the company as a whole, rather than for each single job. As quality is highly prioritized at NOV and determined for each job, better scheduling does not compromise this.

c) Optimization theory

"Optimization means the mathematical process through which best possible results are obtained under the given set of conditions" (Kasana and Kaumar, 2004). In other words, from a range of available alternatives optimization is choosing the best one. In practical optimization the importance is about allocating scarce resources to the best possible effect. (Chinneck, John W., 2000)

With the growth in size and complexity in organizations on a global scale, the need for solving larger and more specialized problems has increased. From a supply chain management and logistics point of view, it has become a bigger challenge to allocate available resources to various parts of a company in a way that could benefit the company as a whole. For this, help is needed and linear programming has through the last four decades contributed to this process.

A common way of using linear programming involves allocating a limited amount of resources under the circumstances of competing activities. The goal is to arrange these activities in the best possible way, also known as optimal. According to Hillier and Lieberman (2010) *"...this problem involves selecting the level of certain activities that compete for scarce resources that are necessary to perform those activities. The choice of activity levels then decides how much of each resource will be consumed by each activity.*"

A mathematical model is in most cases a representation of a real world problem. For instance when solving linear programming problems of a real world problem, it is sometimes necessary for the solution output to be integer. In practical situations one may not be able to use such results for obvious reasons. When assigning for instance machines and vehicles to activities these may not be divided in two or more parts to perform the tasks at the same time. It is therefore a practical need for results to be of integer value. In the case of NOV's resource allocation problem, integer values are needed for both the jobs at hand and the service engineers assigned to the jobs. In other words, some or all decision variables have to be of integer or binary value.

d) Scheduling

Scheduling is an example of a decision-making problem which deals with resources and tasks, according to Pinedo (2008). The goal for this decision-making is to allocate resources to tasks and to optimize one or several objectives. There are many examples of resources and tasks. Machines and workers are commonly used as resources, while jobs and assignment locations can be examples of tasks. The objective could also be presented in many forms, such as minimizing makespan, number of workers etc.

Pinedo (2008) describes also briefly about the scheduling development over the last century. Scheduling was at the beginning of the 1900s getting more and more used within manufacturing and production. Later on, publications and papers confirmed the scheduling position as a planning method. During the sixties, seventies and the eighties, the development continued, and terminologies such as complexity theory, dynamic and integer programming and stochastic scheduling became more known.

Today, scheduling plays a crucial role in the current competitive world market, and especially manufacturing and service industries. The companies have to satisfy the customers growing demand of accurate deliveries dates and fulfillment of these may be crucial (Pinedo, 2008).

1) Traditional scheduling

According to Spieksma (1998), in traditional scheduling the starting times is indeterminate on each job. This gives the scheduler more freedom to create the sequence of jobs. The goal for these problems is to measure the performance of the resources and find the optimal solution, all this within some set of constraints. Examples of measurements that can be used are minimizing total makespan for all jobs, number of machines or workers used, and the total exceedance of due date.

2) Interval Scheduling

Spieksma (1998) states that in interval scheduling, both job start time and job lengths are decided in advance. The only decision variables are with regards to which and the number of resources to be allocated to the various tasks. Some companies have the ability to “pick and choose” jobs, based on the profit they receive for each job. By doing business in such a way they only choose the jobs with good margins (or within a certain limit), and reject the jobs with bad margins. The limit for the “pick and choose” may vary, dependent on how the market is and how the economics of business is.

Some companies may have a policy to accept all jobs, or they can for example take all the jobs for a special customer. The reason for such a behavior might be the fear of losing customers or contracts signed with the client, says Spieksma (1998).

3) Shift in trend

In the later years the trend has shifted in scheduling from traditional scheduling to interval scheduling. Traditionally scheduling was known to be resource oriented logistics and a supply based approached for production. This was a production strategy where resources set the premises for the production level and completion time of the jobs.

According to Spieksma (1998), this new trend represented by interval scheduling is referred to as demand oriented logistics. This is a demand based production strategy, where the demand of jobs set the premises for the planning. The job starting time and length is almost determined, and the needed resources must be allocated thereafter.

Causes of this new trend may be many, but some main reasons stand out. The first reason is that the requirements from customers are constantly increasing, and the companies struggle to follow up. Because of the dedicated aim to always satisfy the customer, and the increasing competition in the world market, the results are that many continuously try to improve their business. This means that customers now play a larger and more important part for the businesses than before. As a result it has led many to become more influenced by their customers when planning, states Spieksma (1998).

In some cases, one of the advantages with the new trend is that the customers push to adjust deliveries more to their own production strategy. This improves predictability for their own production. The same change causes the company to deviate from their optimal production strategy in order to adapt to the customer. This new scenario with customers controlling companies' supply chain differs from earlier, as when companies where planning with their own supply chain unaffected. This of course depends on the industry and the different distribution of power in the supply chain.

Where companies need to add jobs as fixed deals, there is less room for change than if they had solved the problem with traditional scheduling. This also means that resources must be more dynamic. Spieksma (1998) states that traditionally the issue was usually whether the job fits the available resources. The trend has now shifted towards accompanying customers requests given a fixed job time (determined by the customer), almost no matter what. This is highly the current situation within the oil industry. With the uncertainty this brings along, a company might then need a larger workforce than before to man the jobs of the given dates. The challenge is to exploit the workforce in a satisfying manner.

All interval scheduling problems is based upon basic structure for scheduling problems. The objective for these problems is usually to minimize the number of resources used. There are also several limitations that have to be taken into consideration. The two most important limitations deal with resources not having the ability to accept more than one job at the time, and do not have the ability to split a job between two or more resources.

Though the above is a basic structure for this type of problem, most problems in the industry are different, and therefore various features are added to satisfy the various needs. An example is the interval scheduling problems where the objective is to minimize cost, given that all jobs are scheduled. Another problem described is where the number of machines is fixed. There is the pay per job completed, and the goal is to maximize profits.

4) OFISP - several machine and job classes

Leo, Salomon, Van Wassenhove (1993) has formulated a model, explained in the following pages, that is similar to the problems in NOV. This problem is called Operational Fixed Interval Scheduling Problem (OFISP) and is characterized with a fixed starting time, fixed finish time, a job class and priority index. The objective function expresses the maximum total value of the outcome from the priority index. The fixed starting and finish time determines the duration of the job, as mentioned earlier. A job class is a pool where all jobs are categorized in subsets.

The problem is complicated by the fact that each machine only can do one job at a time. For job class, each machine can perform one or more specific jobs from the different subsets, what job each machine can perform is predetermined. Preemption is not allowed in OFISP.

What separates OFISP from NOVs problem is that NOV does not have any form of priority index in their jobs, in the context that the importance of the jobs are more or less equal.

The OFISP-model is as follows, directly copied from the article published by Leo, Salomon, Van Wassenhove (1993) in '*Exact and approximation algorithms for the operational fixed interval scheduling problem'*.

Here we assume that there are C different machine classes, and A different job classes, where each machine class is allowed to handle jobs from a limited number of job classes. Each job j belongs to a certain job class a_j. For $c = 1,...,C,$ the integer M_c represents the predetermined number of machines in class c. Furthermore, α_c is the set of job classes that can be carried out by machines in machine class c. For $j = 1,...,J$, the set ℓ_j consists of all machine classes that can be used for carrying out job j. Mathematically, OFISP can be formulated as:

(1) $Z_{OFISP} = \max \sum_{j=1}^{J} \sum_{c \in \ell_j} p_j x_{j,c}$

(2) $\sum_{\{j | a_j \in \alpha_c \wedge s_j \leq t_r < f\}} x_{j,c} \leq M_c, c = 1,...,C; r = 0,...,R,$

(3) $\sum_{c \in \ell_j}^{J} x_{j,c} \leq 1, j = 1,...,J,$

(4) $x_{j,c} \in \{0,1\}, j = 1,...,J; c \in \ell_j,$

Where $X_{j,c}$ is a binary decision variable, indicating whether job j is assigned to a machine in machine class c ($j = 1,...,J$, and $c \in \ell_j$.).

The objective function (1) states that we look for a feasible schedule for a subset of jobs with maximum total value.

Constraints (3) and (4) guarantees that each job is assigned to at most one machine class at the time. Furthermore, constraints (2) ensure that at any point in time the total number of jobs assigned to machine class c does not exceed the number of machines available in machine class c.

6. Method

After a series of interviews and observations we narrowed the focus to more directly into the resource allocation problem. Through analysis of the current processes we found the theoretical background in scheduling and project management theory. The model to Leo, Salomon, Van Wassenhove (1993) was not suitable and did not fit NOV's problem directly. In order to solve NOV's problem we propose a new model, presented in the next chapter. By using mixed integer programming in the language of AMPL, we ran it through a CPLEX solver and were able to achieve feasible solutions.

7. Mathematical formulation of the problem

In this chapter a mathematical formulation of the resource allocation problem in NOV will be presented.

a) Mathematical model

Formulation: **AMPL names:**

(1) $\min \sum_{w \in W} (Z_w + Z_w P)$ NumberOfWorkers

st

(2) $\sum_{j \in J | S_j \le t < F_j} X_{wj} \le 1, w \in W, t = 1, \ldots, T_{\max}$ MaxJobsAtATime

(3) $\sum_{w \in W | H_w = G_j \& E_w \ge C_j} X_{wj} = R_j, j \in J$ RightQualifiedWorkers

(4) $Z_w \ge X_{wj}, w \in W, j \in J$ LinkingConstraint

(5) $\sum_{j \in J} X_{wj} D_j \le M, w \in W$ MaxWorkDays

(6) $X_{wj} \ge 0; Z_w \ge 0$

b) Notation

Sets:

J – a set of Jobs

W – a set of Workers

T – a set of time (days)

Parameters:

D_j = Duration time for job j, $j \in J$ durationDays {JOBS}

S_j = Starting time for job j, $j \in J$ startDate {JOBS}

F_j = Finish time for job j, $j \in J$ finishDate {JOBS}

G_j = Required job skills for job j, $j \in J$ jobQual {JOB}

R_j = Number of workers required for job j, $j \in J$ workersReq {JOBS}

H_w = Work skills for worker w, $w \in W$ workerQual {WORKERS}

E_w = Work experience for worker w, $w \in W$ workerExp {WORKERS}

C_j = Work experience for job j, $j \in J$ jobExp {JOBS}

M = Max working days during period

P = Penalty cost for hiring external workers penaltyCost{WORKERS}

Variables:

X_{wj} = 1 if worker w is allocated to job j, 0 otherwise,

$w \in W, j \in J$ Allocated {WORKERS, JOBS}

Z_w = 1 if worker w does any job in this time period, 0 otherwise,

$w \in W$ WorkerUsed {WORKERS}

c) Objective function

In this model the goal is here to minimize the total number of workers used both from NOV and external contractors. To maximize each worker's utilization more jobs will be allocated to fewer people.

$\min \sum_{w \in W} Z_w$ is for minimizing the number of workers which NOV already is employing. By adding a penalty option for external contractors we minimize these by setting $\min \sum_{w \in W} Z_w P$ as a parameter.

This results in the following:

(1) $\min \sum_{w \in W} (Z_w + Z_w P)$

d) *Constraints and limitations*

Constraint (2) expresses that at any point in time, a worker can be only be allocated to a maximum of one job at time. This uses the inequality constraint that X_{wj} cannot be larger than 1 and is not binding.

Within the constraint the F_j parameter consists of several other parameters including the following:

	AMPL names
O_j = 1 if it is an offshore job, 0 otherwise, $j \in J$	offShore {JOBS}
$A_j = roundup(O_j * D_j * (1/3))$ = Required time off after job j if the job is offshore, $j \in J$	addOffshore {JOBS}
$F_j = S_j + D_j + A_j$ = Finish time for job j, $j \in J$	finishDate {JOBS}

As shown, A_j takes effect only if a job is offshore (in Norway) or not setting the rest period to 1/3rd of the jobs duration, rounded up to the nearest integer value. The finish time (F_j) then consists of the start time, the duration, and in many cases the offshore addition.

The constraint (3) guarantees that we have the required amount of workers with the right skills and experience for each job. The equality constraint sets the value to be no other than R_j and is binding, restricting against other alternatives.

The constraint (4) is a linking constraint telling if a worker is doing any job at all. The constraint is always true whether a worker is allocated to a job or not.

For each worker the total number of working days cannot exceed a given amount of the total working period and is expressed in constraint (5). M works as an upper bound for the number of days for each worker is on a job during the given time period. In AMPL the problem is modeled with VSFs technically defined as jobs, and has to be subtracted from the constraint. The new parameter is added:

V_w = Total number of vacation/sick leave/flexi time (VSF) days during period.
AMPL name: totalVac {WORKERS}

Constraint (5) then becomes:

$$\sum_{j \in J} (X_{wj} D_j) - V_w \leq M, w \in W$$

Because, as mentioned with the parameter V_w in constraint (5), V_w is technically defined as jobs. The AMPL- model contains fixed restricted intervals for the VSFs where worker w cannot take other jobs than the VSF interval which are predefined in the data. This is written in the following way:

$$X_{wj} = 1$$

For instance:

$$X_{WORKER1,VSF1} = 1$$

By enforcing the restriction of constraint (6), negative values cannot exist in a solution.

8. Data collection

In order to run the above model we needed to collect the data and the following chapter will discuss the approach.

As mentioned in “Statement of problems” an Excel spreadsheet has been the basis for planning the allocation of service personnel for some time. Most of the information and data they use to plan and schedule is located in this file. Historical data about completed jobs, vacations, courses etc. are also stored here. Figure 2 is a screen capture of how the information is located and organized through sorting and filtering options. Because of this the data used in this thesis has come from this source.

Some data characteristics explained for use in the mathematical and AMPL model:

Service engineers:

Data concerning service engineers are given by five parameters. These are the (1) *names*, which (2) *skill* they posses, the level of (3) *experience*, the total number of days on (4) *vacation / sick leave / flexi-time (VSF),* and if they are hired (5) *externally*.

Jobs:

For the jobs there are seven parameters inputted. As there are usually several jobs from each customer every job has a unique (1) *name* starting with the customers’ name ending with a number so it easily can be identified and fit the model. The (2) *start date* is set to be the date before the job actually begins, for modeling purposes. How many whole days the job needs is added in (3) *duration.* Other than these, each job has a need for the right (4) *qualification* and (5) *experience*. The job parameters also need input about whether it is (6) *offshore* in Norway or not, and the number of (7) *workers* needed with the same level of experience and skill set.

Vacations, sick leave and flexi-time (VSF):

In the original data Gantt chart vacations, sick leave and flexi-time are seldom kept apart by any indicators. As explained in ‘Statement of problems’ the yellow marked fields capture all of the three categories where the service engineers are reserved from working.

There are no records of when these VSFs were requested or if they were movable. Therefore they are static in the sense that the service engineers are not available during these periods. For technical matters in AMPL VSFs are defined as jobs with the same parameters.

a) Sample selection

To test the developed model we have chosen to input data from two separate cases which consists of a 45-day-time period on both. To incorporate regular working day restriction explained in 'laws and regulations' we found the job with the longest duration to incorporate this restriction. Looking at the data file for Case 1 in Appendix C, Gazflot3 has duration of 31 days and consequently setting the time horizon to be 45 days. By using the numbers 1-45 the model became a lot more manageable rather than applying the use of actual dates.

Case 1 contains historical data from 1st of May 2010 till mid-June, while case 2 starts at the 1st of September and ends 45 days later in mid-October. These months are one of the most challenging with regards to the number of completed jobs to schedule during the year of 2010, and therefore considered good candidates for testing the model.

Given the 45-day time horizon some jobs are "cut off" as they have a start date before day 1 or end later than day 45. Yet the data set contains parts of these jobs during the time they are within the time horizon. No historical data other than this set is included in the model.

b) Case 1 data structure

The following tables will give an overview of the distribution of experience and skill sets in the data set, for both the workers and jobs. The reason for this is to get an indication of the capacity and demand requirements needed to perform the jobs. This could give a quick insight to whether there is shortage in or excess worker capacity. For instance if there were to be a far greater number of mechanical jobs than electrician ones, the same should apply for the number of workers needed with the same skill sets.

CASE 1										
					Distribution in percentage				VSF	
		Experience				*Experience*				
SE		Less	More	Sum		Less	More	Sum	Days	
	Mech	33	14	47	Mech	55,0 %	23,3 %	78,3 %	548	77,1 %
Skill	EL	11	2	13	EL	18,3 %	3,3 %	21,7 %	163	22,9 %
				60		73,3 %	26,7 %	100,0 %	711	
		Experience				*Experience*				
Jobs		Less	More	Sum		Less	More	Sum		
	Mech	70	23	93	Mech	61,9 %	20,4 %	82,3 %		
Skill	EL	17	3	20	EL	15,0 %	2,7 %	17,7 %		
				113		77,0 %	23,0 %	100,0 %		
				Days						
Vacation / Sick / Flexitime (VSF)				711						
Total days available				2700						
Percentage of total days restricted*				26,3 %						
Duration job days				1068						
*not including offshore work restriction (1/3)										

Table 2 – Case 1 data structure (Self-made, with data from NOV, 2011)

Table 2 shows the overview over the distribution over the skills and the experience the different service engineers and jobs have. Starting with the upper second column, the figures shows that there is an overweight of mechanical skills among the service engineers. For the experience, there are almost three times as many workers with *'less'* experience than compared to '*more'* experienced workers.

Lower second column shows the same figures, but now for jobs. The figures shows that the distribution for jobs are similar to the distribution for service engineers, with an overweight of mechanic skilled jobs and jobs requiring '*less'* experience. Overall it seems like the distribution between available service engineers and the amount of incoming jobs are fairly even and this is for both experience and skills.

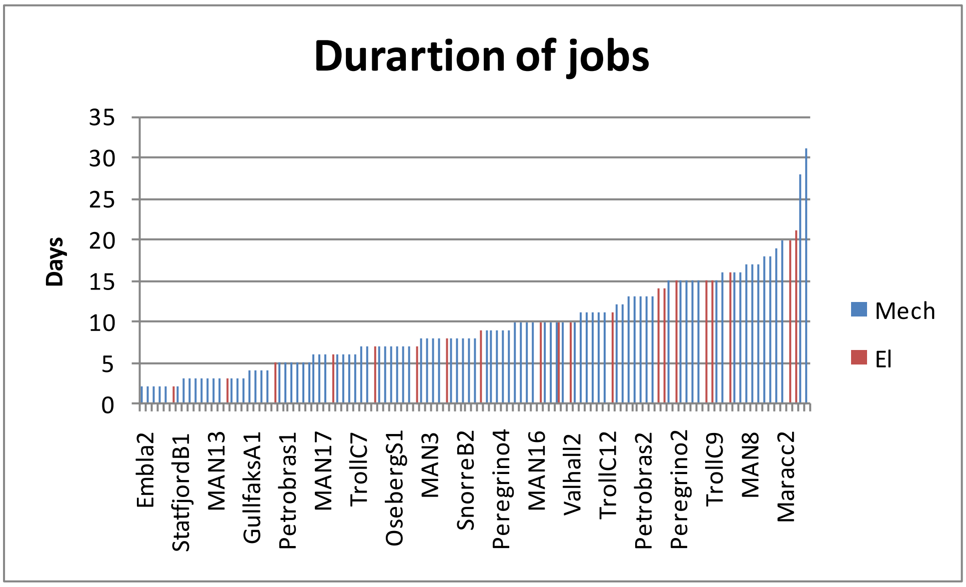


Figure 5 - Case 1 duration jobs (Self-made, with data from NOV, 2011)

Figure 5 indicates that the duration of the jobs is fairly linear, both for 'Mech' and 'EL'. This meaning that the variation in length between the jobs is evenly distributed in the data set, and gives an average duration of 9.45 days per job.

A service engineer is restricted from accepting a job during the yellow marked areas on the spreadsheet, indicating that he is either on vacation, sick leave or using part of his flexi-time (VSF). In case 1 this accounts to a total of 711 days out of 2.700 available working days (60 workers * 45 day time horizon). This means that 26,3% of the given time period is already restricted from being able to accept jobs, and workers cannot be allocated.

c) Case 2 data structure

With the same group of service engineers, the distribution is very similar as monitored in Case 1 data structure. There is still an overweight of skilled mechanics, and more '*less'* experienced workers than experienced ones. The same distribution is current for the jobs.

The only parameter that changes for these is the total number of days they have on VSF, which reduces with approximately 5 percentage points.

Table 3 gives an overview:

CASE 2										
					Distribution in percentage				VSF	
		Experience				*Experience*				
SE		Less	More	Sum		Less	More	Sum	Days	
	Mech	33	14	47	Mech	55,0 %	23,3 %	78,3 %	460	81,7 %
Skill	EL	11	2	13	EL	18,3 %	3,3 %	21,7 %	103	18,3 %
				60		73,3 %	26,7 %	100,0 %	563	
		Experience				*Experience*				
Jobs		Less	More	Sum		Less	More	Sum		
	Mech	59	17	76	Mech	61,5 %	17,7 %	79,2 %		
Skill	EL	20	0	20	EL	20,8 %	0,0 %	20,8 %		
				96		82,3 %	17,7 %	100,0 %		
				Days						
Vacation / Sick / Flexitime (VSF)				563						
Total days available				2700						
Percentage of total days restricted*				20,85 %						
Duration job days				980						
*not including offshore work restriction (1/3)										

Table 3 - Case 2 data structure (Self-made, with data from NOV, 2011)

Figure 6 gives the same indicates that the duration of the jobs is fairly linear and evenly distributed amongst the jobs, both for ‘Mech’ and ‘EL’. A few more jobs with a longer duration, but the tendency are the same. This gives an average duration of 10.21 days per job.

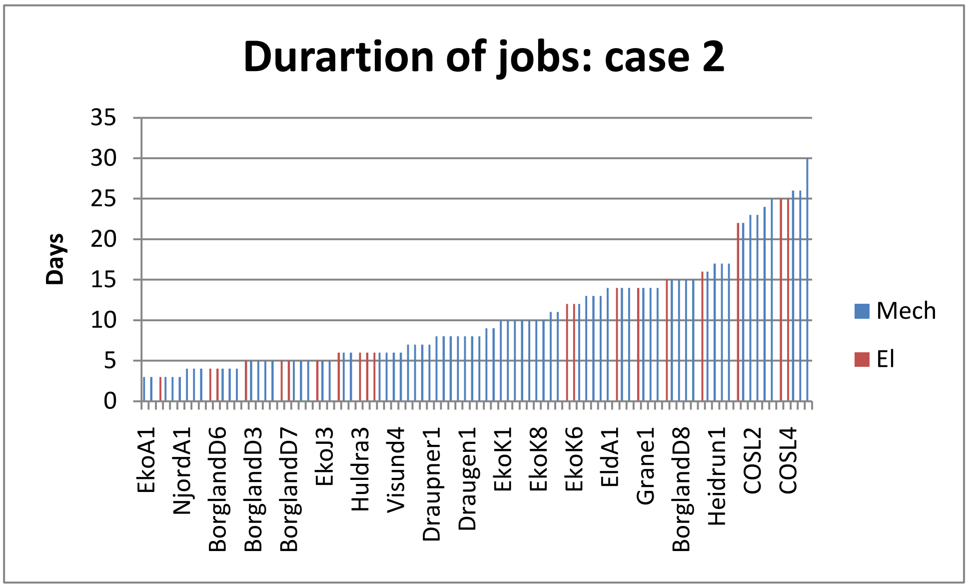


Figure 6 - Case 2 duration jobs (Self-made, with data from NOV, 2011)

d) Parameter values set in the model

The model formulated in chapter 7 contains several parameters needed to run. The three parameters offshore restriction, work restriction and external hiring are to be explained further.

Offshore restriction:

Constraint (2) contains the offshore restriction and is set to be 33.3% of the given time on an offshore job in Norway. This means that no scheduling can be performed in one-third of the time after being on an offshore platform in the North Sea, regulated by the Norwegian government.

Work restriction:

The work restriction sets the upper bound for how much a service engineer is allowed to be at work for NOV during the 45-day-period. As constraint (5) in the model uses number of days a worker is on a job, the number of hours worked and utilization is not exact. From the original historical data set in case 1 (data for case 1 Appendix B) the highest number of days worked by any employee is KrabbesundR with 39 days. By our utilization measure this calculates to be 173,3%, and is too high to be used as a limit for the model from our point of view. By setting the restriction a bit lower the model still is flexible enough to allow high utilization in cases where this is possible.

Setting the limit to 34 days gives an utilization of 151,1%, this is the closest number of days to get 150%. Though this may be a high percentage, most workers are unlikely to be allocated to as many jobs as this. For NOV this number is somewhat flexible as there are those whom want the opportunity to work a lot.

External hiring:

In the objective function, by setting the value of the parameter of external hiring larger than zero the constraint serves this purpose. As the objective function is to minimize the objective value ‘penaltyCost’-parameter as a part of it, any value of the parameter larger than zero will do. In these data sets the value has been set to 1 000.

9. Results and analysis

The following chapter will discuss and give a short analysis about the results and compare the original solutions with the two model cases.

a) *Original solution: Case 1*

To see if the model can prove to give a lower count of workers, a comparison to the original solution is needed. From the *original* solution by NOV, as shown graphically in Appendix B, the results are as follows with a description below:

Case 1: Sample of the original solution from NOV									
Workers		**Jobs**			**Duration (days)**				**Work Utilization**
No.	Name	J1	J1	J3	J1	J1	J3	Sum Duration	
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
55	VikasO	Man2	TrollC9		10	15		25	111,1 %
56	VollanL	Bidefjord1	EckoA1		3	10		13	57,8 %
57	VorpenesS							0	0,0 %
58	AandalD	GullfaksA4	Fjord1	TrollC16	7	1	4	12	53,3 %
59	AasE	Oseberg1			2			2	8,9 %
60	AaseggM	Man18	NjordA4	TrollC22	4	8	6	18	80,0 %
						Sum Total		1071 days	**88,1 %**
						Count workers used:			**54**

Table 4 - Sample case 1 original solution (Self-made, with data from NOV, 2011)

Table 4 is a sample of the original solution which lists the workers on the left side followed to the right by the jobs (1, 2, 3 etc.) and the duration of these. The column 'Work Utilization' shows the workers which have at least one job assigned to them and then calculates the average for the working service engineers in total.

54 of the 60 service engineers located in the data set are used. Though there were 60 workers at the end of the year, six of these were not hired before or during the time period of this sample. 3 of the 54 were hired at day 31 (31st May) to increase capacity, including Steinar Vorpenes as seen in table 4 above. He was not allocated to any jobs during the remaining period that followed his employment.

The original solution from NOV shows an overall utilization of the workforce to be at 88.1%, and is the element which the model is designed to increase.

b) Model solution: Case 1

As our main goal for this thesis is to improve the utilization of service engineers at NOV, the model has done so by reducing the number of service engineers given the fixed number of jobs. Running the model through AMPL and CPLEX the solution is outputted and shown in Appendix A with the following utilization sample from Appendix B here:

Case 1: AMPL solution											
Workers		**Jobs**				**Duration (days)**					**Work Utilization**
No.	Name	J1	J1	J3	J4	J1	J1	J3	J4	Sum Duration	
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
51	TaftesundT									0	-
52	TautraK	SnorreB3	StatfjordB4			9	11			20	88,9 %
53	VarhaugvikA	Gazflot2	GullfaksA3	MAN5	TrollC15	7	2	12	6	27	120,0 %
54	VikenR	MAN22	Maracc2			7	20			27	120,0 %
55	VikasO									0	-
56	VollanL	EkoA1	MAN20			10	11			21	93,3 %
57	VorpenesS	TrollB4				5				5	22,2 %
58	AandalD	Kristin	OsebergD2	SnorreB1		3	5	8		16	71,1 %
59	AasE									0	-
60	AaseggM									0	-
								Sum Total		1068 days	**98,9 %**
										Count workers used:	**48**

Table 5 - Sample case 2 model solution (Self-made, with data from NOV, 2011)

As the sample gives an indication of, the jobs are allocated to fewer service engineers, giving the total count of workers used to be 48. The overall utilization of the workforce then increases to 98.9%. This gives an increase of 10.8 percentage points in utilization, with 6 fewer workers.

c) Analysis: Case 1

By performing a comparison of the two solutions when it comes to distribution of utilization, there are several aspects to consider, and will be discussed in the following paragraphs. Figure 7 shows the comparison.

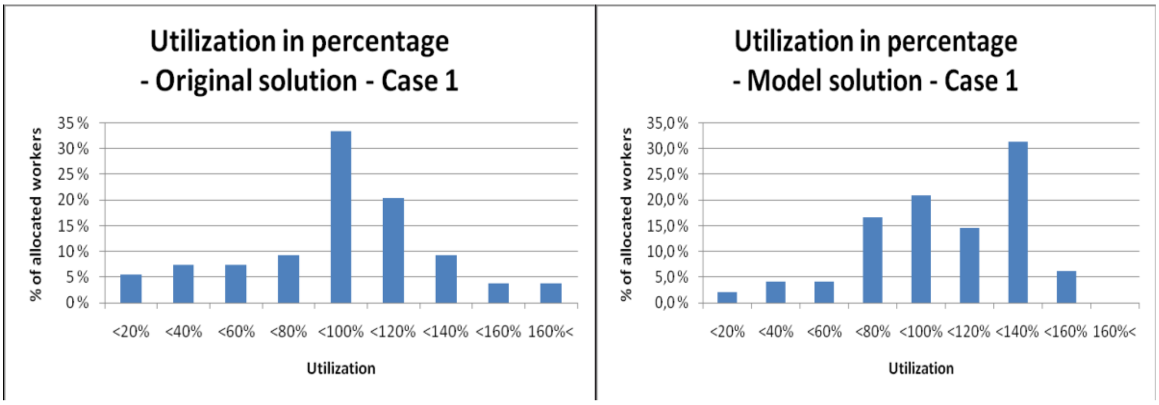


Figure 7 - Case 1 utilization distribution (Self-made, with data from NOV, 2011)

As the AMPL solution illustrated for case 1 in Appendix C, there are six fewer workers being allocated to the jobs. Leaving these out of the comparison the figures above show the distribution of utilization on between the remaining workers with jobs assigned to them during the time horizon. Reading the figures; the first column on the left consists of workers with less than 20% utilization but higher than 0% (0%< X < 20%). The next column "< 40% " consists of the group between 20% and 39% (20 <= X < 40) etc.

Though most of the workers in the original solution located around 80% - 119% of a working schedule, over 20% of their active workforce has less than 60%. On the other extreme point 7% work more than 36 days which accounts to reaching 160%. Though going into specifics may not be very relevant in this case, due to data history which will be discussed in the validity Chapter 10, the importance may be to understand the main changes in distributions in the solutions.

The model solution reduces the "extreme" points and pushes the workers to maximize their utilization. As the model restricts the use of more than 151%, no worker exceeds this value. Also, most of those whom have had low utilization from the original solution were either given more jobs or not used at all.

d) Original solution: Case 2

The original setup of jobs is illustrated in Appendix A, and a sample of the utilization from Appendix B results follows from the original solution:

Case 2: Sample of the original solution from NOV									
Workers		Jobs			Duration (days)				Work Utilization
No.	Name	J1	J1	J3	J1	J1	J3	Sum Duration	
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
53	VarhaugvikA	Peregrino1			23			23	102,2 %
54	VikenR	Visund4	EldA2		6	24		30	133,3 %
55	VikasO	COSL4			25			25	111,1 %
56	VollanL	EkoK8	SleipnerA3		10	17		27	120,0 %
57	VorpenesS	MaerskG2	EkoJ3		5	5		10	44,4 %
58	AandalD	StatfjordA2	OsebergC3		6	10		16	71,1 %
59	AasE	OsloH1			12			12	53,3 %
60	AaseggM	NjordA1	JotunA1	BorglandD9	3	4	5	12	53,3 %
						Sum Total		975 days	**76,0 %**
							Count workers used:		**57**

Table 6 - Sample case 2 original solution (Self-made, with data from NOV, 2011)

The number of workers used from September till mid-October were counted to be 57. One of these 60 service engineers in the data set were not employees of NOV during that period, and one was hired at the end of September.

The original solution from NOV shows an overall utilization of the workforce to be at 76.0% and is a dramatic decrease from case 1 which was at 88.1%.

e) Model solution: Case 2

Case 2: AMPL solution									
Workers		**Jobs**			**Duration (days)**				**Work Utilization**
No.	Name	J1	J1	J3	J1	J1	J3	Sum Duration	
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
54	VikenR	Grane1	Verksted1		14	15		29	128,9 %
55	VikasO	COSL3			25			25	111,1 %
56	VollanL							0	-
57	VorpenesS	StatfjordC1	Verksted3		10	9		19	84,4 %
58	AandalD	EldA2			24			24	106,7 %
59	AasE	Maracc2	StatfjordA1		22	6		28	124,4 %
60	AaseggM							0	-
61	EXT_MEK1	COSL1			30			30	133,3 %
						Sum Total		988 days	**91,2 %**
							Count workers used:		**49**

Table 7 - Sample case 2 model solution (Self-made, with data from NOV, 2011)

Table 7 shows a dramatic increase in the utilization when running the model. From 76.0% to 91.2% the solution uses only 49 workers compared to the original 57.

There has though been added a service engineer on the bottom of the list, worker no. 61, EXT_MEK1. This means that the model needed to use an external contractor to be able to get a feasible solution. Even though there was no need for additional workers in the original solution, the model has not been able to solve the problem by only using the available resources. Reasons for this will be discussed in Chapter 12 'Recommendations and future work'.

f) Analysis: Case 2

Comparing the two cases 1 and 2, there is a large difference in the overall utilization in the original data sets between the two. As mentioned it goes from 88.1% to 76.0%. The main reason for this the number of jobs received during this time period. From 113 jobs in case 1 to 96 in case 2, this is a reduction of 15% and causes a reduction of more than 8% in days being allocated. With the duration of each job increasing slightly as well, as shown and discussed around figure 6, it has a direct influence of the overall utilization.

10. Validity and Reliability

Having seen the results of the model it is now appropriate to discuss the validity in relation to the applied methodology.

Most of the issues with regards to validity have to do with the data used. Especially when it comes to the skills required and the experience needed to perform jobs, the data sets do not contain all of the options a worker or job has in real life skill sets. As mentioned in 'Competence and work experience' in Chapter 4 most of the workers posses a combination of either mechanics and hydraulics, or electrics and automation (PLS). There are a couple of service engineers that for instance have electrics and mechanics, or electrics and hydraulics. Even so, each worker has what is known a primary and secondary skill. Because of this, the data used comes mainly from the primary skills leaving either mechanics or electrics left.

A job from a customer may require a service engineer with hydraulics or PLS background and would then, in the data set, be converted into mechanical or electrics. This simplification is based on the presuppose that the problem would be easier to model and formulate in AMPL. Only a few jobs require hydraulics or PLS, but not all of the workers with mechanical or electrician skills can perform these.

Determining if a worker is able to perform the tasks required of him for a certain job is very difficult. Because of the lack of competency records the PC has to telephone each person to confirm whether or not he can perform the job described by the customer in the job pack. Even though it seems that a mechanical job can be performed by any service engineer with a mechanical background, there are some instances where this may not be the case, due to special circumstances. Because of this uncertainty the simplification to disregard this issue has been made, allowing every worker with the same skill as the job to be allocated to it without further ado.

When dealing with large amount of data and manual labor, some input errors are usually made. In the table 2 there is a deviation of 3 days in the first data set and in the second data set 13 days. But because of the large number of days used in these sets both errors only result in 0.2% variation from one another.

When it comes to the model and data set, because the model does not consider historical data, jobs with start dates before day 1 in the time period are not fully included. Nor are the jobs with finish dates later than day 45 as explained earlier. As a result a truly correct use of the work restriction becomes difficult. Though from a practical point of view, all of the jobs which had started before day 1, these jobs would not have needed to be considered. From a theoretical point of view we found it necessary to add them because of the large number of them.

In this thesis the model has been run twice using two different data sets. To test the most demanding scheduling instances, both these cases contain the largest number of jobs periods during 2010. Running the model in both cases, the results conclude the same and confirm our goal; fewer workers are needed with all constraints in bound. Because the periods used contain the vast amount of jobs, the model is also reliable using data from periods with fewer jobs.

11. Discussion and limitations

The most important results the model has provided have shown that NOV could improve their overall utilization by using fewer workers to conduct the jobs. Or seen in a different way, NOV could increase their capacity to be able to heighten sales and handle a larger number of jobs with the same number of workers. This could be a highly important contribution as the possibilities of saving time and resources are considerate. With more control barriers in place, such as offshore and work restrictions, for the PCs these are some of the variables they continuously do not have to think about any longer.

Based on figure 3 the model incorporates most of the factors which are necessary to perform scheduling in NOV's AM department. Though not able to incorporate all of them, the model gives a fairly realistic picture of the situation. The factors which are not included are that of document handling and job uncertainty. When it comes to document handling it is difficult to link various documents to get validation of different skills, visa, health certificate etc. and cross check these against the model automatically. The option to exclude workers based on insufficient documentation would improve the PCs productivity.

Because of the rapid developments when dealing with incoming jobs, the model has to adapt to small and continuous changes. Unfortunately the model does not take this into too much consideration. All jobs which are not locked to a specific worker may be scheduled differently when running the model. The practical implications this may have from a practical standpoint, is that when a small change is made in the data set the model is most likely to completely generate a new solution. This is both the strength of the model and its' weakness, and must be taken into account when used in practice.

Despite the fact that the output from our model results in a better solution than the original one, it is not given that this is the optimal solution for NOV. The objective function in our model is to use the minimum number of workers, given the jobs at hand. If demand varies a lot over a period of time, NOV cannot hire or fire employees on a month-to-month basis. This is why the present model at this point would be appropriate to use as an allocation tool, and not a necessarily a strategically decision maker for the long term.

Though there has been little research in this industry on this subject, interval scheduling is a well known and applied method for arranging tasks together with resources. When it comes to *fixed* interval scheduling the specific OFISP-model, which the presented model is based upon, we have not found similar examples which could fit NOV's problem description.

12. Recommendations and future work

In this thesis it is important to separate between what NOV- and what the model could improve when it comes to allocating resources in a more efficient way.

a) Recommendations for NOV

1) Reservation time

As explained in 'Processing jobs' under 'Statement of problems' a worker is allocated and locked to a job as soon as the PCs find a suitable match. This means that even though it is three, four weeks etc. until jobs start, specific personnel may already be reserved. When the time comes closer to the start date of this particular job it sometimes becomes difficult for the PCs to optimize the scheduling. This is because of the restriction they put on themselves locking service engineers to a job long time before the start date of the job, and so that workers are not able to take other jobs. This lowers utilization. Especially during peak periods they sometimes have to unlock and re-allocate a large number of workers to be able to reach a feasible solution. Because of this situation, and the influence it has on the utilization and the PCs daily work, it should be easier finding good feasible solutions both with and without the model, if the workers were not reserved for a longer period of time than necessary. The planning time before start date may vary from job to job, especially when dealing with VISA to foreign countries (long) or casualties (short). Also each service engineer is used to and expected to deal with the fact that they sometimes can be telephoned and asked to leave for a job on a short notice. This is in their job description. This shows that it should not be too big of a problem to use shorter terms for scheduling jobs, neither for NOV nor the service engineers.

2) Competency

The number of skills and experience levels each worker can posses is limited to two options each. By allowing combinations of several options it increases the complexity of the problem, but though more realism.

Knowing the service engineers and which skills they posses is vital for keeping up with the quality and service NOV is known to offer its' customers. As briefly mentioned in 'Competence and experience' under 'Statement of problems' the level of documentation regarding this issue is at the moment fairly unstructured. When dealing with 60 service engineers, a good overview of which tasks each worker can perform, is needed. This is especially required by the model which needs skills defined, grouped and separated quantitatively. For the model to ensure reliability, the data has to be accurate and up-to-date.

NOV is in the developing stages of improving their competency base, enabling them to group workers into different levels. To get an overview of the current competence, NOV can perform tests to state this. This could be both theoretical and practical tests performed by NOV themselves.

3) Historical demand analysis

At this time there has been no research into measuring the distribution of incoming jobs over a period of time in NOV's AM. With the ability to output an overview of the number of incoming jobs and comparing them to available company resources, comes great insights into what they are capable of handling. In periods that are expected to be low on demand, the SPOCs could be given incentives to increase sales of services during these times.

Also having the option of sorting jobs based on skills required may form a basis for better forecasting. Having such a tool may help balance the available resources and the usage of them, which could result in a more clear policy behind the utilization goals.

4) Graphical representation

For the model to become a usable application for NOV, the need for graphical visualization, some programming adjustments and most likely some heuristic algorithms is required. For the PCs to efficiently view and allocate jobs manually the need for a similar view as a Gantt chart is preferable.

b) Recommendations for the model

1) AMPL

Multiple skills

There are several features that could improve the validity and the model in general of both the model and data used in this thesis. The use of multiple skills per worker would allow them to have and perform various jobs the AMPL-model does not cover and make it more realistic. This would increase the number of alternative solutions and may result in fewer workers needed.

Vacation / Sick leave / Flexi-time (VSF)

Probably the single element that could greatly improve the utilization results gained by the model can be achieved by handling VSF's in an alternate way. Technically in AMPL VSFs are defined as job. As a result of wanting to minimize the number of workers used, are those with VSF already reserved in the data set automatically prioritized to accept "more jobs" when it comes to the allocation. Because the work restriction subtracts VSFs from constraint (5) the model allows adding more jobs to a worker with a large number of VSF-days. For illustration purposes, a worker has had 35 days of VSF-days during the 45-day period. In the remaining 10 days the AMPL-model will try to allocate at least one job during this time. As a result, this worker ends up having overall a low utilization. The job allocated to this person could have gone to another, increasing that person's utilization and using one less worker. There are several examples of this situation in the solution files.

VSFs are in a practical sense for NOV more flexible to move around depending on whether they are sick leaves, vacations or flexi-time. In the data set VSFs are determined parameters and static rather than in a practice when vacations and flexi-time are planned around certain jobs to better utilize the workers. This restricts the model a bit, but to what degree is hard to say given the dynamic work environment in NOV.

Offshore restriction

The same sort of issue arises with regards to the offshore restriction in the AMPL-model. As VSFs are reserved before running the model, this excludes a range of solutions where workers have been given vacation time right after completing an offshore trip. This is because part of constraint (2) which does not allow for any jobs to be taken within 1/3 of the time after such a job. Therefore in some cases the original scheduling of these workers may not be replicated, even if there were a good match between worker and job. Though the model hinders it, NOV is allowed to send service engineers to onshore jobs right after offshore jobs, but in practice they rarely do. Thus the issue has mainly to deal with the handling of VFSs as jobs.

2) Mathematical

Work restriction

Without incorporating historical data from earlier work load for each service engineer for a longer period of time, it is a challenge to make use of constraint (5) based solely on the data set given the short time period. By adding the parameter L_w and increasing the parameter of M we can make the model more realistic.

L_w: total number of days worked in the previous X months for each worker

new M : maximum number of working days during a total of X+1 months for each worker resulting in the following constraint which could replace the original constraint (5):

$$\sum_{j \in J}(X_{wj}D_j) + L_w - V_w \leq M, w \in W$$

The model will then generate a feasible solution given the historical data and keep the work restriction in bound.

Programming difficulties in AMPL we were not able to implement a constraint that fully satisfied a work restriction. Workers with the number of VFS-days between 5 and 11 could mathematically reach a maximum of 39 working days, which would have exceeded the preferred limit. Because the complexity of scheduling, this was not the case in the two data sets used. To close this gap changes to the model would be as follows:

$K =$ time horizon in days for data set

Constraint (5): $\min\left[\sum_{j\in J} X_{wj} D_j \leq M, \sum_{j\in J} X_{wj} D_j \leq (K - V_w)\right], w \in W$

Constraint (5) chooses the minimum value of the two equations to set the upper bound.

Customer preferences

Some of NOV's customers have preferences to which they would like to have on their installations. These are workers that have been at the customer's base before and are known and liked by management. There could be a group of service engineers that the customers prefer, or just a single one. Therefore being able to use historical data to weight certain workers towards specific customers would increase the models realism.

Working hours

Because of the use of day-scale rather than specific working hours in the model, there are some hourly deviations when it comes to this model restriction. By adding a parameter for the number of hours per day the job needs, the work restriction constraint (5) would become more accurate.

13. Contribution of thesis

The model introduced in this thesis is supposed to give an introduction into the possibility of a future tool that could be used by NOV employees in their daily work. In this thesis we have applied a well-known model in a new environment with additional adjustments to fit the operational requirements at NOV. The findings together with the limitations and opportunities explained in this thesis may form as a basis for further development of this model.

14. Conclusion

There are thousands of different ways to schedule workers against jobs, and there is no "best solution". This because a good solution in NOV has to balance between the workers preferences, the company strategy, programming method and the operational requirements while utilizing them in an efficient way.

With the use of mixed integer modeling this thesis has shown how to use fewer workers to increase utilization for NOV's AM department in Molde.

We believe that by further developing the model it could become a tool which can contribute in NOV's daily work and help with more effective resource allocation of personnel. Using fewer workers to perform the same number of jobs frees up capacity. At the same time the model considers most of what the PCs "have in their heads" and inputs these automatically.

There are several areas which may be of interest for future research, such as changes and possible improvements in the areas of mathematical- and AMPL-model, and at NOV.

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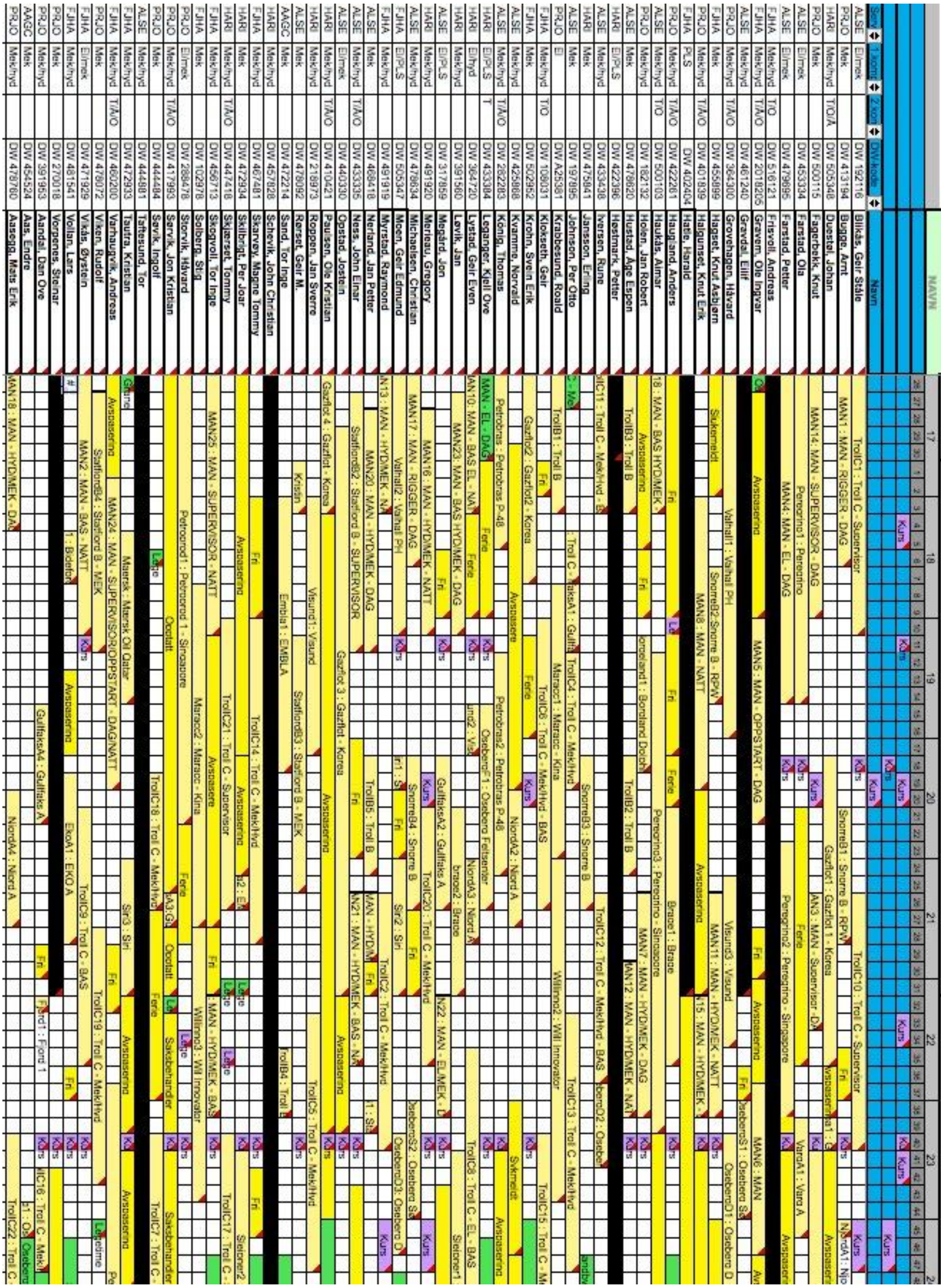
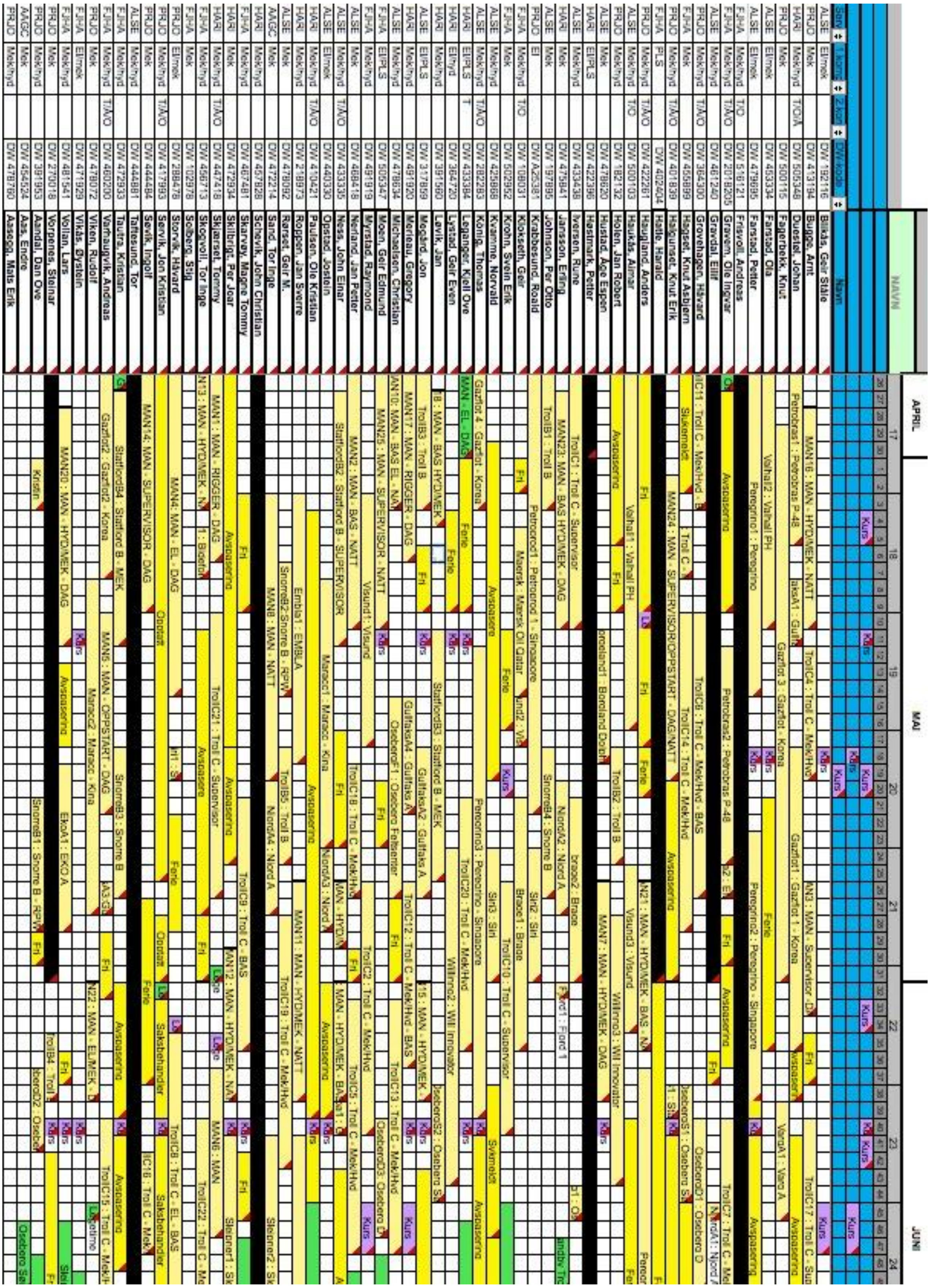
16. Appendix

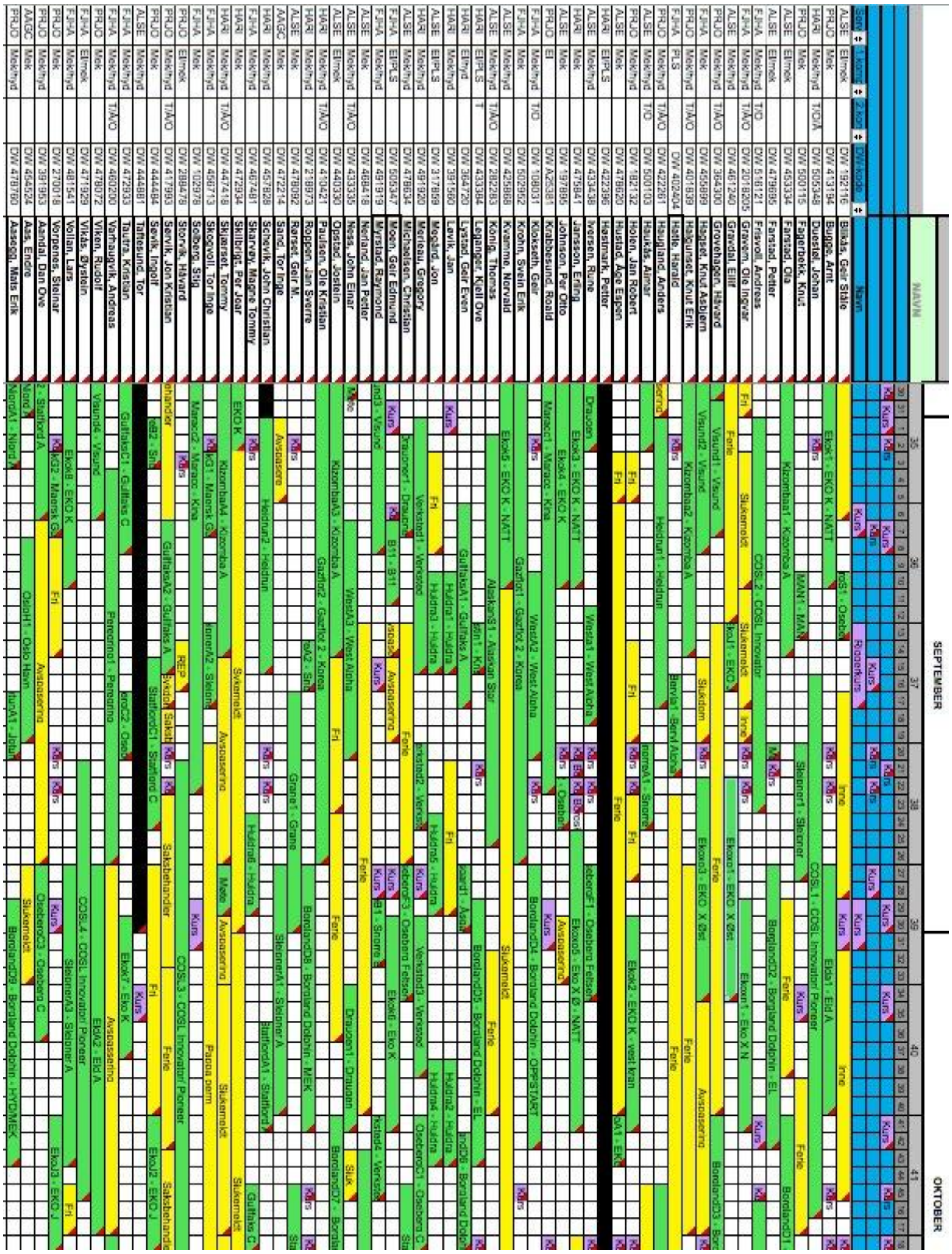
Appendix A – Gantt charts



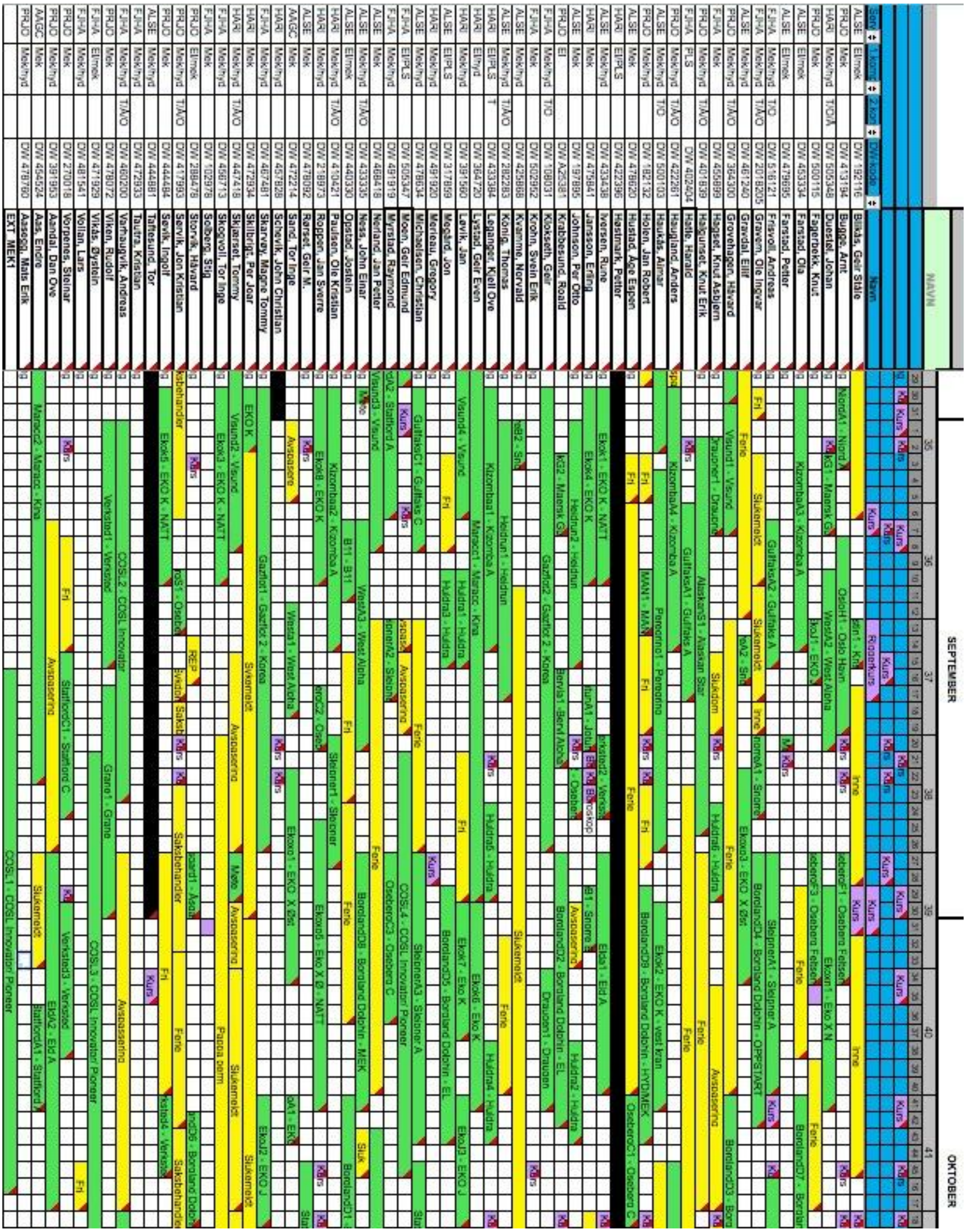
Case 1 - Original solution NOV



Case 1 – Model solution



Case 2 - Original solution NOV



Case 2 – Model solution

Appendix B - Utilization

Case 1 Original Solution										
Workers	**J1**	**J2**	**J3**	**J4**	**J1**	**J2**	**J3**	**J4**	Sum	
BlikasG	TrollC1	TrollC10			10	15			25	111,1 %
BuggeA	Man1	SnorreB1	NjordA1		6	8	2		16	71,1 %
DuestolJ	Gazflot1	Gjoa1			18	3			21	93,3 %
FagerbekkK	Man14	Man3	Wilinno1		10	8	5		23	102,2 %
FarstadO	Peregrino1	VargA1			14	7			21	93,3 %
FarstadP	Man4	Peregrino2			14	15			29	128,9 %
FrisvollA									0	
GravemO	Man5	Man6			12	9			21	93,3 %
GravdalE	osebergS1				7				7	31,1 %
GrovehagenH	Valhall1	Visund3	OsebergD1		16	10	6		32	142,2 %
HagsetK	SnorreB2	Man11			8	13			21	93,3 %
HalgunsetK	Man8	Man15			17	7			24	106,7 %
HatleH									0	
HauglandA	Brage1				15				15	66,7 %
HaukasA	Man18	Peregrino3			4	28			32	142,2 %
HolenJ	Borgeland1	Man7			8	13			21	93,3 %
HustadA	TrollB3	TrollB2	Man12		3	7	9		19	84,4 %
HostmarkP									0	
IversenR	TrollC11	TrollC12	OsebergD2		3	11	5		19	84,4 %
JanssonE	SnorreB3				9				9	40,0 %
JohnsonP	TrollC3	GullfaksA1	TrollC4	TrollC13	3	4	8	13	28	124,4 %
KrabbesundR	TrollB1	Maracc1	Villinno2		3	16	20		39	173,3 %
KloksethG	TrollC6	TrollC15			17	6			23	102,2 %
KrohnS	Gazflot2				7				7	31,1 %
KvammeN	NjordA2				8				8	35,6 %
KonigT	Pererobras1	Pererobras2			5	13			18	80,0 %
LegangerK	OsebergF1				12				12	53,3 %
LystadG	Man10	Visund2	NjordA3	TrollC8	3	3	5	11	22	97,8 %
LovikJ	Man23	Brage2	Sleipner1		10	11	5		26	115,6 %
MegardJ	GullfaksA2	Man22			9	7			16	71,1 %
MerieauG	Man16	TrollC20			10	15			25	111,1 %
MichaelsenC	Man17	SnorreB4	OsebergS2		6	9	7		22	97,8 %
MoenG	Valhall2	Siri1	Siri2	OsebergD	10	2	8	6	26	115,6 %
MyrstadR	Man13	TrollC2			3	15			18	80,0 %
NerlandJ	Man20	TrollB5	Man19	StatfjordB	11	7	4	2	24	106,7 %
NessJ	StatfjordB2	Man21			11	10			21	93,3 %
OpstadJ	Gazflot3				31				31	137,8 %
PaulsenO	Gazflot4				3				3	13,3 %
RoppenJ	Visund1	TrollC5			15	13			28	124,4 %
RorsetG	Kristin	StatfjordB3			3	15			18	80,0 %
SandT	Embla1	TrollB4			16	5			21	93,3 %
SchevikJ									0	
SkarvoyM	TrollC14				19				19	84,4 %
SkilbrigtP	Embla2	Sleipner2			2	5			7	31,1 %
SkjarsetT	TrollC21	TrollC17			17	6			23	102,2 %
SkogvollT	Man25	Man9			10	7			17	75,6 %
SolbergS	Maracc2	Wilnno3			20	16			36	160,0 %
StorvikH	Peteroprod1				21				21	93,3 %
SorvikJ	GullfaksA3				2				2	8,9 %
SovikI	TrollC18	TrollC7			8	6			14	62,2 %
TaftesundT									0	
TautraK	Maersk	Siri3			10	8			18	80,0 %
VarhaugvikA	Man24	Peregrino4			18	9			27	120,0 %
VikenR	StatfjordB4	TrollC19			11	15			26	115,6 %
VikasO	Man2	TrollC9			10	15			25	111,1 %
VollanL	Bidefjord1	EckoA1			3	10			13	57,8 %
VorpenesS									0	
AandalD	GullfaksA4	Fjord1	TrollC16		7	1	4		12	53,3 %
AasE	Oseberg1				2				2	8,9 %
AaseggM	Man18	NjordA4	TrollC22		4	8	6		18	80,0 %
									1071	**88,1 %**
								Worker count		**54**

Case 1 Model Solution

Workers	J1	J2	J3	J4	J1	J2	J3	J4	Sum	
BlikasG									0	
BuggeA	MAN16	MAN3	TrollC17	TrollC4	10	8	6	8	32	142,2 %
DuestolJ	Gazflot1	GullfaksA1	Petrobras1		18	4	5		27	120,0 %
FagerbekkK	Gazflot3				31				31	137,8 %
FarstadO	Vallhall2	VargA1			10	7			17	75,6 %
FarstadP	Peregrino1	Peregrino2			14	15			29	128,9 %
FrisvollA									0	
GravemO	Embla2	Petrobras2	TrollC7		2	13	6		21	93,3 %
GravdalE	NjordA1				2				2	8,9 %
GrovehagenH	OsebergD1	TrollC11	TrollC6		6	3	17		26	115,6 %
HagsetK	OsebergS1	TrollC14	TrollC3		7	19	3		29	128,9 %
HalgunsetK	MAN24	StatfjordB1			18	2			20	88,9 %
HatleH									0	
HauglandA	MAN21	Peregrino4			10	9			19	84,4 %
HaukasA	Vallhall1	Visund3			16	10			26	115,6 %
HolenJ	TrollB2	Willinno3			7	16			23	102,2 %
HustadA	Borgland1	MAN7			8	13			21	93,3 %
HostmarkP									0	
IversenR	Brage2	Oseberg1	TrollC1		11	2	10		23	102,2 %
JanssonE	Fjord1	MAN23	NjordA2		2	10	8		20	88,9 %
JohnsonP	SnorreB4	TrollB1			9	3			12	53,3 %
KrabbesundR	Petroprod1	Siri2			21	8			29	128,9 %
KloksethG	Brage1	Maersk	Visund2		15	10	3		28	124,4 %
KrohnS	TrollC10				15				15	66,7 %
KvammeN	Siri3				8				8	35,6 %
KonigT	Gazflot4	Peregrino3			3	28			31	137,8 %
LegangerK	TrollC20				15				15	66,7 %
LystadG	Willinno2				20				20	88,9 %
LovikJ	MAN18	OsebergS2	StatfjordB3		4	7	15		26	115,6 %
MegardJ	GullfaksA2	MAN15	TrollB3		9	7	3		19	84,4 %
MerieauG	GullfaksA4	MAN17	TrollC12		7	6	11		24	106,7 %
MichaelsenC	MAN10	OsebergF1	TrollC13		3	12	13		28	124,4 %
MoenG	MAN25	OsebergD3			10	6			16	71,1 %
MyrstadR	TrollC2	Visund1			15	15			30	133,3 %
NerlandJ	MAN2	TrollC18	TrollC5		10	8	13		31	137,8 %
NessJ	Gjoa1	MAN19	MAN9	StatfjordB2	3	4	7	11	25	111,1 %
OpstadJ	Maracc1	NjordA3			16	5			21	93,3 %
PaulsenO									0	
RoppenJ	Embla1	MAN11	Willinno1		16	13	5		34	151,1 %
RorsetG	SnorreB2	TrollB5	TrollC19		8	7	15		30	133,3 %
SandT	MAN8	NjordA4	Sleipner2		17	8	5		30	133,3 %
ShevikJ									0	
SkarvoyM	TrollC9				15				15	66,7 %
SkilbrigtP	MAN12	Sleipner1			9	5			14	62,2 %
SkjarsetT	MAN1	MAN6	TrollC21		6	9	17		32	142,2 %
SkogvollT	Bideford1	MAN13	TrollC22		3	3	6		12	53,3 %
SolbergS									0	
StorvikH	MAN4	Siri1	TrollC8		14	2	11		27	120,0 %
SorvikJ									0	
SovikI	MAN14	TrollC16			10	4			14	62,2 %
TaftesundT									0	
TautraK	SnorreB3	StatfjordB4			9	11			20	88,9 %
VarhaugvikA	Gazflot2	GullfaksA3	MAN5	TrollC15	7	2	12	6	27	120,0 %
VikenR	MAN22	Maracc2			7	20			27	120,0 %
VikasO									0	
VollanL	EkoA1	MAN20			10	11			21	93,3 %
VorpenesS	TrollB4				5				5	22,2 %
AandalD	Kristin	OsebergD2	SnorreB1		3	5	8		16	71,1 %
AasE									0	
AaseggM									0	
									1068	**98,9 %**
								Worker count		**48**

Case 2 Original Solution										
Workers	**J1**	**J2**	**J3**	**J4**	**J1**	**J2**	**J3**	**J4**	**Sum**	
BlikasG	OsebergS1				4				4	17,8 %
BuggeA	EkoK1	EldA1			10	14			24	106,7 %
DuestolJ	COSL1				30				30	133,3 %
FagerbekkK	MAN1	Sleipner1			4	7			11	48,9 %
FarstadO	KizombaA1	BorglandD1			14	5			19	84,4 %
FarstadP	BorglandD2				16				16	71,1 %
FrisvollA	COSL2				23				23	102,2 %
GravemO	EkoXN1				13				13	57,8 %
GravdalE	EkoJ1	EkoXO1			4	13			17	75,6 %
GrovehagenH	Visund1	BorglandD3			7	5			12	53,3 %
HagsetK	Visund2	EkoXO3			8	13			21	93,3 %
HalgunsetK	KizombaA2				14				14	62,2 %
HatleH	Beryla1				6				6	26,7 %
HauglandA	Heidrun1				17				17	75,6 %
HaukasA	SnorreA1				5				5	22,2 %
HolenJ	EkoK2				11				11	48,9 %
HustadA	EkoA1				3				3	13,3 %
HostmarkP									0	
IversenR	WestA1	OsebergF1			7	8			15	66,7 %
JanssonE	EkoK3	EkoXO5			10	17			27	120,0 %
JohnsonP	EkoK4	OsebergF2			10	3			13	57,8 %
KrabbesundR	Maracc1				22				22	97,8 %
KloksethG	WestA2	BorglandD4			11	16			27	120,0 %
KrohnS	Gazflot1				26				26	115,6 %
KvammeN	EkoK5				10				10	44,4 %
KonigT	AlaskanS1				25				25	111,1 %
LegangerK	Kristin1	BorglandD5			3	15			18	80,0 %
LystadG	GullfaksA1	Asgard1	BorglandD6		12	4	4		20	88,9 %
LovikJ	Huldra1	Huldra2			6	6			12	53,3 %
MegardJ	Huldra3	Huldra4	Huldra5		6	6	6		18	80,0 %
MerieauG	Verksted1	Verksted2	Verksted3	OsebergC1	15	5	9	5	34	151,1 %
MichaelsenC	Draupner1	OsebergF3			7	8			15	66,7 %
MoenG	B11	EkoK6			5	12			17	75,6 %
MyrstadR	Visund3	SnorreB1	Verksted4		8	4	5		17	75,6 %
NerlandJ									0	
NessJ	WestA3	Draugen1			14	8			22	97,8 %
OpstadJ	KizombaA3	BorglandD7			14	5			19	84,4 %
PaulsenO	Gazflot2				26				26	115,6 %
RoppenJ	SnorreA2	BorglandD8			3	15			18	80,0 %
RorsetG	Grane1				14				14	62,2 %
SandT	SleipnerA1				14				14	62,2 %
SchevikJ	Heidrun2	StatfjordA1			15	6			21	93,3 %
SkarvoyM	Huldra6				6				6	26,7 %
SkilbrigtP									0	0,0 %
SkjarsetT	KizombaA4				14				14	62,2 %
SkogvollT	MaerskG1	SleipnerA2			5	5			10	44,4 %
SolbergS	Maracc2				22				22	97,8 %
StorvikH	COSL3				25				25	111,1 %
SorvikJ	GullfaksA2				9				9	40,0 %
SovikI	SnorreB2	StatfjordC1	EkoJ2		3	10	5		18	80,0 %
TaftesundT									0	
TautraK	GullfaksC1	OsebergC2	EkoK7		8	4	8		20	88,9 %
VarhaugvikA	Peregrino1				23				23	102,2 %
VikenR	Visund4	EldA2			6	24			30	133,3 %
VikasO	COSL4				25				25	111,1 %
VollanL	EkoK8	SleipnerA3			10	17			27	120,0 %
VorpenesS	MaerskG2	EkoJ3			5	5			10	44,4 %
AandalD	StatfjordA2	OsebergC3			6	10			16	71,1 %
AasE	OsloH1				12				12	53,3 %
AaseggM	NjordA1	JotunA1	BorglandD9		3	4	5		12	53,3 %
									975	**76,0 %**
								Worker count		**57**

Case 2 Model Solution										
Workers	**J1**	**J2**	**J3**	**J4**	**J1**	**J2**	**J3**	**J4**	**Sum**	
BlikasG	Kristin1				3				3	13,3 %
BuggeA	NjordA1	OsebergF1	OsloH1		3	8	12		23	102,2 %
DuestolJ	EkoXN1	MaerskG1	WestA2		13	5	11		29	128,9 %
FagerbekkK	EkoJ1	OsebergF3			4	8			12	53,3 %
FarstadO	BorglandD7	KizombaA3			5	14			19	84,4 %
FarstadP									0	
FrisvollA	GullfaksA2	SleipnerA1			9	14			23	102,2 %
GravemO	BorglandD4	SnorreA1			16	5			21	93,3 %
GravdalE	EkoXO3	SnorreA2			13	3			16	71,1 %
GrovehagenH	BorglandD3	Visund1			5	7			12	53,3 %
HagsetK	Draupner1	Huldra6			7	6			13	57,8 %
HalgunsetK	AlaskanS1				25				25	111,1 %
HatleH	GullfaksA1				12				12	53,3 %
HauglandA	KizombaA4				14				14	62,2 %
HaukasA	EkoK2	Peregrino1			11	23			34	151,1 %
HolenJ	BorglandD9	MAN1			15	4			19	84,4 %
HustadA	OsebergC1				5				5	22,2 %
HostmarkP									0	
IversenR	EkoK1	EldA1	Verksted2		10	14	8		32	142,2 %
JanssonE	EkoK4	JotunA1	SnorreB1		10	4	4		18	80,0 %
JohnsonP	Heidrun2	Huldra2	OsebergF2		15	6	3		24	106,7 %
KrabbesundR	BerylA1	BorglandD2	MaerskG2		6	16	5		27	120,0 %
KloksethG	Draugen1	Gazflot2			8	26			34	151,1 %
KrohnS									0	
KvammeN	SnorreB2				3				3	13,3 %
KonigT	Heidrun1				17				17	75,6 %
LegangerK	Huldra4	Huldra5	KizombaA1		6	6	14		26	115,6 %
LystadG	EkoK6	Maracc1			12	22			34	151,1 %
LovikJ	EkoJ3	EkoK7	Huldra1	Visund4	5	8	6	6	25	111,1 %
MegardJ	BorglandD5	Huldra3			15	6			21	93,3 %
MerieauG									0	
MichaelsenC	GullfaksC1	SleipnerA3			8	17			25	111,1 %
MoenG	COSL4				25				25	111,1 %
MyrstadR	OsebergC3	SleipnerA2	StatfjordA2		10	5	6		21	93,3 %
NerlandJ	Visund3				8				8	35,6 %
NessJ	BorglandD8	WestA3			15	14			29	128,9 %
OpstadJ	B11	BorglandD1			5	5			10	44,4 %
PaulsenO	KizombaA2	Sleipner1			14	7			21	93,3 %
RoppenJ	EkoK8	EkoXO5	OsebergC2		10	17	4		31	137,8 %
RorsetG									0	
SandT	EkoA1	EkoXO1	WestA1		3	13	7		23	102,2 %
SchevikJ									0	
SkarvoyM	EkoJ2	Gazflot1			5	26			31	137,8 %
SkilbrigtP									0	
SkjarsetT	Visund2				8				8	35,6 %
SkogvollT	EkoK3				10				10	44,4 %
SolbergS									0	
StorvikH	Asgard1	BorglandD6			4	4			8	35,6 %
SorvikJ	OsebergS1				4				4	17,8 %
SovikI	EkoK5	Verksted4			10	5			15	66,7 %
TaftesundT									0	
TautraK									0	
VarhaugvikA	COSL2				23				23	102,2 %
VikenR	Grane1	Verksted1			14	15			29	128,9 %
VikasO	COSL3				25				25	111,1 %
VollanL									0	
VorpenesS	StatfjordC1	Verksted3			10	9			19	84,4 %
AandalD	EldA2				24				24	106,7 %
AasE	Maracc2	StatfjordA1			22	6			28	124,4 %
AaseggM									0	
EXT_MEK1	COSL1				30				30	133,3 %
									988	**91,2 %**
								Worker count		**49**

Appendix C – AMPL files

CASE 1

Data file

```
set WORKERS:= BlikasG   BuggeA      DuestolJ    FagerbekkK  FarstadO
      FarstadP    FrisvollA   GravemO     GravdalE    GrovehagenH
      HagsetK     HalgunsetK  HatleH      HauglandA   HaukasA     HolenJ
      HustadA     HostmarkP   IversenR    JanssonE    JohnsonP
      KrabbesundR KloksethG   KrohnS      KvammeN     KonigT
      LegangerK   LystadG     LovikJ      MegardJ     MerieauG
      MichaelsenC MoenG MyrstadR    NerlandJ    NessJ OpstadJ
      PaulsenO    RoppenJ     RorsetG     SandT SchevikJ    SkarvoyM
      SkilbrigtP  SkjarsetT   SkogvollT   SolbergS    StorvikH    SorvikJ
      SovikI      TaftesundT  TautraK     VarhaugvikA       VikenR
      VikasO      VollanL     VorpenessS  AandalD     AasE  AaseggM
      EXT_MEK1    EXT_MEK2  EXT_EL1 EXT_EL2 ;

set JOBS := Bideford1   Borgland1   Brage1      Brage2      EkoA1 Embla1
      Embla2      Fjord1      Gazflot1    Gazflot2    Gazflot3
      Gazflot4    Gjoa1 GullfaksA1  GullfaksA2  GullfaksA3  GullfaksA4
      Kristin     Maersk      MAN1  MAN10 MAN11 MAN12 MAN13 MAN14 MAN15
      MAN16 MAN17 MAN18 MAN19 MAN2  MAN20 MAN21 MAN22 MAN23 MAN24 MAN25
      MAN3  MAN4  MAN5  MAN6  MAN7  MAN8  MAN9  Maracc1     Maracc2
      NjordA1     NjordA2     NjordA3     NjordA4     Oseberg1
      OsebergD1   OsebergD2   OsebergD3   OsebergF1   OsebergS1
      OsebergS2   Peregrino1  Peregrino2  Peregrino3  Peregrino4
      Petrobras1  Petrobras2  Petroprod1  Siri1 Siri2 Siri3 Sleipner1
      Sleipner2   SnorreB1    SnorreB2    SnorreB3    SnorreB4
      StatfjordB1 StatfjordB2 StatfjordB3 StatfjordB4 TrollB1     TrollB2
      TrollB3     TrollB4     TrollB5     TrollC1     TrollC10
      TrollC11    TrollC12    TrollC13    TrollC14    TrollC15
      TrollC16    TrollC17    TrollC18    TrollC19    TrollC2
      TrollC20    TrollC21    TrollC22    TrollC3     TrollC4     TrollC5
      TrollC6     TrollC7     TrollC8     TrollC9     Valhall1
      Valhall2    VargA1      Visund1     Visund2     Visund3
      WillInno1   WillInno2   WillInno3
      VACBuggeA   VACDuestolJ VACDuestolJ2      VACFarstadO VACFarstadP
      VACFrisvollA      VACGravemO  VACGravemO2 VACGravdalE VACGravdalE2
      VACHagsetK  VACHalgunsetK     VACHalgunsetK2    VACHatleH
      VACHatleH2  VACHauglandA      VACHaukasA  VACHolenJ   VACHostmarkP
```

```
      VACKloksethG      VACKrohnS   VACKvammeN  VACKvammeN2 VACKonigT
      VACLegangerK      VACLystadG  VACMegardJ  VACMichaelsenC
      VACMoenG    VACNerlandJ VACNessJ    VACNessJ2   VACOpstadJ
      VACPaulsenO VACSchevikJ VACSkarvoyM VACSkarvoyM2      VACSkilbrigtP
      VACSkogvollT      VACStorvikH VACSorvikJ  VACSorvikJ2 VACSorvikJ3
      VACSorvikJ4 VACSovikI   VACTaftesundT     VACTautraK  VACTautraK2
      VACVarhaugvikA    VACVollanL  VACVollanL2 VACVorpenesS
      VACVorpenesS2     VACAandalD ;

#workerSkill:                        1-Mek,                        2-El
#workerExp: 1-Less experienced, 2-More experienced
param : workerQual      workerExp   totalVac    penaltyCost:=
BlikasG     2     1     0     0
BuggeA      1     1     4     0
DuestolJ    1     2     10    0
FagerbekkK  1     1     0     0
FarstadO    2     1     16    0
FarstadP    2     1     8     0
FrisvollA   1     2     45    0
GravemO     1     2     20    0
GravdalE    1     1     35    0
GrovehagenH 1     2     0     0
HagsetK     1     1     3     0
HalgunsetK  1     2     19    0
HatleH      2     1     45    0
HauglandA   1     2     21    0
HaukasA     1     2     7     0
HolenJ      1     1     10    0
HustadA     1     1     0     0
HostmarkP   2     1     45    0
IversenR    1     1     0     0
JanssonE    1     1     0     0
JohnsonP    1     1     0     0
KrabbesundR 2     2     0     0
KloksethG   1     2     3     0
KrohnS      1     1     7     0
KvammeN     1     1     29    0
KonigT      1     2     6     0
LegangerK   2     1     10    0
LystadG     2     1     7     0
LovikJ      1     1     0     0
```

```
MegardJ     2     2     5     0
MerieauG    1     1     0     0
MichaelsenC 1     1     6     0
MoenG       2     1     5     0
MyrstadR    1     1     0     0
NerlandJ    1     1     3     0
NessJ       1     2     12    0
OpstadJ     2     1     9     0
PaulsenO    1     2     42    0
RoppenJ     1     1     0     0
RorsetG     1     1     0     0
SandT       1     1     0     0
SchevikJ    1     1     45    0
SkarvoyM    1     1     8     0
SkilbrigtP  1     1     25    0
SkjarsetT   1     2     0     0
SkogvollT   1     1     22    0
SolbergS    1     1     0     0
StorvikH    2     1     9     0
SorvikJ     1     2     45    0
SovikI      1     1     12    0
TaftesundT  1     1     46    0
TautraK     1     1     9     0
VarhaugvikA 1     2     5     0
VikenR      1     1     0     0
VikasO      2     1     0     0
VollanL     1     1     9     0
VorpenesS   1     1     37    0
AandalD     1     1     1     0
AasE        1     1     0     0
AaseggM     1     1     0     0
EXT_EL1     2     2     0     1000
EXT_EL2     2     2     0     1000
EXT_MEK1    1     2     0     1000
EXT_MEK2    1     2     0     1000
;

#startTime: When the job starts
#durationTime: The duration of the job
#jobSkill: Type of skill the job requires
#jobExp: Type of experience the job requires
```

```
#offShore: If the job is offshore in Norway the value 1 is set, 0
otherwise
#workersReq: How many workers required for the job
#The time period is from 1 to 45 days


param : startDate durationDays jobQual jobExp offshore workersReq:=
Bideford1    4      3      1      1      1      1
Borgland1    10     8      1      1      1      1
Brage1       20     15     1      2      1      1
Brage2       20     11     1      1      1      1
EkoA1        18     10     1      1      1      1
Embla1       2      16     1      1      1      1
Embla2       24     2      1      1      1      1
Fjord1       31     2      1      1      0      1
Gazflot1     17     18     1      2      0      1
Gazflot2     1      7      1      1      0      1
Gazflot3     1      31     1      1      0      1
Gazflot4     1      3      1      2      0      1
Gjoa1        38     3      1      2      1      1
GullfaksA1   7      4      1      1      1      1
GullfaksA2   17     9      2      2      1      1
GullfaksA3   25     2      1      2      1      1
GullfaksA4   14     7      1      1      1      1
Kristin      1      3      1      1      1      1
Maersk       4      10     1      1      0      1
MAN1         1      6      1      1      0      1
MAN10        1      3      1      1      0      1
MAN11        25     13     1      1      0      1
MAN12        29     9      1      1      0      1
MAN13        1      3      1      1      0      1
MAN14        1      10     1      1      0      1
MAN15        31     7      2      2      0      1
MAN16        1      10     1      1      0      1
MAN17        1      6      1      1      0      1
MAN18        1      4      1      1      0      1
MAN19        25     4      1      1      0      1
MAN2         1      10     1      1      0      1
MAN20        1      11     1      1      0      1
MAN21        25     10     1      2      0      1
MAN22        31     7      1      1      0      1
```

MAN23	1	10	1	1	0	1
MAN24	1	18	1	2	0	1
MAN25	1	10	2	1	0	1
MAN3	25	8	1	1	0	1
MAN4	1	14	2	1	0	1
MAN5	9	12	1	2	0	1
MAN6	36	9	1	2	0	1
MAN7	25	13	1	1	0	1
MAN8	2	17	1	1	0	1
MAN9	31	7	1	2	0	1
Maracc1	7	16	2	1	0	1
Maracc2	7	20	1	1	0	1
NjordA1	44	2	1	1	1	1
NjordA2	19	8	1	1	1	1
NjordA3	23	5	2	1	1	1
NjordA4	19	8	1	1	1	1
Oseberg1	43	2	1	1	1	1
OsebergD1	39	6	1	2	1	1
OsebergD2	36	5	1	1	1	1
OsebergD3	39	6	2	1	1	1
OsebergF1	14	12	1	1	0	1
OsebergS1	37	7	1	1	1	1
OsebergS2	37	7	1	1	1	1
Peregrino1	1	14	2	1	0	1
Peregrino2	22	15	2	1	0	1
Peregrino3	11	28	1	2	0	1
Peregrino4	36	9	1	2	0	1
Petrobras1	1	5	1	2	0	1
Petrobras2	11	13	1	2	0	1
Petroprod1	1	21	2	2	0	1
Siri1 17	2	2	1	1	1	
Siri2 23	8	2	1	1	1	
Siri3 23	8	1	1	1	1	
Sleipner1	40	5	1	1	1	1
Sleipner2	40	5	1	1	1	1
SnorreB1	20	8	1	1	0	1
SnorreB2	6	8	1	1	1	1
SnorreB3	17	9	1	1	1	1
SnorreB4	17	9	1	1	1	1
StatfjordB1	37	2	1	1	1	1
StatfjordB2	1	11	1	2	1	1

StatfjordB3	10	15	1	1	1	1	
StatfjordB4	1	11	1	1	1	1	
TrollB1	1	3	1	1	1	1	
TrollB2	17	7	1	1	1	1	
TrollB3	1	3	2	1	1	1	
TrollB4	34	5	1	1	1	1	
TrollB5	17	7	1	1	1	1	
TrollC1	1	10	1	1	1	1	
TrollC10	25	15	1	1	1	1	
TrollC11	1	3	1	1	1	1	
TrollC12	25	11	1	1	1	1	
TrollC13	32	13	1	1	1	1	
TrollC14	9	19	1	1	1	1	
TrollC15	39	6	1	2	1	1	
TrollC16	41	4	1	1	1	1	
TrollC17	39	6	1	1	1	1	
TrollC18	18	8	1	1	1	1	
TrollC19	27	15	1	1	1	1	
TrollC2	25	15	1	1	1	1	
TrollC20	20	15	2	1	1	1	
TrollC21	9	17	1	2	1	1	
TrollC22	39	6	1	1	1	1	
TrollC3	4	3	1	1	1	1	
TrollC4	11	8	1	1	1	1	
TrollC5	32	13	1	1	1	1	
TrollC6	9	17	1	2	1	1	
TrollC7	39	6	1	2	1	1	
TrollC8	34	11	2	1	1	1	
TrollC9	20	15	1	1	1	1	
Valhall1	1	16	1	2	1	1	
Valhall2	1	10	2	1	1	1	
VargA1	38	7	2	1	1	1	
Visund1	2	15	1	1	1	1	
Visund2	14	3	1	1	1	1	
Visund3	24	10	1	2	1	1	
WillInno1	40	5	1	1	0	1	
WillInno2	23	20	2	1	0	1	
WillInno3	27	16	1	1	0	1	
VACBuggeA		34	4	1	1	0	1
VACDuestolJ		35	4	1	2	0	1
VACDuestolJ2		40	6	1	2	0	1

VACFarstadO	20	16	2	1	0	1
VACFarstadP	38	8	2	1	0	1
VACFrisvollA	1	46	1	2	0	1
VACGravemO	1	10	1	2	0	1
VACGravemO2	27	10	1	2	0	1
VACGravdalE	1	32	1	1	0	1
VACGravdalE2	35	3	1	1	0	1
VACHagsetK	1	3	1	1	0	1
VACHalgunsetK	19	13	1	2	0	1
VACHalgunsetK2	40	6	1	2	0	1
VACHatleH	1	29	2	1	0	1
VACHatleH2	30	16	2	1	0	1
VACHauglandA	1	21	1	2	0	1
VACHaukasA	39	7	1	2	0	1
VACHolenJ	1	10	1	1	0	1
VACHostmarkP	1	46	2	1	0	1
VACKloksethG	1	3	1	2	0	1
VACKrohnS	10	7	1	1	0	1
VACKvammeN	1	20	1	1	0	1
VACKvammeN2	37	9	1	1	0	1
VACKonigT	40	6	1	2	0	1
VACLegangerK	1	10	2	1	0	1
VACLystadG	3	7	2	1	0	1
VACMegardJ	5	5	2	2	0	1
VACMichaelsenC	26	6	1	1	0	1
VACMoenG	19	5	2	1	0	1
VACNerlandJ	29	3	1	1	0	1
VACNessJ	16	8	1	2	0	1
VACNessJ2	42	4	1	2	0	1
VACOpstadJ	31	9	2	1	0	1
VACPaulsenO	3	42	1	2	0	1
VACSchevikJ	1	46	1	1	0	1
VACSkarvoyM	2	8	1	1	0	1
VACSkarvoyM2	41	5	1	1	0	1
VACSkilbrigtP	1	25	1	1	0	1
VACSkogvollT	10	22	1	1	0	1
VACStorvikH	20	9	2	1	0	1
VACSorvikJ	1	26	1	2	0	1
VACSorvikJ2	27	5	1	2	0	1
VACSorvikJ3	32	8	1	2	0	1
VACSorvikJ4	40	6	1	2	0	1

VACSovikI	26	12	1	1	0	1
VACTaftesundT	1	46	1	1	0	1
VACTautraK	31	9	1	1	0	1
VACTautraK2	40	6	1	1	0	1
VACVarhaugvikA	28	5	1	2	0	1
VACVollanL	12	6	1	1	0	1
VACVollanL2	35	3	1	1	0	1
VACVorpenesS	1	32	1	1	0	1
VACVorpenesS2	41	5	1	1	0	1
VACAandalD	28	3	1	1	0	1

Model file

```
 set WORKERS ;     #w
 set JOBS ;        #j
 param offShore{j in JOBS};          #Offshore job or not
 param durationDays{j in JOBS};      #The number of days the job takes
 param startDate{j in JOBS};         #The start date for a job
 param addOffshore{j in JOBS} = ceil(offShore[j]*durationDays[j]*0.333);
                                     #Rest period for offshore restriction
 param finishDate{j in JOBS} = startDate[j] + durationDays[j] +
addOffshore[j];                      #The finish date is the start date
                                     plus duration
 param jobQual{j in JOBS};           #Qualifications required for this job
param workersReq{j in JOBS};         #The number of workers with the
                                     specified skill that are required to
                                     complete this job
 param workerQual{w in WORKERS};     #Qualifications the worker has to
                                     have assigned a job
 param workerExp{w in WORKERS};      #Level of experience the worker has
                                     to have to be assigned a job
 param jobExp{j in JOBS};            #Level of experience required for
                                     this job
 param totalVac{w in WORKERS};       #Total number of VSF days within
                                     the period
 param penaltyCost{w in WORKERS};    #Penalty cost per worker hired
                                     externally

 var Allocated{w in WORKERS, j in JOBS} binary;
                                     #1 if worker w is allocated to job
                                     j,0 else
```

```
 var WorkerUsed{w in WORKERS} binary;
                                    #1 if worker w does any job in this
                                    time period, 0 else.

 minimize NumberOfWorkers:
sum{w in WORKERS} (WorkerUsed[w] + (WorkerUsed[w]*penaltyCost[w]));
                                    #The objective is to minimize the
                                    number of workers that we need to
                                    complete  these jobs


 subject to MaxJobsAtATime {w in WORKERS, t in 0..max{j in JOBS}
finishDate[j]}:
sum{j in JOBS: startDate[j]<= t and finishDate[j] > t} Allocated[w,j] <=
1;                                  #For any period t, a worker can only
                                    be allocated to at most one job

 subject to RightQualifiedWorkers {j in JOBS}:
sum{w in WORKERS: workerQual[w] = jobQual[j] and workerExp[w] >=
jobExp[j]} Allocated[w,j] = workersReq[j];
                                    #This guarantees that we have the
                                    required amount of workers with the
                                    right skills with the right
                                    experience for each job

 subject to LinkingConstraint {w in WORKERS, j in JOBS}:
WorkerUsed[w] >= Allocated[w,j];
                                    #This will find out if a worker
                                    likes mojito at all

 subject to MaxWorkDays {w in WORKERS}:
sum{j in JOBS} (Allocated[w,j]*durationDays[j]) - totalVac[w] <= 34;
                                    #For each worker the total number of
                                    working days cannot exceed a given
                                    amount of the total working period

subject to VAC1 {w in WORKERS,j in JOBS}:
Allocated['BuggeA','VACBuggeA'] = 1;
subject to VAC2 {w in WORKERS,j in JOBS}:
Allocated['DuestolJ','VACDuestolJ'] = 1;
```

```
subject to VAC3 {w in WORKERS,j in JOBS}:
Allocated['DuestolJ','VACDuestolJ2'] = 1;
subject to VAC4 {w in WORKERS,j in JOBS}:
Allocated['FarstadO','VACFarstadO'] = 1;
subject to VAC5 {w in WORKERS,j in JOBS}:
Allocated['FarstadP','VACFarstadP'] = 1;
subject to VAC6 {w in WORKERS,j in JOBS}:
Allocated['GravemO','VACGravemO'] = 1;
subject to VAC7 {w in WORKERS,j in JOBS}:
Allocated['GravemO','VACGravemO2'] = 1;
subject to VAC8 {w in WORKERS,j in JOBS}:
Allocated['GravdalE','VACGravdalE'] = 1;
subject to VAC9 {w in WORKERS,j in JOBS}:
Allocated['GravdalE','VACGravdalE2'] = 1;
subject to VAC10 {w in WORKERS,j in JOBS}:
Allocated['HagsetK','VACHagsetK'] = 1;
subject to VAC11 {w in WORKERS,j in JOBS}:
Allocated['HalgunsetK','VACHalgunsetK'] = 1;
subject to VAC12 {w in WORKERS,j in JOBS}:
Allocated['HalgunsetK','VACHalgunsetK2'] = 1;
subject to VAC13 {w in WORKERS,j in JOBS}:
Allocated['FrisvollA','VACFrisvollA'] = 1;
subject to VAC14 {w in WORKERS,j in JOBS}:
Allocated['HatleH','VACHatleH'] = 1;
subject to VAC15 {w in WORKERS,j in JOBS}:
Allocated['HatleH','VACHatleH2'] = 1;
subject to VAC16 {w in WORKERS,j in JOBS}:
Allocated['HauglandA','VACHauglandA'] = 1;
subject to VAC17 {w in WORKERS,j in JOBS}:
Allocated['HaukasA','VACHaukasA'] = 1;
subject to VAC18 {w in WORKERS,j in JOBS}:
Allocated['HolenJ','VACHolenJ'] = 1;
subject to VAC19 {w in WORKERS,j in JOBS}:
Allocated['HostmarkP','VACHostmarkP'] = 1;
subject to VAC20 {w in WORKERS,j in JOBS}:
Allocated['KloksethG','VACKloksethG'] = 1;
subject to VAC21 {w in WORKERS,j in JOBS}:
Allocated['KrohnS','VACKrohnS'] = 1;
subject to VAC22 {w in WORKERS,j in JOBS}:
Allocated['KvammeN','VACKvammeN'] = 1;
```

```
subject to VAC23 {w in WORKERS,j in JOBS}:
Allocated['KvammeN','VACKvammeN2'] = 1;
subject to VAC24 {w in WORKERS,j in JOBS}:
Allocated['KonigT','VACKonigT'] = 1;
subject to VAC25 {w in WORKERS,j in JOBS}:
Allocated['LegangerK','VACLegangerK'] = 1;
subject to VAC26 {w in WORKERS,j in JOBS}:
Allocated['LystadG','VACLystadG'] = 1;
subject to VAC27 {w in WORKERS,j in JOBS}:
Allocated['MegardJ','VACMegardJ'] = 1;
subject to VAC28 {w in WORKERS,j in JOBS}:
Allocated['MichaelsenC','VACMichaelsenC'] = 1;
subject to VAC29 {w in WORKERS,j in JOBS}:
Allocated['MoenG','VACMoenG'] = 1;
subject to VAC30 {w in WORKERS,j in JOBS}:
Allocated['NerlandJ','VACNerlandJ'] = 1;
subject to VAC31 {w in WORKERS,j in JOBS}:
Allocated['NessJ','VACNessJ'] = 1;
subject to VAC32 {w in WORKERS,j in JOBS}:
Allocated['NessJ','VACNessJ2'] = 1;
subject to VAC33 {w in WORKERS,j in JOBS}:
Allocated['OpstadJ','VACOpstadJ'] = 1;
subject to VAC34 {w in WORKERS,j in JOBS}:
Allocated['PaulsenO','VACPaulsenO'] = 1;
subject to VAC35 {w in WORKERS,j in JOBS}:
Allocated['SchevikJ','VACSchevikJ'] = 1;
subject to VAC36 {w in WORKERS,j in JOBS}:
Allocated['SkarvoyM','VACSkarvoyM'] = 1;
subject to VAC37 {w in WORKERS,j in JOBS}:
Allocated['SkarvoyM','VACSkarvoyM2'] = 1;
subject to VAC38 {w in WORKERS,j in JOBS}:
Allocated['SkilbrigtP','VACSkilbrigtP'] = 1;
subject to VAC39 {w in WORKERS,j in JOBS}:
Allocated['SkogvollT','VACSkogvollT'] = 1;
subject to VAC40 {w in WORKERS,j in JOBS}:
Allocated['StorvikH','VACStorvikH'] = 1;
subject to VAC41 {w in WORKERS,j in JOBS}:
Allocated['SorvikJ','VACSorvikJ'] = 1;
subject to VAC42 {w in WORKERS,j in JOBS}:
Allocated['SorvikJ','VACSorvikJ2'] = 1;
```

```
subject to VAC43 {w in WORKERS,j in JOBS}:
Allocated['SorvikJ','VACSorvikJ3'] = 1;
subject to VAC44 {w in WORKERS,j in JOBS}:
Allocated['SorvikJ','VACSorvikJ4'] = 1;
subject to VAC45 {w in WORKERS,j in JOBS}:
Allocated['SovikI','VACSovikI'] = 1;
subject to VAC46 {w in WORKERS,j in JOBS}:
Allocated['TaftesundT','VACTaftesundT'] = 1;
subject to VAC47 {w in WORKERS,j in JOBS}:
Allocated['TautraK','VACTautraK'] = 1;
subject to VAC48 {w in WORKERS,j in JOBS}:
Allocated['TautraK','VACTautraK2'] = 1;
subject to VAC49 {w in WORKERS,j in JOBS}:
Allocated['VarhaugvikA','VACVarhaugvikA'] = 1;
subject to VAC50 {w in WORKERS,j in JOBS}:
Allocated['VollanL','VACVollanL'] = 1;
subject to VAC51 {w in WORKERS,j in JOBS}:
Allocated['VollanL','VACVollanL2'] = 1;
subject to VAC52 {w in WORKERS,j in JOBS}:
Allocated['VorpenesS','VACVorpenesS'] = 1;
subject to VAC53 {w in WORKERS,j in JOBS}:
Allocated['VorpenesS','VACVorpenesS2'] = 1;
subject to VAC54 {w in WORKERS,j in JOBS}:
Allocated['AandalD','VACAandalD'] = 1;
;
```

Run file

```
model full.mod;
data full.dat;

solve;

display sum{w in WORKERS} WorkerUsed[w] > full.sol;
display NumberOfWorkers > full.sol;
display WorkerUsed > full.sol;
display {w in WORKERS} sum{j in JOBS} Allocated[w,j] > full.sol;
display {j in JOBS} sum{w in WORKERS} Allocated[w,j] > full.sol;

option omit_zero_rows 1;
```

```
option display_width 700;
display Allocated > full.sol;

exit;
```

Solve file (illustrated partially without the Allocated variable due to excess amount of output)

```
sum{w in WORKERS} WorkerUsed[w] = 55

NumberOfWorkers = 55

WorkerUsed [*] :=
 AandalD 1     FrisvollA 1      JanssonE 1         MoenG 1     SkogvollT 1
 AasE 0      GravdalE 1      JohnsonP 1      MyrstadR 1      SolbergsS 0
 AaseggM 0       GravemO 1     KloksethG 1      NerlandJ 1       SorvikJ 1
 BlikasG 0   GrovehagenH 1        KonigT 1         NessJ 1        SovikI 1
 BuggeA 1       HagsetK 1   KrabbesundR 1      OpstadJ 1      StorvikH 1
 DuestolJ 1    HalgunsetK 1        KrohnS 1      PaulsenO 1    TaftesundT 1
 EXT_EL1 0        HatleH 1       KvammeN 1      RoppenJ 1       TautraK 1
 EXT_EL2 0     HauglandA 1     LegangerK 1      RorsetG 1   VarhaugvikA 1
 EXT_MEK1 0       HaukasA 1        LovikJ 1         SandT 1        VikasO 0
 EXT_MEK2 0        HolenJ 1       LystadG 1      SchevikJ 1        VikenR 1
 FagerbekkK 1   HostmarkP 1       MegardJ 1      SkarvoyM 1       VollanL 1
 FarstadO 1       HustadA 1      MerieauG 1    SkilbrigtP 1     VorpenesS 1
 FarstadP 1      IversenR 1   MichaelsenC 1     SkjarsetT 1
;

sum{j in JOBS} Allocated[w,j] [*] :=
  AandalD 4     FrisvollA 1      JanssonE 3        MoenG 3     SkogvollT 4
  AasE 0          GravdalE 3      JohnsonP 2      MyrstadR 2      SolbergsS 0
  AaseggM 0     GravemO 5     KloksethG 4      NerlandJ 4       SorvikJ 4
  BlikasG 0   GrovehagenH 3        KonigT 3        NessJ 6        SovikI 3
  BuggeA 5       HagsetK 4   KrabbesundR 2      OpstadJ 3      StorvikH 4
 DuestolJ 5    HalgunsetK 4        KrohnS 2      PaulsenO 1    TaftesundT 1
 EXT_EL1 0        HatleH 2       KvammeN 3      RoppenJ 3       TautraK 4
 EXT_EL2 0     HauglandA 3     LegangerK 2      RorsetG 3   VarhaugvikA 5
EXT_MEK1 0       HaukasA 3        LovikJ 3        SandT 3        VikasO 0
EXT_MEK2 0        HolenJ 3       LystadG 2     SchevikJ 1        VikenR 2
```

```
FagerbekkK 1     HostmarkP 1      MegardJ 4      SkarvoyM 3       VollanL 4
FarstadO 3       HustadA 2      MerieauG 3    SkilbrigtP 3     VorpenessS 3
FarstadP 3      IversenR 3   MichaelsenC 4     SkjarsetT 3
;

sum{w in WORKERS} Allocated[w,j] [*] :=
     Bideford1 1             MAN9 1          TrollC11 1          VACKrohnS 1
     Borgland1 1           Maersk 1          TrollC12 1         VACKvammeN 1
        Brage1 1          Maracc1 1          TrollC13 1        VACKvammeN2 1
        Brage2 1          Maracc2 1          TrollC14 1        VACLegangerK 1
         EkoA1 1          NjordA1 1          TrollC15 1         VACLystadG 1
        Embla1 1          NjordA2 1          TrollC16 1         VACMegardJ 1
        Embla2 1          NjordA3 1          TrollC17 1     VACMichaelsenC 1
        Fjord1 1          NjordA4 1          TrollC18 1           VACMoenG 1
      Gazflot1 1         Oseberg1 1          TrollC19 1         VACNerlandJ 1
      Gazflot2 1        OsebergD1 1           TrollC2 1           VACNessJ 1
      Gazflot3 1        OsebergD2 1          TrollC20 1          VACNessJ2 1
      Gazflot4 1        OsebergD3 1          TrollC21 1         VACOpstadJ 1
         Gjoa1 1        OsebergF1 1          TrollC22 1        VACPaulsenO 1
    GullfaksA1 1        OsebergS1 1           TrollC3 1        VACSchevikJ 1
    GullfaksA2 1        OsebergS2 1           TrollC4 1        VACSkarvoyM 1
    GullfaksA3 1       Peregrino1 1           TrollC5 1       VACSkarvoyM2 1
    GullfaksA4 1       Peregrino2 1           TrollC6 1      VACSkilbrigtP 1
       Kristin 1       Peregrino3 1           TrollC7 1       VACSkogvollT 1
          MAN1 1       Peregrino4 1           TrollC8 1         VACSorvikJ 1
         MAN10 1      Petrobras1 1            TrollC9 1        VACSorvikJ2 1
         MAN11 1      Petrobras2 1         VACAandalD 1        VACSorvikJ3 1
         MAN12 1      Petroprod1 1          VACBuggeA 1        VACSorvikJ4 1
         MAN13 1            Siri1 1       VACDuestolJ 1          VACSovikI 1
         MAN14 1            Siri2 1      VACDuestolJ2 1        VACStorvikH 1
         MAN15 1            Siri3 1       VACFarstadO 1      VACTaftesundT 1
         MAN16 1        Sleipner1 1       VACFarstadP 1         VACTautraK 1
         MAN17 1        Sleipner2 1      VACFrisvollA 1        VACTautraK2 1
         MAN18 1         SnorreB1 1       VACGravdalE 1    VACVarhaugvikA 1
         MAN19 1         SnorreB2 1      VACGravdalE2 1         VACVollanL 1
          MAN2 1         SnorreB3 1        VACGravemO 1        VACVollanL2 1
         MAN20 1         SnorreB4 1       VACGravemO2 1       VACVorpenessS 1
         MAN21 1      StatfjordB1 1        VACHagsetK 1      VACVorpenessS2 1
         MAN22 1      StatfjordB2 1     VACHalgunsetK 1           Valhall1 1
         MAN23 1      StatfjordB3 1    VACHalgunsetK2 1           Valhall2 1
         MAN24 1      StatfjordB4 1         VACHatleH 1             VargA1 1
```

```
          MAN25 1          TrollB1 1       VACHatleH2 1          Visund1 1
           MAN3 1          TrollB2 1     VACHauglandA 1          Visund2 1
           MAN4 1          TrollB3 1       VACHaukasA 1          Visund3 1
           MAN5 1          TrollB4 1        VACHolenJ 1        WillInno1 1
           MAN6 1          TrollB5 1     VACHostmarkP 1        WillInno2 1
           MAN7 1          TrollC1 1     VACKloksethG 1        WillInno3 1
           MAN8 1         TrollC10 1        VACKonigT 1
;
```

CASE 2

Data file

```
set WORKERS:=  BlikasG        BuggeA         DuestolJ       FagerbekkK
               FarstadO       FarstadP       FrisvollA      GravemO
               GravdalE       GrovehagenH    HagsetK        HalgunsetK
               HatleH         HauglandA      HaukasA        HolenJ
               HustadA        HostmarkP      IversenR       JanssonE
               JohnsonP       KrabbesundR    KloksethG      KrohnS
               KvammeN        KonigT         LegangerK      LystadG
               LovikJ         MegardJ        MerieauG       MichaelsenC
               MoenG          MyrstadR       NerlandJ       NessJ
               OpstadJ        PaulsenO       RoppenJ        RorsetG
               SandT          SchevikJ       SkarvoyM       SkilbrigtP
               SkjarsetT      SkogvollT      SolbergS       StorvikH
               SorvikJ        SovikI         TaftesundT     TautraK
               VarhaugvikA    VikenR         VikasO         VollanL
               VorpenessS     AandalD        AasE           AaseggM
               EXT_EL1        EXT_EL2        EXT_MEK1       EXT_MEK2
;

set JOBS :=
OsebergS1      EkoK1          EldA1          COSL1          MAN1
Sleipner1      KizombaA1      BorglandD1     BorglandD2     COSL2
EkoXN1         EkoJ1          EkoXO1         Visund1        BorglandD3
Visund2        EkoXO3         KizombaA2      BerylA1        Heidrun1
SnorreA1       EkoK2          EkoA1          WestA1         OsebergF1
EkoK3          EkoXO5         EkoK4          OsebergF2      Maracc1
WestA2         BorglandD4     Gazflot1       EkoK5          AlaskanS1
Kristin1       BorglandD5     GullfaksA1     Asgard1        BorglandD6
Huldra1        Huldra2        Huldra3        Huldra4        Huldra5
```

```
Verksted1       Verksted2       Verksted3       OsebergC1       Draupner1
OsebergF3       B11             EkoK6           Visund3         SnorreB1
WestA3          Draugen1        BorglandD7      KizombaA3       Gazflot2
SnorreA2        BorglandD8      Grane1          SleipnerA1      Heidrun2
StatfjordA1     Huldra6         KizombaA4       MaerskG1        SleipnerA2
Maracc2 C       OSL3            GullfaksA2      SnorreB2        StatfjordC1
EkoJ2           GullfaksC1      OsebergC2       EkoK7           Peregrino1
Visund4         EldA2           COSL4           EkoK8           SleipnerA3
MaerskG2        EkoJ3           StatfjordA2     OsebergC3       NjordA1
OsloH1          JotunA1         BorglandD9      Verksted4
        VACBlikasG      VACBlikasG2     VACBlikasG3     VACFagerbekkK
        VACFarstadO     VACGravemO      VACGravdalE     VACGrovehagenH
        VACHagsetK      VACHagsetK2     VACHalgunsetK   VACHatleH
        VACHolenJ       VACHolenJ2      VACHolenJ3      VACHustadA
        VACJohnsonP     VACKvammeN      VACKonigT       VACLovikJ
        VACMegardJ      VACMichaelsenC  VACMoenG        VACNerlandJ
        VACNessJ        VACOpstadJ      VACSandT        VACSkilbrigtP
        VACSkjarsetT    VACSkogvollT    VACStorvikH     VACSorvikJ
        VACSorvikJ2     VACSorvikJ3     VACSovikI       VACVarhaugvikA
        VACVorpenesS    VACAandalD      VACAasE
;
#workerSkill: 1-Mek, 2-El
#workerExp: 1-Less experienced, 2-More experienced
param :         workerQual workerExp totalVac penaltyCost:=
BlikasG         2       1       32      0
BuggeA          1       1       0       0
DuestolJ        1       2       0       0
FagerbekkK      1       1       9       0
FarstadO        2       1       10      0
FarstadP        2       1       0       0
FrisvollA       1       2       0       0
GravemO 1       2       17      0
GravdalE        1       1       12      0
GrovehagenH     1       2       28      0
HagsetK         1       1       16      0
HalgunsetK      1       2       19      0
HatleH          2       1       23      0
HauglandA       1       2       0       0
HaukasA         1       2       0       0
HolenJ          1       1       14      0
HustadA         1       1       38      0
```

HostmarkP	2	1	0	0
IversenR	1	1	0	0
JanssonE	1	1	0	0
JohnsonP	1	1	4	0
KrabbesundR	2	2	0	0
KloksethG	1	2	0	0
KrohnS	1	1	0	0
KvammeN	1	1	35	0
KonigT	1	2	9	0
LegangerK	2	1	0	0
LystadG	2	1	0	0
LovikJ	1	1	9	0
MegardJ	2	2	6	0
MerieauG	1	1	0	0
MichaelsenC	1	1	14	0
MoenG	2	1	7	0
MyrstadR	1	1	0	0
NerlandJ	1	1	28	0
NessJ	1	2	3	0
OpstadJ	2	1	22	0
PaulsenO	1	2	0	0
RoppenJ	1	1	0	0
RorsetG	1	1	0	0
SandT	1	1	5	0
ScheviKJ	1	1	0	0
SkarvoyM	1	1	0	0
SkilbrigtP	1	1	43	0
SkjarsetT	1	2	31	0
SkogvollT	1	1	26	0
SolbergS	1	1	0	0
StorvikH	2	1	3	0
SorvikJ	1	2	33	0
SovikI	1	1	14	0
TaftesundT	1	1	0	0
TautraK	1	1	0	0
VarhaugvikA	1	2	19	0
VikenR	1	1	0	0
VikasO	2	1	0	0
VollanL	1	1	0	0
VorpenesS	1	1	7	0
AandalD	1	1	20	0

```
AasE            1       1       7       0
AaseggM         1       1       0       0
EXT_EL1         2       2       0       1000
EXT_EL2         2       2       0       1000
EXT_MEK1        1       2       0       1000
EXT_MEK2        1       2       0       1000
;


#startTime:     When the job starts
#durationTime: The duration of the job
#jobSkill:      Type of skill the job requires
#jobExp:        Type of experience the job requires
#offShore:      If the job is offshore in Norway the value 1 is set, 0
otherwise
# The time period is from 1 to 45 days


param : startDate durationDays jobQual jobExp offshore workersReq:=
OsebergS1       9       4       1       1       1       1
EkoK1           1       10      1       1       1       1
EldA1           26      14      1       1       1       1
COSL1           15      30      1       2       0       1
MAN1            9       4       1       1       0       1
Sleipner1       19      7       1       1       1       1
KizombaA1       1       14      2       1       0       1
BorglandD1      40      5       2       1       1       1
BorglandD2      26      16      2       1       1       1
COSL2           1       23      1       2       0       1
EkoXN1          28      13      1       2       1       1
EkoJ1           12      4       1       1       1       1
EkoXO1          21      13      1       1       1       1
Visund1         1       7       1       2       1       1
BorglandD3      40      5       1       2       1       1
Visund2         1       8       1       1       1       1
EkoXO3          21      13      1       1       1       1
KizombaA2       1       14      1       2       0       1
BerylA1         15      6       2       1       1       1
Heidrun1        1       17      1       2       1       1
SnorreA1        19      5       1       2       1       1
EkoK2           29      11      1       1       1       1
```

EkoA1	40	3	1	1	1	1
WestA1	11	7	1	1	1	1
OsebergF1	26	8	1	1	1	1
EkoK3	1	10	1	1	1	1
EkoXO5	24	17	1	1	1	1
EkoK4	1	10	1	1	1	1
OsebergF2	21	3	1	1	1	1
Maracc1	1	22	2	1	0	1
WestA2	9	11	1	2	1	1
BorglandD4	26	16	1	2	1	1
Gazflot1	1	26	1	1	0	1
EkoK5	1	10	1	1	1	1
AlaskanS1	1	25	1	2	0	1
Kristin1	12	3	2	1	1	1
BorglandD5	28	15	2	1	1	1
GullfaksA1	5	12	2	1	1	1
Asgard1	25	4	2	1	1	1
BorglandD6	41	4	2	1	1	1
Huldra1	9	6	1	1	1	1
Huldra2	37	6	1	1	1	1
Huldra3	9	6	2	1	1	1
Huldra4	37	6	2	1	1	1
Huldra5	23	6	2	1	1	1
Verksted1	1	15	1	1	0	1
Verksted2	19	5	1	1	0	1
Verksted3	29	9	1	1	0	1
OsebergC1	40	5	1	1	1	1
Draupner1	1	7	1	1	1	1
OsebergF3	26	8	1	1	1	1
B11	6	5	2	1	0	1
EkoK6	29	12	2	1	1	1
Visund3	1	8	1	1	1	1
SnorreB1	28	4	1	1	1	1
WestA3	6	14	1	2	1	1
Draugen1	33	8	1	2	1	1
BorglandD7	40	5	2	1	1	1
KizombaA3	1	14	2	1	2	1
Gazflot2	1	26	1	2	0	1
SnorreA2	13	3	1	1	1	1
BorglandD8	26	15	1	1	0	1
Grane1	16	14	1	1	1	1

SleipnerA1	26	14	1	1	1	1
Heidrun2	1	15	1	1	1	1
StatfjordA1	35	6	1	1	1	1
Huldra6	23	6	1	1	1	1
KizombaA4	1	14	1	2	0	1
MaerskG1	2	5	1	1	0	1
SleipnerA2	12	5	1	1	1	1
Maracc2	1	22	1	1	0	1
COSL3	20	25	2	1	0	1
GullfaksA2	6	9	1	2	1	1
SnorreB2	1	3	1	1	1	1
StatfjordC1	14	10	1	1	1	1
EkoJ2	40	5	1	1	1	1
GullfaksC1	1	8	1	1	1	1
OsebergC2	16	4	1	1	1	1
EkoK7	29	8	1	1	1	1
Peregrino1	3	23	1	2	0	1
Visund4	1	6	1	1	1	1
EldA2	26	24	1	1	1	1
COSL4	20	25	2	1	0	1
EkoK8	1	10	1	1	1	1
SleipnerA3	26	17	1	1	1	1
MaerskG2	2	5	2	1	0	1
EkoJ3	40	5	1	1	1	1
StatfjordA2	1	6	1	1	1	1
OsebergC3	26	10	1	1	1	1
NjordA1	1	3	1	1	1	1
OsloH1	7	12	1	1	0	1
JotunA1	16	4	1	1	1	1
BorglandD9	28	15	1	1	1	1
Verksted4	40	5	1	1	0	1
VACBlikasG	1	6	2	1	0	1
VACBlikasG2	16	12	2	1	0	1
VACBlikasG3	31	14	2	1	0	1
VACFagerbekkK	38	9	1	1	0	1
VACFarstadO	28	10	2	1	0	1
VACGravemO	2	17	1	2	0	1
VACGravdalE	1	12	1	1	0	1
VACGrovehagenH	12	28	1	2	0	1
VACHagsetK	14	5	1	1	0	1

```
VACHagsetK2    34    11    1    1    0    1
VACHalgunsetK  26    19    1    2    0    1
VACHatleH      22    23    2    1    0    1
VACHolenJ      2     3     1    1    0    1
VACHolenJ2     13    6     1    1    0    1
VACHolenJ3     22    5     1    1    0    1
VACHustadA     2     38    1    1    0    1
VACJohnsonP    29    4     1    1    0    1
VACKvammeN     10    35    1    1    0    1
VACKonigT      31    9     1    2    0    1
VACLovikJ      20    9     1    1    0    1
VACMegardJ     2     6     2    2    0    1
VACMichaelsenC 12    14    1    1    0    1
VACMoenG       12    7     2    1    0    1
VACNerlandJ    12    28    1    1    0    1
VACNessJ       42    3     1    2    0    1
VACOpstadJ     14    22    2    1    0    1
VACSandT       1     5     1    1    0    1
VACSkilbrigtP  2     43    1    1    0    1
VACSkjarsetT   14    31    1    2    0    1
VACSkogvollT   19    26    1    1    0    1
VACStorvikH    13    3     2    1    0    1
VACSorvikJ     1     6     1    2    0    1
VACSorvikJ2    15    4     1    2    0    1
VACSorvikJ3    22    23    1    2    0    1
VACSovikI      26    14    1    1    0    1
VACVarhaugvikA 26    19    1    2    0    1
VACVorpenesS   7     7     1    1    0    1
VACAandalD     6     20    1    1    0    1
VACAasE 26     7     1     1    0    1
;
```

Model file

```
set WORKERS ;    #w
set JOBS ;       #j
param offShore{j in JOBS};         #Offshore job or not
param durationDays{j in JOBS};     #The number of days the job takes
param startDate{j in JOBS};        #The start date for a job
param addOffshore{j in JOBS} = ceil(offShore[j]*durationDays[j]*0.333);
                                   #Rest period for offshore restriction
```

```
 param  finishDate{j  in  JOBS}  =  startDate[j]  +  durationDays[j]  +
addOffshore[j];                      #The finish date is the start date
                                     plus duration

 param jobQual{j in JOBS};           #Qualifications required for this job

param workersReq{j in JOBS};         #The number of workers with the
                                     specified skill that are required to
                                     complete this job

 param workerQual{w in WORKERS};     #Qualifications the worker has to
                                     have assigned a job

 param workerExp{w in WORKERS};      #Level of experience the worker has
                                     to have to be assigned a job

 param jobExp{j in JOBS};            #Level of experience required for his
                                     job

 param totalVac{w in WORKERS};       #Total number of VSF days within
                                     the period

 param penaltyCost{w in WORKERS};    #Penalty cost per worker hired
                                     externally

 var Allocated{w in WORKERS, j in JOBS} binary;
                                     #1 if worker w is allocated to job j,
                                     0 else

 var WorkerUsed{w in WORKERS} binary;
                                     #1 if worker w does any job in this
                                     time period, 0 else

 minimize NumberOfWorkers:
sum{w in WORKERS} (WorkerUsed[w] + (WorkerUsed[w]*penaltyCost[w]));
                                     #The objective is to minimize the
number
                                     of workers that we need to complete
                                     these jobs
```

```
 subject to MaxJobsAtATime {w in WORKERS, t in 0..max{j in JOBS}
finishDate[j]}:
sum{j in JOBS: startDate[j]<= t and finishDate[j] > t} Allocated[w,j] <=
1;                                    #For any period t, a worker can only
                                      be allocated to at most one job

 subject to RightQualifiedWorkers {j in JOBS}:
sum{w in WORKERS: workerQual[w] = jobQual[j] and workerExp[w] >=
jobExp[j]} Allocated[w,j] = workersReq[j];
                                      #This guarantees that we have the
                                      required amount of workers with the
                                      right skills with the right
                                      experience for each job

 subject to LinkingConstraint {w in WORKERS, j in JOBS}:
WorkerUsed[w] >= Allocated[w,j];
                                      #This will find out if a worker is
                                      doing any job at all

 subject to MaxWorkDays {w in WORKERS}:
sum{j in JOBS} (Allocated[w,j]*durationDays[j]) - totalVac[w] <= 34;
                                      #For each worker the total number of
                                      working days cannot exceed a given
                                      amount of the total working period

subject to VAC1: Allocated['BlikasG','VACBlikasG'] = 1;
subject to VAC2: Allocated['BlikasG','VACBlikasG2'] = 1;
subject to VAC3: Allocated['BlikasG','VACBlikasG3'] = 1;
subject to VAC4: Allocated['FagerbekkK','VACFagerbekkK'] = 1;
subject to VAC5: Allocated['FarstadO','VACFarstadO'] = 1;
subject to VAC6: Allocated['GravemO','VACGravemO'] = 1;
subject to VAC7: Allocated['GravdalE','VACGravdalE'] = 1;
subject to VAC8: Allocated['GrovehagenH','VACGrovehagenH'] = 1;
subject to VAC9: Allocated['HagsetK','VACHagsetK'] = 1;
subject to VAC10: Allocated['HagsetK','VACHagsetK2'] = 1;
subject to VAC11: Allocated['HalgunsetK','VACHalgunsetK'] = 1;
subject to VAC12: Allocated['HatleH','VACHatleH'] = 1;
subject to VAC13: Allocated['HolenJ','VACHolenJ'] = 1;
subject to VAC14: Allocated['HolenJ','VACHolenJ2'] = 1;
subject to VAC15: Allocated['HolenJ','VACHolenJ3'] = 1;
subject to VAC16: Allocated['HustadA','VACHustadA'] = 1;
```

```
subject to VAC17: Allocated['JohnsonP','VACJohnsonP'] = 1;
subject to VAC18: Allocated['KvammeN','VACKvammeN'] = 1;
subject to VAC19: Allocated['KonigT','VACKonigT'] = 1;
subject to VAC20: Allocated['LovikJ','VACLovikJ'] = 1;
subject to VAC21: Allocated['MegardJ','VACMegardJ'] = 1;
subject to VAC22: Allocated['MichaelsenC','VACMichaelsenC'] = 1;
subject to VAC23: Allocated['MoenG','VACMoenG'] = 1;
subject to VAC24: Allocated['NerlandJ','VACNerlandJ'] = 1;
subject to VAC25: Allocated['NessJ','VACNessJ'] = 1;
subject to VAC26: Allocated['OpstadJ','VACOpstadJ'] = 1;
subject to VAC27: Allocated['SandT','VACSandT'] = 1;
subject to VAC28: Allocated['SkilbrigtP','VACSkilbrigtP'] = 1;
subject to VAC29: Allocated['SkjarsetT','VACSkjarsetT'] = 1;
subject to VAC30: Allocated['SkogvollT','VACSkogvollT'] = 1;
subject to VAC31: Allocated['StorvikH','VACStorvikH'] = 1;
subject to VAC32: Allocated['SorvikJ','VACSorvikJ'] = 1;
subject to VAC33: Allocated['SorvikJ','VACSorvikJ2'] = 1;
subject to VAC34: Allocated['SorvikJ','VACSorvikJ3'] = 1;
subject to VAC35: Allocated['SovikI','VACSovikI'] = 1;
subject to VAC36: Allocated['VarhaugvikA','VACVarhaugvikA'] = 1;
subject to VAC37: Allocated['VorpenesS','VACVorpenesS'] = 1;
subject to VAC38: Allocated['AandalD','VACAandalD'] = 1;
subject to VAC39: Allocated['AasE','VACAasE'] = 1;
```

Run file

```
model full.mod;
data full.dat;

solve;

display sum{w in WORKERS} WorkerUsed[w] > full.sol;
display NumberOfWorkers > full.sol;
display WorkerUsed > full.sol;
display {w in WORKERS} sum{j in JOBS} Allocated[w,j] > full.sol;

display {j in JOBS} sum{w in WORKERS} Allocated[w,j] > full.sol;

option omit_zero_rows 1;

option display_width 700;
display Allocated > full.sol;
```

```
exit;
```

Solve file (illustrated partially without the Allocated variable due to excess amount of output)

```
sum{w in WORKERS} WorkerUsed[w] = 50

NumberOfWorkers = 1050

WorkerUsed [*] :=
AandalD 1        FrisvollA 1      JanssonE 1         MoenG 1     SkogvollT 1
AasE 1           GravdalE 1      JohnsonP 1      MyrstadR 1      SolbergS 0
AaseggM 0      GravemO 1     KloksethG 1      NerlandJ 1       SorvikJ 1
BlikasG 1   GrovehagenH 1        KonigT 1         NessJ 1        SovikI 1
BuggeA 1       HagsetK 1   KrabbesundR 1       OpstadJ 1      StorvikH 1
DuestolJ 1    HalgunsetK 1        KrohnS 0      PaulsenO 1    TaftesundT 0
EXT_EL1 0        HatleH 1       KvammeN 1       RoppenJ 1       TautraK 0
EXT_EL2 0     HauglandA 1     LegangerK 1       RorsetG 0   VarhaugvikA 1
EXT_MEK1 1       HaukasA 1        LovikJ 1         SandT 1        VikasO 1
EXT_MEK2 0        HolenJ 1       LystadG 1      ScheikJ 0        VikenR 1
FagerbekkK 1     HostmarkP 0       MegardJ 1      SkarvoyM 1       VollanL0
FarstadO 1       HustadA 1      MerieauG 0    SkilbrigtP 1     VorpenesS 1
FarstadP 0      IversenR 1   MichaelsenC 1     SkjarsetT 1
;

sum{j in JOBS} Allocated[w,j] [*] :=
AandalD 2     FrisvollA 2      JanssonE 3         MoenG 2     SkogvollT 2
AasE 3      GravdalE 3      JohnsonP 4      MyrstadR 3      SolbergS 0
AaseggM 0       GravemO 3     KloksethG 2      NerlandJ 2       SorvikJ 4
BlikasG 4   GrovehagenH 3        KonigT 2         NessJ 3        SovikI 3
BuggeA 3       HagsetK 4   KrabbesundR 3       OpstadJ 3      StorvikH 3
DuestolJ 3    HalgunsetK 2        KrohnS 0      PaulsenO 2    TaftesundT 0
EXT_EL1 0        HatleH 2       KvammeN 2       RoppenJ 3       TautraK 0
EXT_EL2 0     HauglandA 1     LegangerK 3       RorsetG 0   VarhaugvikA 2
EXT_MEK1 1       HaukasA 2        LovikJ 5         SandT 4        VikasO 1
EXT_MEK2 0        HolenJ 5       LystadG 2      ScheikJ 0        VikenR 2
FagerbekkK 3     HostmarkP 0       MegardJ 3      SkarvoyM 2       VollanL0
FarstadO 3       HustadA 2      MerieauG 0    SkilbrigtP 1     VorpenesS 3
FarstadP 0      IversenR 3   MichaelsenC 3     SkjarsetT 2
;

sum{w in WORKERS} Allocated[w,j] [*] :=
```

AlaskanS1 1
Asgard1 1
B11 1
BerylA1 1
BorglandD1 1
BorglandD2 1
BorglandD3 1
BorglandD4 1
BorglandD5 1
BorglandD6 1
BorglandD7 1
BorglandD8 1
BorglandD9 1
COSL1 1
COSL2 1
COSL3 1
COSL4 1
Draugen1 1
Draupner1 1
EkoA1 1
EkoJ1 1
EkoJ2 1
EkoJ3 1
EkoK1 1
EkoK2 1
EkoK3 1
EkoK4 1
EkoK5 1
EkoK6 1
EkoK7 1
EkoK8 1
EkoXN1 1
EkoXO1 1
EkoXO3 1
EkoXO5 1
EldA1 1
EldA2 1
Gazflot1 1
Gazflot2 1
Grane1 1
GullfaksA1 1
GullfaksA2 1
GullfaksC1 1
Heidrun1 1
Heidrun2 1
Huldra1 1
Huldra2 1
Huldra3 1
Huldra4 1
Huldra5 1
Huldra6 1
JotunA1 1
KizombaA1 1
KizombaA2 1
KizombaA3 1
KizombaA4 1
Kristin1 1
MAN1 1
MaerskG1 1
MaerskG2 1
Maracc1 1
Maracc2 1
NjordA1 1
OsebergC1 1
OsebergC2 1
OsebergC3 1
OsebergF1 1
OsebergF2 1
OsebergF3 1
OsebergS1 1
OsloH1 1
Peregrino1 1
Sleipner1 1
SleipnerA1 1
SleipnerA2 1
SleipnerA3 1
SnorreA1 1
SnorreA2 1
SnorreB1 1
SnorreB2 1
StatfjordA1 1
StatfjordA2 1
StatfjordC1 1
VACAandalD 1
VACAasE 1
VACBlikasG 1
VACBlikasG2 1
VACBlikasG3 1
VACFagerbekkK 1
VACFarstadO 1
VACGravdalE 1
VACGravemO 1
VACGrovehagenH 1
VACHagsetK 1
VACHagsetK2 1
VACHalgunsetK 1
VACHatleH 1
VACHolenJ 1
VACHolenJ2 1
VACHolenJ3 1
VACHustadA 1
VACJohnsonP 1
VACKonigT 1
VACKvammeN 1
VACLovikJ 1
VACMegardJ 1
VACMichaelsenC 1
VACMoenG 1
VACNerlandJ 1
VACNessJ 1
VACOpstadJ 1
VACSandT 1
VACSkilbrigtP 1
VACSkjarsetT 1
VACSkogvollT 1
VACSorvikJ 1
VACSorvikJ2 1
VACSorvikJ3 1
VACSovikI 1
VACStorvikH 1
VACVarhaugvikA 1
VACVorpenesS 1
Verksted1 1
Verksted2 1
Verksted3 1
Verksted4 1
Visund1 1
Visund2 1
Visund3 1
Visund4 1
WestA1 1
WestA2 1
WestA3 1

Appendix D – E-mails

Sylthe, B. 2011. Barbro.Sylthe@NOV.com . [E-mail] Message to Skutholm, M. (martin.skutholm@himolde.no). Sent 11.04.11, 14:27. [Accessed 12.04.11].

Hei – her noen opplysninger:

Omsetning 2008	*Omsetning 2009*	*Omsetning 2010*
36 651' USD	*43 322' USD*	*45 330' USD*

I tillegg til at omsetningen har økt de siste årene har også dekningsbidraget i prosent økt. Noe som gjenspeiler at vi har blitt operasjonelt flinkere da våre rater stort sett har vært uendret de senere årene.

Prosesser og prosedyrer er på plass og iverksatt.

Selv om industrien har hatt en dropp de siste årene, fra 2007 – viser det seg at AM har opprettholdt og faktisk økt aktiviteten. Det som kan være synergi for AM NOV sin del de neste årene er at mangelen på ny salg har ført til redusert backlog for installasjon av nykran (som er en Ettermarket jobb), som igjen medfører at vi må selge mere service for å oppnå samme resultat. Det er her utfordringen med kapasitetsutnyttelse kommer inn. Ved installasjoner er det planlagte turer over min. fire uker, de reiser ut 2 og 2 eller flere, og det er fra to til fem turer pr team, samt at disse oppdragene planlegges i perioder fremover. Service er mer uforutsigbart, korte ikke planlagte turer (Korrektiv vedlikehold) og det igjen medfører krevende ressursplanlegging fra administrasjonsgruppen vår.

Har dessverre ikke tallene for nysalg, men om det er nødvendig kan jeg få disse i løpet av uken. (kontrolleren er på tur)

Håper dette kan hjelpe dere litt!

Barbro

Kilen, A. 2011. Arild.kilen@NOV.com . [E-mail] Message to Skutholm, M. (martin.skutholm@himolde.no). Sent 23.05.11, 15:16. [Accessed 24.05.11].

Hei Martin,

Lykke til med oppgaven i morgen. Jeg ser frem til å få en kopi.

Ansatte er :

NOV Molde (inkl. Hjelset) pr. Mai 2011 – 332 ansatte

Derav Aftermarket Molde pr. Mai 2011 – 140 ansatte

Mvh
Arild Kilen