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REVIEW
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VOC Emission from Cargo Tanks

Crude oil transported with ships consists mainly of a mixture of hydrocarbons ranging from light to heavy. During loading, voyage and discharge, the crude oil may not always be in equilibrium with the gas atmosphere in the cargo tank. As a consequence some light-end products known as volatile organic compounds (VOC) are released from the cargo to the tank atmosphere. Most of the released gas is emitted from the cargo tanks to the atmosphere when the tanks are being filled, but some VOC may also be emitted on the laden voyage.

Methane, being a part of the VOC, is a greenhouse gas with a global warming potential (GWP) of 21 (CO2 has a GWP of one). The remainder of the VOC, known as NMVOC (VOC apart from methane), forms together with NO_X and sunlight ground-level ozone that is detrimental to vegetation and human health. Norwegian authorities have committed themselves to a 37% reduction in NMVOC emissions compared to the 1990 level (Gothenburg Protocol, 1999). Since the storage and loading of crude oil on ships are responsible for more than 50% of Norway's NMVOC emissions, the Norwegian authorities have implemented stringent emission reduction regulations in this area.

The Gulf of Mexico Air Quality Study reported by the US Minerals Management Service revealed that ozone concentration in the onshore areas of Texas and Louisiana frequently exceeded the National Ambient Air Quality Standard. In 1993 emissions from oil and gas exploration, development and production in the Outer Continental Shelf (OCS) regions of the Gulf of Mexico contributed a small but significant fraction of this ozone concentration. In 2001 the US Minerals Management Service decided that the operation of Floating Production Storage and Offloading units (FPSOs) and shuttle tankers was an acceptable means for producing and transporting crude oil in OCS. Unless they are appropriately dealt with, VOC emissions from such activities will increase ozone concentrations in onshore areas in the future.

Loading crude oil from the buoy.

How to determine the magnitude?

Several methods have been used to determine VOC emissions from cargo tanks. These include:

- Measuring the flow, pressure, temperature and composition of the gas emitted. This provides the most accurate determination of VOC emissions.
- Simulating with the aid of a dedicated simulation tool. The input data to the simulation tool must be representative.
- Determining the difference between the loaded and discharged mass of cargo. Results may be hampered by measurement errors at both ends, which may be larger than this difference.
- Sampling of the loaded and discharged cargos with determination of their composition, which is used to calculate the VOC emission.The uncertainty may become large.

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Offshore Operations Logistics Support

Offshore operations logistics support (OOLS) is the main "umbilical" linking the onshore support organizations, including suppliers, and the revenue/-generating assets offshore. MARINTEK's approach to the offshore supply chain is made up of an understanding of the requirements and potential of each part of the supply chain. Better utilization of offshore supply vessels and building up the supply chain as a smooth and well-functioning complete entity are important elements of our approach.

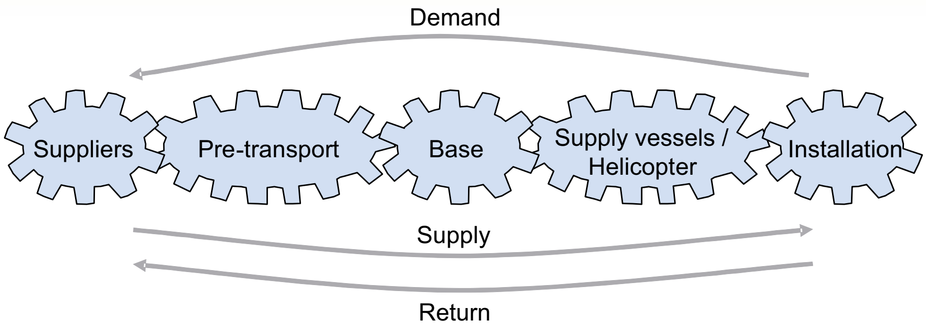

Figure 1. The offshore operations supply chain.

An illustration of the concept of an integrated system is offered by the gear/wheels in Figure 1. Well-functioning chain interfaces are important for gears to work smoothly together, avoiding reductions in service and/or increased costs, as well as friction-free throughput of demand information and supplies of goods and services.

Like all logistics operations, OOLS has a cost side and a service side. Improvements in these two aspects of the logistics equation may be realized through better resource utilization per chain element and/or improvements in system interactions as a whole. For the latter, the dimensioning management of the demand side versus the supply side is important. It is vital to balance the demand and supply sides in order to obtain a correct and cost-effective service through improved utilization of the chain elements.

Fleet optimization, planning and management

The use of offshore supply vessels is a major cost element in the offshore supply chain. Optimization of the utilization of offshore supply vessels can produce significant cost savings.

Irrespective of the types of resources or tasks being planned, planning largely consists of assigning resources to a set of tasks, or adjusting resources or tasks. Examples of resources are helicopters, supply vessels, beds, and personnel. These are allocated to tasks in a given sequence, making up a complex operation that is taken care of by experienced personnel. The MARINTEK software package TurboRouter©-MARINTEK has been developed to provide decision support to operating personnel in this process. Combining the speed of the computer with the insight of experienced operating personnel has proven to be of great value in daily operations.

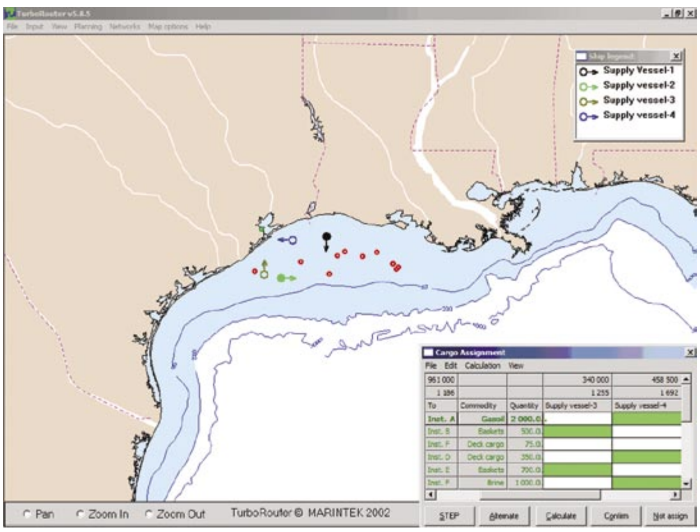

Figure 2. Fleet scheduling of supply vessel operations.

Integrated operations

Offshore supply vessels and supply base operations are parts of the logistical infrastructure and resources needed for the offshore supply chain. The offshore demand chain is driven by offshore operations such as drilling and well operations, production, maintenance and modifications. The integration of functions involved in the demand and supply side of the operations is an important element in achieving improved overall logistics support with respect to good service and cost-effective operations.

Essential elements include:

- differentiation of supply requirements and good demand management
- consolidation and effective resource management in the supply chain
- implementation of decision-support systems and collaborative processes to improve real-time decision-making capabilities.

Agreements between operational stakeholders and providers on the support and supply side are important means of increasing efficiency.

Decision support in operations support centres

With the development of integrated onshore operations support centres, the use of integrated processes and decision support systems along the lines presented above

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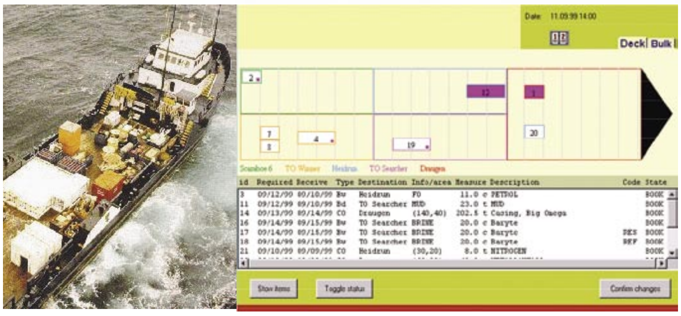
LoadManager – Cargo Stowage and Load Segregation

MARINTEK's LoadManager prototype was developed for stowing the deck and the bulk areas of vessels supplying oil installations or platforms off coast of Norway. A graphical user web interface is used to "drag and drop" cargo from the quayside.

The system checks the content and position of the cargo stowed on the ship, and alerts the user if the regulations for handling dangerous goods are violated, based on the cargo description and the segregation rules (IMDG – International Maritime Dangerous Goods Code). The information contained in the system also facilitates the planning of cargo loading and discharge at destinations, and the handling of back-loads from the installations. These features improve vessel utilisation and raise safety levels when handling cargo, as well as contribute to follow shipping regulations. LoadManager can easily be configured to handle other modes of transport than supply shipping such as cargo handling at a terminal.



Stowing a supply vessel.

The main objectives of the LoadManager are:

- To ensure that transport of dangerous goods is handled safely, and in accordance with current regulations for transport of dangerous and/or polluting materials. The system will also be used to report the cargo to the parties involved and to the authorities.
- To make offshore supply services more efficient by optimizing loading and discharging at the supply base, and by taking care of the planning of back-loads safely and efficiently. It will also optimize deck utilization on board the vessel by providing a better overview at an early stage and thereby offering the possibility of carrying more cargo. It has also functionality to view status below deck in the tank area also used for supply.
- To provide a better overview of the location of the containers on board the vessel, on the installation or at the terminal. A good overview of cargo on board the vessel enables the operator to plan lifting operations in advance to be more efficient and safe. He can also plan deck operations and thereby take actions to prevent dangerous situations. Cargo and containers for individual offshore fields should be placed within the service areas on board the supply vessel dedicated for the specific offshore fields.
- If an accident occurs the system can be used to find more information about the cargo and thereby provide the appropriate instructions to deal with the accident (EMS – Emergency Schedule and MFAG – Medical First Aid Guide information)

Benefits of using LoadManager

- Improved vessel utilization
- Less downtime at the shore base and the platform
- Accurate and efficient load and backload planning
- Easy to use
- Improved invoicing and charging
- Correct segregation of dangerous goods
- Improved safety of crane operations
- Automatic warning and explanation of violation of safety regulations.

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becomes even more important. The main business case for good integration of logistics processes and decision-support systems is improved integrated decision timelines and quality. Our approach to decision-support system thinking covers the long-term strategic planning horizon, via tactical planning to operational day-to-day planning.

Among the benefits are:

- finding the correct trade-off between cost effectiveness versus operational benefit and long- and short-term risk
- enabling proactive and/or highly responsive disruption management (loss mitigation)
- focus on mission-critical decision-support systems for management and control of operations
- judgement of the operations support centres based on their situational awareness

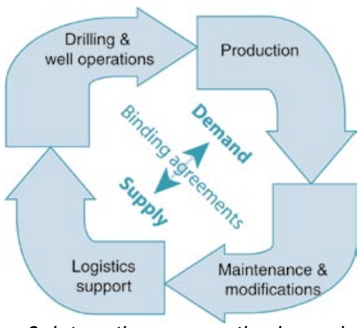

Figure 3. Interactions among the demand- and supply-side actors in the offshore supply chain.

As a result, in addition to the direct physical system issues,the proposed process, which provides system support and necessary competence development, will increase personnel motivation and work satisfaction by the staff of the operations centres.

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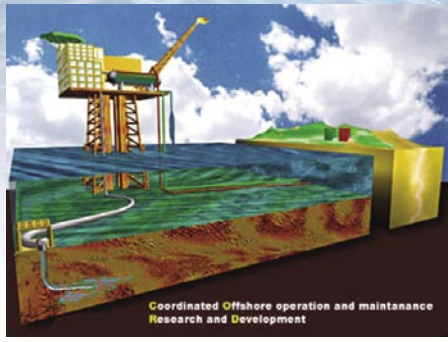
E-Operation and Maintenance



E-Field, Smart Field, Intelligent Field, Operations and Integrated Operations are frequently-used terms for the new era in offshore and subsea oil and gas development and operations. E-field is about working more efficiently through the integration of data and models, and utilising the powers of cross-disciplinary teamwork and work processes.

Applying E-field solutions is highly applicable to all oil-producing regions and to both "green-field" and "brown-field developments". However, strategies for e-Operation need to take account of whether we are dealing with "brown field" where the implementation of new e-field technology is often more difficult, or a "green field" site where it is possible to build in a high level of automation, instrumentation and sophisticated ICT solutions from the outset.

Annual costs related to operation and maintenance on the Norwegian continental shelf (NCS) is predicted to remain steady in the range of USD 4 – 6 billion over the next ten years. At the same time, unit costs are expected to increase greatly. It is believed that e-Operation and maintenance will make major contributions to dealing with this challenge. More comprehensive utilisation of the growing amounts of operational data will produce a change of paradigm for increased efficiency, and will provide new opportunities for the offshore industry.

To meet this challenge, CORD, a joint industry project involving several operators on the NCS and Norwegian research institutes was launched in 2001. CORD projects were financed by the participating operators; Statoil, Norsk Hydro, ConocoPhillips, BP and Esso, in the amount of 3 million USD during the three-year period 2002 – 2004. The CORD secretariat is managed by MARINTEK.

Three CORD projects have addressed three different aspects related to e-Operation;

- MTO issues related to remote control
- Technical conditions related to remote monitoring
- Safety issues related to assessment of safety-critical equipment.

These projects all produced significant results of high interest to the industry:

- Practical CORD MTO methodology for allocation of offshore and onshore functions
- Handbook describing a cost-benefit based method for qualification of systems for remote condition monitoring of offshore equipment
- Methodology for identification and follow-up of safety-critical equipment ensuring the integrity of barriers
- New methodology for condition assessment of safety-critical ESVs

All the methodologies involved were developed and tested on the basis of real cases and installations, and have shown very good results.

CORD is continuing in the shape of four new projects in 2005 – 2007, with an increased budget.

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VOC Emission from .....

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MARINTEK has measured variations in emissions from 0.1 kg VOC per tonne of cargo (terminal loading) to 2.8 kg VOC per tonne (offshore loading in bad weather).

VOC emission reduction methods

Reducing the release of VOC from the cargo will obviously reduce the VOC emission. This can be achieved, for example by:

- Reducing the content of light ends in the cargo before loading.
- Reducing the temperature of the cargo.
- Filling cargo tanks sequentially instead of in parallel.
- Increasing the cargo tank pressure.
- Reducing the amount of crude oil washing.
- Reducing the roll and pitch of the vessel.

If the above measures cannot be employed, or they do not provide a sufficient reduction in VOC emission, other measures must be adopted, such as:

- The emitted gas is returned ashore or to the supplying unit, e.g. a floating storage unit, where it can be appropriately treated.
- A hydrocarbon gas is used as blanket gas during discharge instead of inert gas. This is particularly suitable for a floating production, storage and offloading unit where the blanket gas is taken from the process, and returned to the process again during tank filling.
- Recovery plants that separate VOC from the inert gas and store the separated VOC. Such plants have been and still are installed on many shuttle tankers that carry cargos from Norwegian offshore fields.

MARINTEK's VOC experience

MARINTEK has participated in several industry projects, combining in-house dedicated software and hands-on measurement expertise. For example, we have:

- Specified instrumentation to perform emission measurements, and carried out VOC emission measurements on shuttle tankers for the past 20 years.
- Participated in developing and testing recovery plants.
- Simulated and measured emission reduction efficiency of recovery plants and processes.
- Used model tests to:
  - Identify the parameters that determine the level of the VOC emission.
  - Study processes for recovery plants
- Developed tools for VOC emission simulation. The latest version, VOCSim, has been verified against measured values.
- Used VOCSim to:
  - Determine VOC and NMVOC emission factors for offshore and onshore loadings.
  - Determine the effect on the emission of changing operational parameters such as cargo composition.
  - Provide process boundary conditions for recovery plants.

MARINTEK can offer operators of FPSOs and shuttle tankers to quantify VOC emissions and to assist in their search for ways of reducing such emissions.

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