Improved vessel safety in offshore supply services

L.Hansson
Norwegian Marine Technology Research Institute

ABSTRACT: The supply services in the North Sea are a working place with a high level of personnel risk mainly in occupational accidents. Supply vessels, anchor handling vessels and stand-by vessels are operating in a harsh environment in an integrated logistic chain including offshore installations, mobile installations and shore bases. An ongoing research project for a Norwegian oil company addresses the risk for the vessels in the supply services and will develop a risk model that aims at giving decision support in the process of selecting the correct risk reducing measures. This paper describes available methodology for risk analysis and their application in the maritime and offshore industry. Further it discusses the similarities and differences between the vessels in the supply services and the rest of the maritime and offshore industry with regard to traditions, working conditions, operations and regulations. Finally, it gives some guidelines for choosing a risk methodology for the vessels in the supply services. The methodology will be based on task analysis for the most exposed operations on the supply and anchor handling vessels.

1 INTRODUCTION

The number of injuries in offshore supply services has increased year by year since the reporting started in 1996. The increasing number of injuries is the background for the work reported in this paper and the work is based on the injuries reported in the oil company Statoil. Statoil has made considerable efforts to stop this negative development and the choice of risk-reducing measures has been based on common knowledge, experience and accident investigations. One measure is employee or user involvement. The captains operating the vessels participate in a seminar every year were safety aspects are the main topic. These seminars have given positive effects, and the number of injuries in year 2002 has decreased drastically compared to the previous year. A systematic approach to assist the choice of the most effective risk-reducing measures could be helpful.

The events and injuries on the vessels in the supply services are first of all so-called occupational accidents. Occupational accidents happen during work operations, there is a direct connection between the cause and the consequence and the accidents often involve only one or a few people. The consequence can be serious; from first aid injuries to death but the material damage is usually limited. If a person falls down a ladder and breaks his leg during a work operation, this is an occupational accident. The other type of accidents is the major accidents were the chain from the cause to the accidental event can be long, many people can be involved and the material damage can be substantial. One relevant major accident in the supply services is collision between vessel and installation. In 2000, 12 collisions (or contacts) were reported in Statoil.

The risk model described in this paper is developed in order to give decision support for the choice of risk-reducing measures. The second objective for this risk model is to give enhanced knowledge and understanding about risky situations. The next sections give an overview over risk analysis, the different methods available and a detailed description of the model developed for use in the offshore supply services. The last section of this paper discusses the model that has been developed in relation to the objectives. It also outlines ideas for further work.

2 THEORY AND METHODOLOGIES

2.1 *Risk analysis and available methods*

Risk analyses have been used in all types of industries over the past decades. One major objective of risk analysis is to measure risk for the purpose of risk control. In the development phase of a project, risk analysis is used as a design tool. Risk analysis plays an important role in the task of developing safety related rules and regulations in maritime and offshore industries. Formal safety assessment applied to the maritime industry has this as its primary aim. Risk analysis can be used for educational purposes as well. According to the British sociologist Robert Moore "*hazards and risks are often identified and controlled most effectively by those involved in the work tasks by a process of constant monitoring or risk evaluation from below. In order for operational-level safety intelligences to be effective, workers need to be involved in the process of risk assessment*". (Flin, 1996)

Several methods exist for use in risk analysis. While the first generation of risk analysis covered only technical aspects it has been realized that the whole story cannot be told without including and understanding the influence of human and organizational factors. Some of the available methods are Fault trees, Event trees, FMEA (Failure Mode Effect Analysis), Risk Assessment Matrix, Influence Diagram, HRA (Human reliability assessment) and HAZOP (Hazard Operability Analysis).

The area of risk analysis is mainly developed and used for major accidents. Major accidents have complicated cause-consequence chains and a potential of ending up in a catastrophe. The other category of accidents is the occupational accidents, events happening during work operations and with a direct connection between cause and consequences. The consequences are limited to one or a few people, but the damage or injury to the exposed person may be serious and in worse case fatal. Some of the methods used for major accidents can be used for occupational accidents as well but there are also some additional methods for occupational accidents (Harms-Ringdahl, 1993); Deviation analysis, Action error analysis, Energy analysis, Job Safety Analysis, MORT and Change Analysis.

2.2 *Human error and occupational accidents*

Kirwan (Kirwan, 1990) points out that one of the future challenges within risk assessment and human reliability analysis is to cover individual accidents (occupational accidents). "*The HRA (Human Reliability Analysis) field has mainly concerned itself with the high risk, high technology industry sector, including nuclear power plants and chemical plants. There exist however, a large number of other lower technology sectors, e.g. mining, which often incur a high risk via a large number of "small" accidents (one or two fatalities), rather than (high technology) industries where the high risk is caused by a very small probability of an accident with many and serious consequences. This is clearly an area where applied human reliability should be able to help reduce risk."*

2.3 *Influence diagram and Bayesian network*

The influence diagram is an important part of the developed model and this method is described more in detail. Mathematically, fault trees are probabilistic influence diagrams. (Barlow, 1998) The fault tree approach was based on engineering considerations and was invented by mechanical engineers. Influence diagrams provide an excellent graphical tool for understanding probabilistic conditional independence. The influence diagram is a graphical representation of the relationships between random quantities that are judged relevant to a real problem. The fault tree is the more useful representation for analysing system failure events. For decision problems the influence diagram is the more useful representation.

Influence diagrams have a sound mathematical basis in Bayesian probability theory. According to Rettedal (1997) the Bayesian approach is considered attractive since it does not break down in the absence of experience data and allows a systematic integration of expert opinions.

According to Øien (2001) there are specific advantages with the influence diagram (or Bayesian network) technique. It provides an intuitive representation of the causal relationships linking the organizational factors to the quantitative risk model. This intuitive representation is essential when communicating with experts. The relations as well as the states may be represented probabilistically, and there is no limitation on the number of states (thus we are not restricted to binary representation). Interaction between factors can be explicitly taken into account, e.g. the effect of poor training and poor procedures at the same time may be worse than the added individual effects of these factors being in a bad state.

The number of weights that have to be assigned is rather large even for moderately complex models. The propagation of the rates and the weights are an inherent part of the influence diagram techniques, and are no longer a problem even for large models. It has recently been solved by the development of "clever" algorithms. What really constitutes the practical challenge is the assignment of weights, that is the conditional probabilities given all possible combinations of states. Usually some kind of expert judgment procedure is proposed in order to establish these weights, but also data-driven approaches have been suggested.

3 CASE AND RISK PICTURE

3.1 *The case*

The offshore supply services cover the transport of goods to the oil and gas installations in the North Sea by supply vessels. Further it covers anchor-handling activities performed by special equipped vessels and the emergency preparedness which is taken care of by the stand-by vessels. The supply vessels transport food, chemicals, piping, equipment and spare parts from the shore base to the installations offshore and empty cargo back to the shore base. The stand-by vessels are located in a position close to the installation they are serving. Their main aim is to assist the installation in an emergency situation. To be well prepared they repeatedly rehearse, which may be a risky situation in itself. The anchor handlers are involved when the mobile drilling rigs move from one location to another. Their task is to fasten and unfasten the drilling rig anchors. The case to be discussed in this paper focuses on the supply services in Statoil.

Statoil operates the supply services but the vessels are contracted from different shipowners. All crew in the supply services have a shift with 4 weeks on duty and 4 weeks off duty. Traditionally the crew were recruited among seamen or fishermen, and for these groups the supply services were an attractive work place. Today there is a recruitment problem, one reason is that the conditions for the personnel onboard the vessels are worse the conditions for the crew onboard the installations. For the offshore workers on the installation the wages are higher, the working hours are shorter (they are on duty for 2 weeks and off duty for 3 or 4 weeks) and in addition or partly due to this, the offshore worker has a higher social status than the vessel crew.

The supply services operate in accordance to rules and regulations from the Norwegian Maritime Directorate and partly from the Norwegian Petroleum directorate. Vessels are operating partly according to Statoil procedures and partly according to shipowners' procedures. The captain is in charge onboard the vessel but is reporting to the Statoil Traffic control.

3.2 *Risky operations*

The main risky operations identified for the vessels in the supply services are:

- loading and unloading from supply vessels
- anchor handling activities
- maintenance
- navigation along installations

3.3 *Risk picture of the vessels in the supply services compared to merchant vessels*

"Normal accidents" by Perrow (1984) dedicates a section to marine accidents. The accidents described by Perrow are related mainly to merchant vessels, and according to Perrow the marine system is an "error-inducing system". In an error-inducing system, the components promote error inducement and it does not help to change one component. The tendency to attribute blame to operator error is prominent in an error-inducing system. Perrow predicts that the main reason for the marine system being error-inducing, is that the victims of an accident have a low status, third party victims of pollution and toxic spills are anonymous and the effect of pollution is delayed and the federal presence is minor.

It can be argued that the vessels in the supply services constitute a less error-inducing system than the merchant vessels. The vessels in the supply services operate closer to shore and in close contact with the other actors in the offshore industry. The safety level in the supply services is compared to the safety level at the oil and gas installations and this makes the accidents more visible. As a collision between vessel and installation is a threat to the installation itself, the system is less error inducing because the victims have a high status, the victims are not anonymous, the effect is not delayed and the federal presence is high. Some conditions affecting safety according to "Normal accidents" (Perrow 1984), are discussed below. The statements marine accident is given in italic.

Captains and crew can be on duty for 40-50 hours without sleep. This has been and is still a problem in the offshore business, on the installations as well as on the vessels in the supply services. For the vessels, especially anchor-handling activities can result in long hours. Relocation of a mobile drilling rig is a cost intensive operation and it is important to avoid delay.

The captains are avoiding radio contact. This is not described as a problem for the captains in the supply services. They are in frequent contact with the other actors in the services. Communication problems may however be addressed as a problem and can partly be blamed on the seamen tradition.

The captain is in supreme command and problems may stem from incompetent captains. If one person has unquestioned, absolute authority over a system, a human error by that person will not be checked by others. The competence of the captains on the vessels has not been questioned, but the average age of the captains is high, and the industry is concerned about the recruitment situation in the future.

4 DESCRIPTION OF THE DEVELOPED MODEL

4.1 *Model objective and choice of methods*

The aim of the developed risk model is first of all to give decision support to the process of prioritizing between risk reducing measures. A second aim is to enhance competence and knowledge about risky situations. Employment involvement is one important way to reduce the risk and the developed model will also fulfill this aim. The development process itself may serve as a process that increase the level of skill. Based on the fact that the model will be semi-quantitative, will be used for occupational accidents and decision support and for educational purposes it was decided to use a combination of the influence diagram and operational task analysis.

4.2 *Limitations*

The model has been developed for the loading and unloading operations from a supply vessel. The loading and unloading operations can be divided into three categories dependent on the cargo handled; deck cargo, bulk and casing. SYNERGI is the reporting system (database) used by Statoil and other companies for accidents and near-misses. The database contains reports on injuries on the vessels from 1996 until today. There have been 31 injuries during unloading/loading. The number of injuries reported on supply vessels in this period is approximately twice as high. The second half of these events happened during maintenance, in the machine room or in the kitchen.

The reporting of the injuries in SYNERGI includes a short verbal description and different coding describing the event, the causal chain and the personnel involved. Coding is defined for direct as well as the organizational factors. The organizational factors are however most often not described.

4.3 *Influence diagram*

An influence diagram has been drawn for the reported injuries. The first level represents the different event types, such as "hit by" and "hit against". The second level represents the direct causes and the third level the organizational factors. The influence diagram presented in Figure 1, includes the number of events and direct causes.

4.4 *Organizational factors in the influence diagram*

The organisational factors are approximately the same factors as described by Øien (2001) that are representative for the accidental event "leak of hydrocarbons" on offshore installations. The factor "individual" was described but not used by Øien (2001). For the supply services with a risk picture characterised by occupational accidents, the "individual" factor seems rather important.

The organizational factors are:

- **Individual factor** refers to slips and lapses. Loss of motivation and fatigue are examples on individual factors.
- **Competence** refers to the training and competence that is necessary for the operating personnel to carry out their jobs.
- **Procedures** refer to all written and oral information describing how to perform the operational and maintenance tasks in a correct and safe manner.
- **Planning** refers to the preparation being necessary before execution of tasks.
- **Design** refers to the physical construction of equipment. The design must be such that operation can be performed in a safe manner.
- **Management** refers to management on the vessel, in the shipowner's office and in the Statoil organization.

The connections between the organizational factors and the direct causes are made based on common knowledge. These are hardly indicated in accident reporting. In the resulting model an expert team of people with more experience in the field, should draw these connections. The relative importance between the organizational factors and probabilities should be included for the model to be used in decision support.

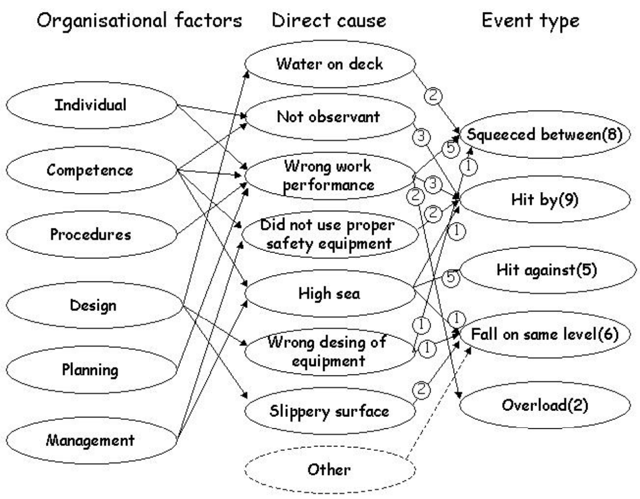

Figure 1 Influence diagram for events related to loading/unloading from supply vessels.

4.5 *Direct causes in the influence diagram*

The direct causes are identical to those used in the reporting system SYNERGI. The list of direct causes is long and these are reported for most of the events. As we can see the list of direct causes consist of a mixture of causes and of factors influencing on the consequences. "High sea" is a direct cause but needs to be combined with some sort of risky operation or lack of observation from the personnel. The cause "high sea" occurs frequently and this can indicate that loading/unloading operations have been done under too rough conditions.

"Did not use proper safety equipment" is rarely a direct cause. The event does not happen because the personnel does not use safety equipment such as helmets and glasses, but the consequence of the event is dependent on the use of the safety equipment. It can be argued that, if safety equipment was used in the reported injuries, these events would not have been reported at all because the personnel would not been injured.

The causes "water on deck" and "slippery surface" are quite similar. This is a general problem for the supply vessels and the vessel deck becomes slippery when the sea flushes over the deck. This problem can be prevented with a good vessel design.

4.6 *Event types in the influence diagram*

The event types used in the influence diagram are also taken from the reporting system SYNERGI. In the event type "hit by", a moving object is hitting a person. While in the event type "hit against" the person itself is moving and is hit by something. "Squeezed between" is used both when describing a person being squeezed between two containers and when a finger is squeezed in the bulk hose coupling. "Overload" has been used a couple of times describing the situation were a foot is twisted. "Hooked" has been used only once for an incident in which the wire was splintered and hooked in a person's hand.

4.7 *Task analysis*

One of the objectives with the risk model is to increase the understanding and applying competence in knowledge to the risky situations and for this purpose; a set of task analysis was drawn. The three categories of operations (loading of deck cargo, loading of casing and loading of bulk) were described in three separate task analysis. It was obvious from the reported events that the injuries could be connected to a limited number of the subtasks and based on this it was decided to keep the task analysis on a course level. Some of the injuries could not be connected directly

to the task analyses and were defined as "general deck work". Figure 2 presents the task analyses for the loading/unloading operations of deck cargo. The shaded subtask, fasten/loosen the hook on the cargo, indicates where most of the injuries are happening.

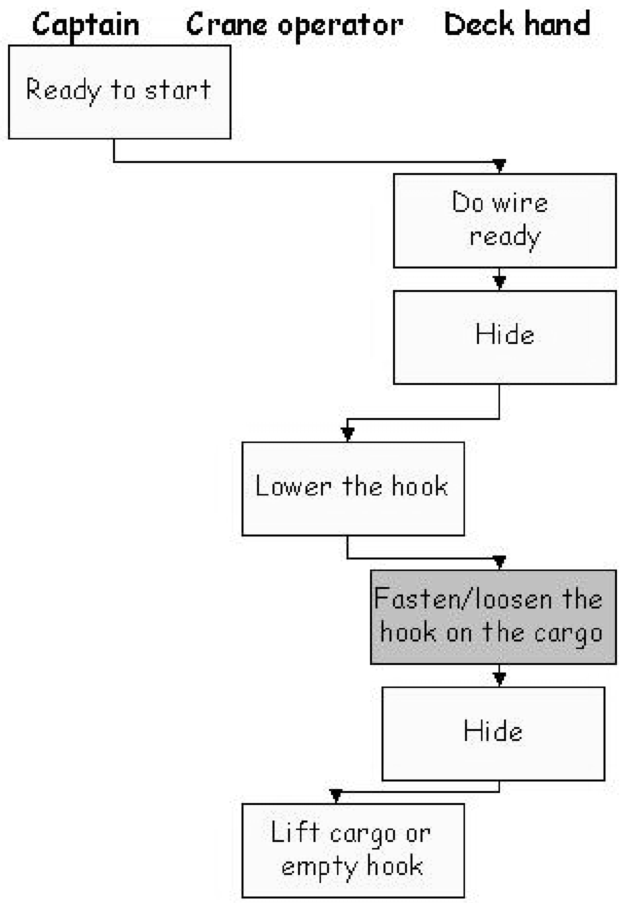

Figure 2 Task analyses for unloading of deck cargo

The task analyses describe the main tasks carried out by the captain, the crane operator and the deck hand; the main actors in the loading/unloading process. The captain decides if the sea state and the weather conditions are good enough to start the operation and gives the start signal. The deck hand checks the load manifest and makes the first cargo ready for loading. The operations continue as a close cooperation between these three actors until the cargo is placed on the installation deck or the return cargo on the vessel deck.

5 APPLICATION OF THE DEVELOPED MODEL

5.1 *Decision support for risk reducing measures*

A number of different risk reducing measures are identified but the problem is to prioritizing between these measures. The influence diagram will support these decisions. More time for rest, reduced noise on the vessel and improved quality of safety equipment are some examples on risk reducing measures. The first step in the analysis is to discuss the effect of these measures on the technical and organisational factors on the left side in the influence diagram. This discussion should be performed in an expert panel and the documentation of the discussion is essential. The second step is to quantify the influence and thereafter the resulting effect of the number of unwanted events can be calculated.

One result from the model is that the number of injuries can be reduced by for example 5 % by the introduction of a specific risk reducing measure. Held together with the cost of the measure, this give a cost benefit estimate. The other result, which is as important, is the discussion about why and how this measure affects the safety level.

The influence diagram in Figure 1 indicates that "hit by" and "hit against" are two important types of events ending in injuries. The most prevailing causes of these events are that loading and unloading is performed in sea states that are probably too harsh ("high sea"). If we look at "best practice" and procedures we find some limitations given by conditions when the operation should be stopped. In real life it is difficult to give an exact measure of the sea state and the wind speed. The organizational factors applicable for these events are "competence", "management" and "procedures". The captain is the one to decide if operations are to continue or stop, and to be able to do so the captain needs the right competence and experience. He is under pressure by the crew on the installation because they need the cargo and he is under pressure from the rig owner company because they will have a good reputation when they are to renegotiate the contract with Statoil. In addition the captain has to consider the safety of his crew. If the conditional limits for safe operations were more conservative, these limitations would have been a support for the captain under these circumstances.

5.2 *Educational purposes*

In order to use the influence diagram directly for educational purposes, examples can be presented in the influence diagram by marking out the events and causes and supporting this by a verbal description. One example is given in Figure 3. The event described in the influence diagram in Figure 3 happened during unloading of a container from the installation deck to the vessel. The crane had been used for lifting of casing on the installation deck previous to this operation and was therefore equipped with a double "forerunner". The high weight of this forerunner made it difficult for the

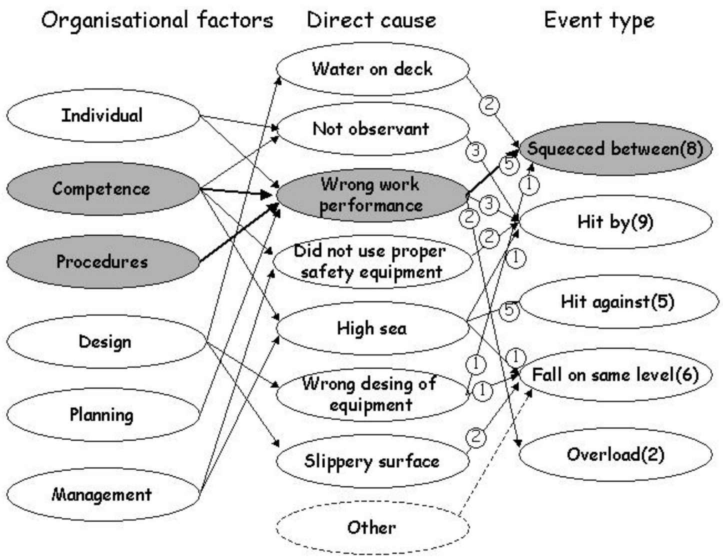

Figure 3 Influence diagram illustrating one given event

deckhand to loosen the hook and he squeezed his finger between the hook and the container. The result was a broken finger. The direct cause in this event is "wrong work performance"; the forerunner should have been removed before starting the container lifting. The vessel crew should not have accepted to start operation with this double forerunner. The organizational factors are partly "competence" and partly "procedures". The reason for not removing the forerunner could be that the crew did not know the procedures or they could have known the procedure but left the forerunner on to save some time. The influence diagram should be verified and quantified by support from expert panels and by expert judgment.

The task analyses presented in Figure 2 cannot be used for educational purposes on their own. If we combine the task analysis and the influence diagram this will give us some useful information, see Figure 4. This example describes the operation loading/unloading of deck cargo. About half of the events could be connected to one specific sub-task in the task analyses while the rest could be classified as "general deck work". As the model in Figure 4 indicates, the division in different task analyses result in a low number of events connected to each of the operations, and as these are described by many different causes the result is more a description of some specific events than a general model.

The stories from concrete events should be used in order to give an increased understanding and knowledge. If the reported injuries could be told as a story, using animation, text or video this could be attached to the task analysis.

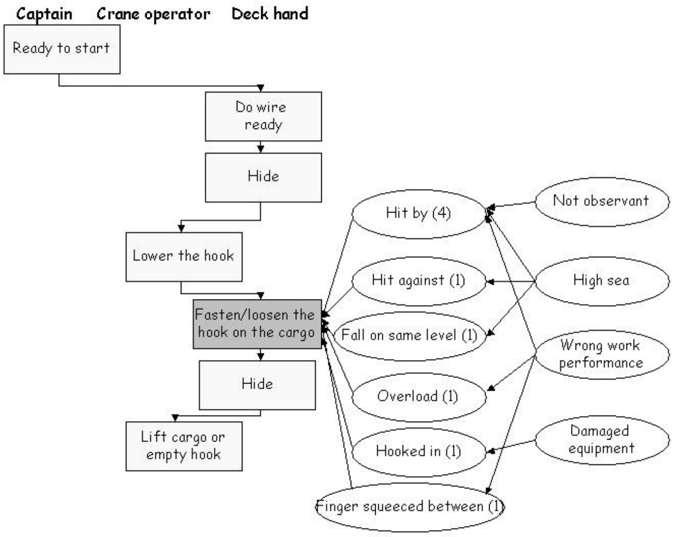

Figure 4 Combined task analysis and influence diagram for loading/unloading of deck cargo

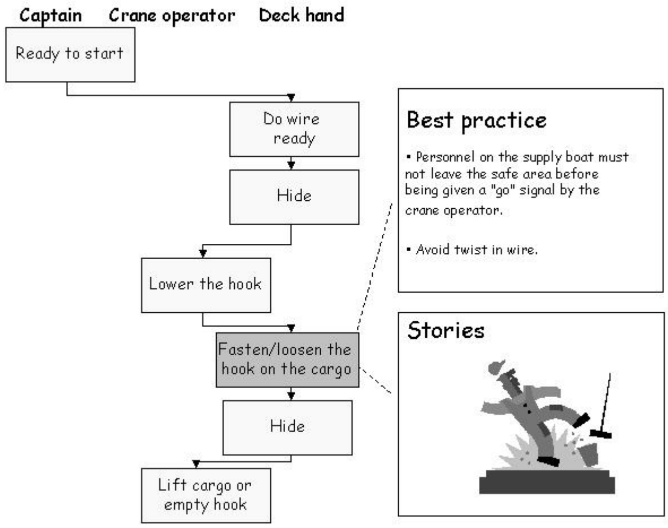

Figure 5 Task analysis used for educational purposes

If the same task analyses also give a link to "best practice", this will be a good basis for a training package. This idea is presented in Figure 5. The model in the influence diagram will be used to choose some of the most common events. The influence diagram and the description of events should be updated in a continuous process as more events are reported. In addition, the influence diagram can be used in training about how to report accidents. This will illustrate what "happens" with the reported material.

5.3 *Best practice*

Crane operations are regarded as one of the most high-risk offshore activities. Statoil operates around 15 cranes on 15 installations and an effort to improve operation and safety has been made through the "best practice" work, (Hepsø, 2001). The development of this common practice was made to create a collective reflection process among the 400 crane operators and banks men in Statoil. A task force spent considerable time in discussing the values of the work practice via search conference seminars and these seminars discussed what is required to further improve safety in crane and lift operations with given safety targets? What are the elements of a safety culture? How do we communicate with those involved in crane and lifting operations? And what are the skills and demands expected from those working in this domain? The resulting written and explicit practice does not describe how crane and lifting should be conducted in detail. It includes tips on important issues, how to maintain the crane, prepare and execute crane operations, how to handle critical situations, how to load cargo with what straps, how to communicate during crane and lifting operations, provide guidelines for special lifts, the transport of personnel and internal transport on the installation. Examples of formulations related to crane and lift operations:

"All lifting operations are high risk. A good practice for each person is to think through the whole lifting operation and evaluate if all necessary efforts for safe operations are taken".

"Everybody involved in the loading/unloading operation must be equipped with UHF communication equipment that have a headset and an integrated microphone".

"A safety zone must be defined before the operations start".

"Personnel on the supply boat must not leave the safe area before being given a "go" signal by the crane operator".

The idea with the "best practice" is that the conversation shall be kept going, meaning reflection and action as a continuous activity. Best practice has been made for the anchor handling activities as well. These are supported with animated stories describing some of the serious accidents.

6 CONCLUSION

The influence diagram is suitable for the purpose of decision support. The developed influence diagram includes the most important events happening during loading/unloading operations from supply vessels. These represent about half of the events reported on the supply vessels. The rest of the events happened during maintenance, in the machinery room and in the galley. It should be considered to include all these events and events occurring during anchor-handling activities and on the stand-by vessels in the same influence diagram.

For educational purposes it should be considered using the stories from concrete events. The overall influence diagram gives a good overview of the most relevant events. A combination of task analysis, influence diagram, best practice and stories should be developed for training purposes.

The implementation of the risk model in the safety management system should be illustrated showing the process from accident reporting, through risk reducing initiatives to risk statistics. The developed model should be built on the same categories and definitions as the reporting system SYNERGI, to secure the possibility of this implementation. The safety management system should also include the training aspects and feedback of experience from the accident reporting to the crew, management and to procedure development.

7 REFERENCES

Barlow, R.E., (1998), *Engineering Reliability*, University of California, Berkeley, California

Flin, R., Slaven, G., (1996), *Managing the offshore installation workforce*, Penn Well Publishing Company ISN 0-87814-396-3

Harms-Ringdahl, L., (1993), *SAFETY ANALYSIS principles and practice in occupational safety*, Elsvier Science Publishers LTD., London

Hepsø, V., Botnevik, R., (2001), *Improved Crane Operations and Competence Development in a Community of Practice*, Paper, Statoil, Norway

Kirwan, B., 1990, Evaluation of Human Work, Chapter 28 in Human Reliability Assessment, Taylor& Francis Ltd, ISBN 0-85066-480-2

Øien, K. (2001), *Risk Control of Offshore Installations*, NTNU Report 200104, Trondheim, Norway

Perrow, C. (1984), *Normal Accidents, Living with High-Risk Technologies*, Basic Books, New York

Rettedal, W.K., (1997), *Quantitative Risk Analysis and structural reliability analysis in construction and marine operations of offshore structures*, Stavanger University College, Stavanger, Norway