Human Reliability Assessment of Maritime Teams During Hazardous Operations

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SUMMARY

The paper introduces the concept of System Integrity Level (SIL) and its use when characterising hazardous operations. The operation under investigation here is the embarkation and disembarkation of stores from a ship. The stores in this investigation were assumed as non-hazardous but requiring a trained team and specialist equipment. The investigation compared the relative benefit of having an additional team member working to ensure the safety of the personnel within the team. Eight specialist participants made a set of comparisons between team performance carried out with no safety specialist and teams working with a safety specialist. It was assessed that the introduction of the safety specialist may make a substantial contribution to the reduction in error of the non-hazardous elements of the manual handling operations.

KEYWORDS

Human Reliability, teams, hazards

Introduction

The concept of Safety Integrity Levels is used within various parts of the engineering profession to generate indicators able to describe the safety of their products. It is supported by ISO 61508.

The SIL is related to the probability of Failure on Demand (Table 1).

Table 1: SIL and PFD

Safety Integrity Level	Probability of Failure on Demand
1	0.1 – 0.01
2	0.01 - 0.001
3	0.001 – 0.0001
4	0.0001 – 0.00001

The SIL assigned to a system is not a function of the equipment alone but is assigned taking account of the hazard. It is an important indication of the degree of protection afforded by a system. Hence it is important when estimating the degree of protection afforded by equipment in operations carried out within a maritime environment where hazardous materials are involved.

The stores/loads described in this assessment are assumed to be intrinsically safe. These are stores that might be handled in the routine loading and unloading of ships prior to embarkation or on return from an operation.

There are two aspects to the SILs. The first directly involves the hazardous nature of the stores, while the second addresses the impact of store within the context of the operation, on the individual. These impacts are referred to as Local Hazards to the Individual (LHIs).

In this case the hazards being addressed are those involving risks to the individual (LHIs) as a result of human error. This means the hazard is not a function of the stores' material content but only such characteristics as the volume and mass in the context of manual handling within the ship and alongside.

However, there is little specific empirical evidence associated with human performance on maritime team tasks including error rates which can be used when ergonomists support SIL investigations.

The Ergonomics Issue

Human Reliability Assessments (HRAs) are used widely throughout the UK engineering profession. However, for many maritime assessments, we have to borrow extensively from data gathered with the prime purpose of being used within the nuclear industry.

There is a substantial system reliability literature which links equipment reliability to SILs, and the best means of combining various sources of information to enhance overall equipment reliability. These address the high hazard aspects of operation but it is also necessary to understand the hazards to the individuals who may be working in teams as part of the operation.

The human data that is available generally refers to individual performance with a specified set of equipment where he/she has total responsibility for a set of activities. However, the category of manual handling tasks being addressed in this study are carried out by groups acting as a team where each member is dependent on the other. The team is the important unit: individuals have roles which must be considered in the context of the team and the overall system which includes the equipment.

The question then is how can human reliability data for a team be generated, so that it can be compared with other team organisations or the teams where a variety of aids have been introduced?

There are numerous sources of work which address the organisational and cultural influences on the performance reliability of an individual. These include:

(a) Adhikari, Sondipon, Bayley, Clare, Bedford, Tim, Busby, Jerry, Cliffe, Andrew, Devgun, Geeta, Eid, Moetaz, French, Simon, Keshvala, Ritesh, Pollard, Simon J. T. and others (2021) Human Reliability Analysis: A Review and Critique. Technical report. University of Manchester, Manchester, UK
(b) Barry Kirwin (1994) who reported on supervision as an influencing factor of the order of a single magnitude.

However, the emphasis is generally on the individual and hence team performance would be estimated as the sum of individual performances. This is true no matter which the reliability estimation technique is used.

There are few sources of information on human reliability to help understand how reliability estimates can be associated with team working where the focus is on the team rather than a set of individuals.

In the case of embarking and disembarking of stores from a naval ship, we are investigating a task which has been carried out for centuries as it is highly dependent on the architecture and design of the ships. (Obviously, container ships are specifically designed to avoid the events addressed here.) Although concentrating on an operation which is largely external to the ship, it may also be an operation which is a normal part of seagoing routine i.e. moving stores through the compartment of the ship.

The composition of teams is important and especially as we need to take into account the roles, their skill sets and knowledge, and their sizes and strengths.

In this investigation, we wish to find out:

(a) The potential benefits of employing additional personnel within a team in terms of error reduction.
(b) The benefit of a preferred team compositions expressed in terms that help support the SIL rating of a system and its associated operational hazards.

Maritime Operations

The application considered here is embarkation and disembarkation of stores: operations which have changed little over time. In the maritime environment, much of the operational work is carried out by highly trained teams. There is extensive research in the research literature to show how reliability estimates can be combined for a set of individuals but the estimation processes tend to consider the performance of team members as being largely independent.

The particular tasks that I am addressing here can involve substantial numbers of personnel over a sustained period of time. The individuals involved may know the other team members well and take up their stations for the task in a preplanned and well trained routine. All of the team members may be specifically qualified for their role.

The Approach

Tainsh (2021) described work to generate a set of human reliabilities for use when assessing the performance of a maritime command team. The technique employed was taken from Hunns (1982), as reported by Kirwin (1994). However, it is based on the work of Thurstone (1927) which is an entirely general technique for describing comparative judgements.

The advantage of using a technique based on Thurstone is that it is identical no matter what the application. Hence it offers an effective way of comparing two sets of characteristics, such as team compositions, when conducting a set of tasks.

The work reported here, employs the same approach as my previous work on command teams, but will address an operation which includes a set of tasks that include manual handling and team coordination.

SQEP employees of BAES were asked to make comparative judgements on teams of users and their performance reliability.

The Overall Aim

The aim was to investigate whether it is possible to estimate human reliabilities for teams, and whether teams of different compositions can perform sufficiently differently that team composition may be used when estimating the SIL rating of a system.

The Tasks

Discussions were held with personnel who had served in relevant occupational roles and had experience of manual handling, in order to develop a list of tasks which could characterise the embarkation and disembarkation of stores. The list of tasks is summarised in Table 2 along with a brief statement of a possible additional role.

All of the tasks are associated with hazards/LHIs and form part of the overall operation.

The Trial

A group of eight SQEP participated – all had experience of this category of work where there was a high risk and special equipment was used. Most had experience of working on military systems while two had relevant non-military experience.

Each participant completed the task in a quiet interview room with the author.

The Briefing

The purpose was explained. The participants were told that the investigation was addressing team performance and the composition of the two teams carrying out the tasks. Their comparative judgements would include:

(a) Initial performance assessment of a team of users on tasks as currently specified.
(b) A second assessment of a team where an additional person was added with a specific safety/protection role to ensure that a hazard to a team member was avoided.
(c) A comparison between the two team's safety performance where the comparison must be made in terms of human reliability.
(d) Each team's performance on these tasks will be assessed in terms of human reliabilities i.e. the likelihood of error leading to injury due to a hazard.

Table 2: Initial summary description of the team's members, their tasks, and the additional team member role

No.	Initial Description	Hazard	Additional role for protection	Operation Name
1	The embarkation pallet is lowered onto the stores.	Dropped store	Safety role	Initial dockside loading Lifting from Dockside
2	The soft sling (used by the dockside crane for lifting the pallet) is secured incorrectly.	Dropped store	Sling checker	
3	Loss of control when lifting the stores with the dockside crane.	Crush hazard	Controller support	
4	With the pallet inclined, the embarkation hoist raises the stores and is over raised.	Dropped store	Controller support	Movement into the ship.
5	Lowering the stores into the ship	Crush hazard	Safety role	
6	The control system or operator error causes rotation of the pallet	Dropped store	Controller support	Moving out of ship
7	Personnel are not stood clear and their hands become trapped.	Crush hazard	Safety role	
8	Operators controlling the stores trap their hands.	Crush hazard	Safety role	Lowing on to dockside

A comparison table was constructed (as shown for the case of three tasks in Table 3). However, the matrix in this case is sixteen by sixteen matrix. (The grey boxes on the diagonal are not addressed.) At no time did I question or seek clarification on the outcome of the participants' judgements.

Each person completed 120 assessments and the outcome was recorded manually prior to being fed into a table for analysis.

Table 3: Comparison Table for comparison between three items

	Task 1	Task 2	Task 3
Task 1			
Task 2			
Task 3			

The HRA Estimation

The data analysis progressed through five stages (Hunns, Kirwin)

(a) The data from each participant was recorded on a data sheet and a “Raw Frequency Matrix” compiled.
(b) The “Proportion Matrix,” was calculated, and the “Transformation X Matrix” derived.
(c) The “Column-Difference Z Matrix” was derived.
(d) The scale values were calculated using calibration points taken from HEART. These were selected anticipating a widespread in the error rates. There is no naval data available to this investigation.
(e) Finally the probabilistic values are computer.

The Results

The data analysis gives the human performance reliabilities for the tasks, but I can only quote the ranks here (Table 4) as the quantitative results reflect the operational experience and equipment used by the participants.

Table 4: Rank order of error rates, highest rank is consistent with high error rates.

No.	Revised Issue Description	Human Error Probability Rank	Human Error Probability Rank
1.1	The embarkation pallet is lowered onto the stores using the dockside crane. Operators controlling the pallet insert their hands between the pallet and the stores.	8	
1.2	Additional safety role – checking individual safety and compliance with procedures.		9
2.1	The soft sling (used by the dockside crane for lifting the pallet) is secured incorrectly and the stores falls causing fuel leak or injury to personnel.	5	
2.2	Sling checker – engineering assurance to enable compliance with procedures.		13
3.1	Loss of control when lifting the stores with the dockside crane. Stores impacts personnel or equipment causing personal injury.	6	
3.2	Controller support – supervisory checker to enable compliance with procedures.		15

No.	Revised Issue Description	Human Error Probability Rank	Human Error Probability Rank
4.1	With the pallet inclined, the embarkation hoist raises the stores and is over raised causing a clash. The load path fails and the stores runs away causing injury to personnel.	7	
4.2	Controller support – supervisory checker to enable compliance with procedures.		16
5.1	Whilst lowering the stores into the ship the operators fail to keep their hands clear of the hatch operating causing injury.	3	
5.2	Additional safety role – checking individual safety and compliance with procedures.		10
6.1	As the stores is raised up from the ship, the control system or operator error causes rotation of the pallet, the hoist cable to snag and overload the load path causing failure which results in a dropped load of stores.	4	
6.2	Controller support – supervisory checker to enable compliance with procedures.		11
7.1	As the hoist starts to lift the pallet out of the compartment personnel are not stood clear and their hands become trapped in moving equipment.	2	
7.2	Additional supervisory safety role – checking individual safety and compliance with procedures.		12
8.1	The dockside crane lowers the stores onto the dockside facility. Operators controlling the stores trap their hands between the stores and the table.	1	
8.2	Additional supervisory safety role – checking individual safety and compliance with procedures.		14

We have to be careful in making numerical claims as we used a small sample of participants to make the judgements. Additionally, we have to be careful in making quantitative claims as we do not have a wealth of actuarial data to act as calibration points. However these results are consistent with expert experience.

There are two general results:

(a) All teams which employed a safety role to address hazards in the operational teams are associated with lower error rates than when a specific safety role is not employed.
(b) It is possible to report that in all cases where there was a safety team member there were two orders of magnitude improvement over the task with no safety role.

Additional specific consideration was possible for specific applications.

Conclusions

In this case we were addressing the users' injuries due to hazards and the reliability of human performance. However, studies such as this indicate the general value of the technique for other ergonomics/human factors investigations where comparisons are needed. They can yield results which can be understood and acted upon within the context of system development or assessment.

It is important to note that the error rates observed when there was a person responsible for safety were consistent with the SIL levels that are often required when handling high hazard stores. Such results can be important as part of the safety case, to include estimates of LHIs. It is conventional to quote the SIL values for equipment but using techniques such as developed here we can quote estimates for both the equipment and the personnel involved. It is most important that the estimates that are quoted can be easily related to the application and its hazards.

References

Adhikari, Sondipon, Bayley, Clare, Bedford, Tim, Busby, Jerry, Cliffe, Andrew, Devgun, Geeta, Eid, Moetaz, French, Simon, Keshvala, Ritesh, Pollard, Simon J. T. et al (2021) Human Reliability Analysis: A Review and Critique. Technical report. University of Manchester

Hunns D M (1982) Discussion Around a Human Factors Data-Base. An Interim Solution: The Method of Paired Comparisons. In High Risk Safety Technology, A E Green (Ed). John Wiley, UK

Kirwin B (1994) A Guide to Practical Human Reliability Assessment, Taylor and Francis, UK.

Tainsh (2021) Estimating Human Reliabilities for Maritime Control Systems, Contemporary Ergonomics & Human Factors 2021, CIEHF.

Thurstone L. L. (1927) A Law of Comparative Judgements. Psychological Review Vol 34, pp 273-286.