

Hoisting: What could possibly go wrong?

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SUMMARY

The handling of hazardous materials requires the careful consideration of potential human errors and their consequences. Further to several risk assessment and safety justification activities in support of hoist equipment and hoist operations design, a baseline model of hoisting operations, potential human error and consequences was developed. This model is presented as a useful starting point for any safety assessor undertaking hazard analysis in the context of high hazard hoisting operations.

KEYWORDS

High hazard, Hoisting, Model, Human Error, Nuclear

Introduction

Wherever hazardous material is required, at some point it must be handled and transported. To enable hazardous materials to be handled safely, they are packaged, often in vessels, containers, or flasks that when sealed correctly, prevent the hazardous material from escaping, and provide withstand protection against accidental impacts. Either due to the volume of material or the design of the container, the size and mass of the overall package usually precludes manual handling. Therefore, at some point mechanical handling, and hoisting is necessary.

The hoisting of hazardous materials introduces a range of potential fault sequences that could lead to significant consequences that must be managed to being As Low As Reasonably Practicable.

Risk reduction typically requires the implementation of an array of safety systems, or safeguards, which may be mechanical or engineered, administrative systems, or human-based actions. The identification of the required safeguards may be necessary in support of the design of hoisting equipment and operational processes, and the implementation of safe systems of work (SSoW).

Required safeguards are typically identified through risk assessment, which in high hazard contexts may take the form of Hazard and Operability (HAZOP) studies and Failure Modes and Effects Analysis (FMEA). Their subsequent assessment is presented in detailed Hazard Analysis (HAZAN).

The risk assessment process would seek to identify the worst-case unmitigated consequences, in order to identify the necessary protection systems and safety measures required to reduce the risk to acceptable levels.

Given the potentially significant claims on the role of the operator in support of safety, Human Factors (HF) assessment can play a key role in identifying the potential for human error, which may for example lead to a latent fault in the system, an initiating event, a failure to recover, or a failure to mitigate the consequences of error.

Although the context of high hazard hoisting operations may vary significantly between organisations and locations, there is a large degree of commonality in the potential hazards and

risks, the safety measures that should be implemented, and the claims placed on operators to ensure operations are undertaken safely.

Method

A generic baseline model has been developed to provide a useful starting point for any safety assessor undertaking hazard analysis in the context of high hazard hoisting operations. It is a compilation of hoist operation tasks, potential human errors and likely consequences, developed following HF professional support to a variety of safety assessment activities over a number of years for a number of Nuclear Site Licensees. These assessment activities included Task Analysis, Human Error Identification, Human Reliability Assessment, Hazard Identification (HAZID), and Design Risk Assessment in support of hoist design, hoist operation HAZAN and safety justification.

The method is not explicitly focussed on conventional safety and has been developed with high hazard contexts in mind. In most cases therefore, the worst-case consequence is not equipment damage, or personnel injury, but container drop or damage that could lead to explosion, release of hazardous material, chemicals, radiation or the explosive release of radioactivity.

It is also worth noting three further potential consequences relating to abnormal events, namely:

- Loss of time and / or productivity which will have financial, or programme related consequences.
- Potential loss of reputational damage in the event of a reportable incident.
- Potential loss of licence to operate.

Maintenance and the potential for maintenance error to introduce latent faults is not explicitly considered within the scope of this method. Such error should be detected through commissioning activity and hoist pre-use checks, which are included.

Although there are many different crane types and designs, in high hazard industries, fixed overhead travelling cranes or fixed cantilever (jib) cranes are preferred due to their inherent stability. The model was developed within the context of fixed crane operations, although is equally applicable to the use of mobile, temporary or fixed tower cranes.

Crane & Hoisting Terminology

The typical components of a hoist are presented in Figure 1.

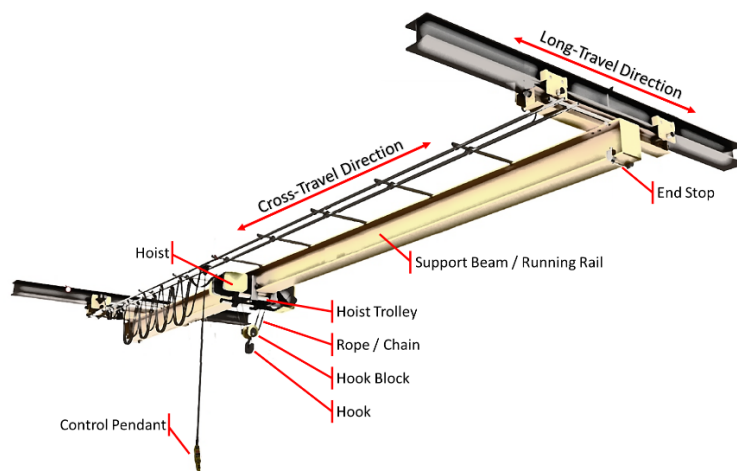


Figure 1: Hoist Components

Strictly speaking, the term hoisting relates only to the raising and lowering of a load. Cranes, to which hoisting equipment is attached, enable loads to be transferred from one location to another. For the purposes of this methodology, the following definitions apply.

- **Item:** The load being moved by the hoist or crane (e.g. container, package, equipment).
- **Hoisting:** The motion of raising or lowering the item in a vertical direction.
- **Traversing:** Either long-travel or cross-travel along a beam or track.
- **Cross Traverse:** The motion of the trolley along the bridge of an overhead travelling crane.
- **Luffing:** Angular movement of a crane jib in a vertical plane.
- **Level Luffing:** Horizontal movement of the item during luffing operation.
- **Slewing:** Rotary motion of a crane jib about a vertical axis.
- **Jib (arm):** Horizontal or near horizontal beam used to support the item.
- **Load path:** The physical path of the stresses along or through engineered components. (Load path does **not** relate to the movement or direction of travel of the item).
- **Movement path:** The path of the item when being moved from point to point.
- **Grounded Load:** Situation where the item to be hoisted is secured to the ground.
- **Loss of control:** The point at which the operation of the hoist (whether intended or unintended) deviates from the prescribed safe system of work or safe operating envelope. Exceedance of safe (controlled) limits, conditions and formally recognised operational boundaries.

Although many crane and hoist designs share common safety systems, the model does not define or identify specific safety measures as these will be unique to each assessment or context.

Model Terminology

The operator error or failure model, specifically developed for use during HAZID studies, is deliberately agnostic to the specific type of hoist, crane or lifting equipment being operated.

Hoisting operations are divided into subsections as set out below.

Unloaded Hoist Operations

The consideration of unloaded hoist operations is important where the hoist and lifting apparatus may present a hazard to personnel, the item, local equipment or structures. Errors are broken down in a similar format to those presented for loaded hoist operations as set out below.

Loaded Hoist Operations

Hoist operations, errors and consequences are sub-divided as follows:

- **Pre-hoisting:** Operations undertaken in advance of hoisting that may influence the probability for error or failure.
- **Hoisting:** Operations undertaken during crane operation that if undertaken incorrectly could lead to a number of different consequences depending on the specific context of the operation and item being transferred. Such operations include hoist raise, hoist traverse and hoist lower.
- **Suspended Item Manipulation:** During complex lifts, operators may be required to manipulate the item whilst it is suspended, e.g. physically handle, adjust, position or rotate. Such operations present unique challenges to safety.
- **Post-hoisting:** Having successfully transferred the item, operators will be required to undertake a number of post-hoist operations in order to secure the load and ensure it is safe to withdraw the hoist.

Although it is important to consider recovery operations in the event of fault or failure (e.g. hoist failure leading to stranded load), the specific contextual and Performance Shaping Factors (PSF) relating to such an event would require a unique assessment to be undertaken. However, the general principles and potential error modes presented within this methodology would apply.

Performance Shaping Factors

Although it is recognised that there are likely to be more context specific factors that may be required to be considered, the following list presents the most common and influential factors relating to crane operation safety.

- Environmental Conditions: Wind / Air speed, moisture / humidity, light, & noise.
- Control / controllability: The ability of the operator to position the item.
- Visibility: Operator or supporting crew / banksman line-of-sight to the hoisted item.
- Time Pressure: Programme or throughput related pressures.
- Working Environment: The general cleanliness and safety of the operating environment.
- Operator familiarity / understanding.

The Model

The detailed table of operations, potential errors and consequences is presented within Table 1 Appendix A as a baseline model or starting point upon which further assessment can be developed.

Table 2 provides an additional list of typical administrative safety arrangements and checks that would be undertaken. Although a failure to undertake these activities would not lead directly to an initiating event, their contribution to the overall safety of the system and risk mitigation is acknowledged.

Conclusion

This paper summarises a model of human errors associated with a set of common crane and hoisting operations, to be used as a baseline assessment or starting point for further assessment. The aim is to promote consistency when assessing such operations in support of safety assessment and justification.

Acknowledgements

For security and classification reasons, it has not been possible to reference the many and varied HAZID, Risk Assessment, Task and Error Analysis documents that contributed to the development of this model. The author recognises the significant contribution made by the many and various Engineers, Operators, Maintainers, Safety Case, Assurance and HF professionals that he has worked with over many years to develop the knowledge and understanding required to collate this model. A huge thanks to all – you know who you are!

Appendix A

Table 1: Crane Operation Errors and Potential Consequences

Operations & Errors	Potential Consequence
UNLOADED HOIST	
Pre-hoist Operations	
Failure to break load path.	Operator fails to disconnect an item (previously) connected to the hoist leading to inadvertent or uncontrolled lift of the item.
	Grounded load leading to hoist collapse and / or damage to the item.
Failure to manage or secure suspended strops / cables	Snag / drag of the cable / strops during movement leading to damage to the item.
	Impact during movement leading to operator injury or damage to the item.
Failure to confirm the transfer path is clear of obstacles	Impact during movement leading to operator injury or damage to the item.
Unloaded Hoist Raise	
Hoist over-raise	High stress exerted through the hoist load path leading to failure (equipment drop onto item) (Double blocking).
Inadvertent traverse	Rigging / tooling impact (collision) or snag leading to item damage or hoist overload.
Inadvertent lower	Rigging / tooling impact (collision) leading to item and / or equipment damage.
Hoist under-raise	Rigging / tooling impact (collision) or snag during movement leading to item damage or hoist overload.
Unloaded Hoist Traverse	
Hoist misalignment	Snag of item on surrounding equipment during raise leading to damage or abnormal load (grounded load).
Loss of control	Inadvertent travel leading to rigging / tooling impact (collision) or snag leading to damage or abnormal load (grounded load).
Inadvertent raise	High stress exerted through the hoist load path leading to failure (dropped item) (Double blocking).
Over-traverse	Inadvertent travel leading to rigging / tooling impact (collision) or snag leading to damage or abnormal load (grounded load).
Inadvertent lower	Rigging / tooling impact (collision) leading to item and / or equipment damage.
Unloaded Hoist Lower	
Over-lower	Rigging / tooling impact (collision) leading to item and / or equipment damage.
Inadvertent raise	High stress exerted through the hoist load path leading to failure (dropped item) (Double blocking).
Inadvertent traverse	Rigging / tooling impact (collision) or snag leading to item damage or hoist overload.
LOADED HOIST	
Pre-hoist Operations	
Wrong Load	Loss of control, unstable load, hoist overload (collapse), dropped item leading to damage and / or operator injury.

Operations & Errors	Potential Consequence
Wrong tooling leading to load path failure	Loss of control, unstable load, hoist overload (collapse), dropped item leading to damage and / or operator injury.
Poorly configured load - balance	Loss of control, unstable load, hoist overload (collapse), dropped item leading to damage and / or operator injury.
Poorly configured load - weight	Loss of control, hoist overload (collapse), dropped item leading to damage and / or operator injury.
Poorly configured load - insecure	Loss of control, unstable load, dropped item leading to damage and / or operator injury.
Wrong tooling - Strop length too long	see Hoist under-raise.
Wrong tooling - Strop length too short	see Hoist over-raise.
Load path connection error:	Swing / drop: impact with ground - item damage.
	Swing / drop: Impact (collision) with personnel - physical injury.
	Swing / drop: Impact (collision) with other equipment - item damage.
	Swing / drop: Impact (collision) with valuable assets - inability to operate.
	Swing / drop: Impact (collision) with valuable assets - latent fault.
	Swing / drop: Impact (collision) with other hazardous materials - domino effect.
	Inadvertent lift of pallet / transport configuration leading to abnormal load / hoist overload - see above.
	Grounded Load leading to hoist collapse - item damage and operator injury.
Failure to check movement path	Higher risk of impact (collision) or snag during movement.
Loaded Hoist Raise	
Hoist over-raise	Failure to undertake a low-level check-lift (where required) to ensure the validity and security of the item and load path prior to full raise.
	High stress exerted through the hoist load path leading to failure (dropped item) (Double blocking).
	High stress exerted through the hoist load path leading to failure (equipment drop onto item) (Double blocking).
Inadvertent traverse	Item impact (collision) leading to item damage.
	Item snag leading to hoist overload (collapse and impact on item).
	Item impact (collision) with personnel - injury.
Inadvertent lower	Rigging / tooling impact (collision) leading to item damage.
	Item ledging leading to swing and damage to item or equipment.
	Item ledging leading to swing and hang-mans-drop - load path failure - dropped item.
	Item ledging leading to swing and hang-mans-drop - load path failure - crane collapse.
Over speed	Abnormal force through load path (snatched load) - load path failure - dropped item.
	Abnormal force through load path (snatched load) - load path failure - crane collapse.

Operations & Errors	Potential Consequence
Hoist under-raise	Item impact (collision) or snag during movement leading to item damage or hoist overload.
Inadvertent snag / contact	Item impact (collision) damage.
	Load path overload leading to item drop and damage.
	Load path overload / hoist overload leading to failure / collapse.
Loaded Hoist Traverse	
Over traverse	Item impact (collision) or snag during movement leading to item damage or hoist overload.
	Challenge to safety system (end-stop)
Hoist misalignment	Item impact (collision) during raise or lower leading to item damage. See also Ledged Load below.
<i>Loss of control leading to injury or damage</i>	Impact (collision) with (elevated) ground leading to item damage.
	Impact (collision) with personnel leading to injury.
	Impact (collision) with other equipment leading to item damage.
	Impact (collision) with other equipment leading to damage to valuable assets.
	Impact (collision) with other equipment leading to Safety Systems (loss of Safety Function).
	Impact (collision) with hazardous materials
	Potential unrevealed damage.
Loss of control - speed	<i>See above: Loss of control leading to injury or damage.</i>
	<i>Increased risk of damage due to speed / item swing.</i>
Inadvertent stop	Uncontrolled swing leading to impact (collision).
	Uncontrolled swing leading to excessive load resulting in dropped load.
Inadvertent raise (early) - over-raise	See Loaded Hoist Raise - Hoist over-raise.
	See Loaded Hoist Raise - Inadvertent snag / contact
Inadvertent (early) lower	<i>See above: Loss of control leading to injury or damage.</i>
	Item impact (collision) during raise or lower leading to item damage. See also Ledged Load below.
Inadvertent traverse in wrong direction	<i>See above: Loss of control leading to injury or damage.</i>
	See above: Loaded Hoist Raise - Inadvertent Traverse.
Loaded Hoist Lower	
Over-lower	<i>See above: Loss of control leading to injury or damage.</i>
Inadvertent raise - over-raise	See Loaded Hoist Raise - Hoist over-raise.
	See Loaded Hoist Raise - Inadvertent snag / contact
Inadvertent traverse	<i>See above: Loss of control leading to injury or damage.</i>
	See above: Loaded Hoist Raise - Inadvertent Traverse.
Ledged load	Item ledging leading to swing and damage to item or equipment.
	Item ledging leading to swing and hang-mans-drop - load path failure - dropped item.

Operations & Errors	Potential Consequence
	Item ledging leading to swing and hang-mans-drop - load path failure - crane collapse.
Over-speed / harsh handling	<i>See above: Loss of control leading to injury or damage.</i>
	<i>Increased risk of damage due to speed / item swing.</i>
	<i>Note: Operators may use a "tagline" to support item stability and handling. Where taglines are implemented, this would prompt a separate assessment.</i>
SUSPENDED ITEM	
Suspended Item Manipulation	
Failure to check movement path	<i>See above: Loss of control leading to injury or damage.</i>
	<i>See above: Ledged load.</i>
Over-rotation / Under-rotation	<i>See above: Loss of control leading to injury or damage.</i>
Failure to secure prior to further operation	<i>See Pre-hoist Operations: Load path connection error.</i>
Load path broken too early	Dropped load.
Post-hoist operation	
Failure to make load path	Load not secured prior to withdrawal of support from hoist (load path).
	<i>See Pre-hoist Operations: Load path connection error.</i>
Failure to break load path	<i>See Pre-hoist Operations: Failure to break load path.</i>

Table 2: Potential pre-hoisting administrative procedure failures

Pre-hoist administrative procedures
Failure to put SSoW in place.
Failure to confirm operators are Suitably Qualified and Experienced.
Failure to confirm full safety complement - all required personnel present.
Failure to confirm task-based risk (TBRA) assessment complete.
Failure for all personnel to sign-on to TBRA.
Failure to undertake pre-job brief.
Failure to check equipment commissioning record / calibration / certification.
Failure to check facility alarms working.
Failure to check communications working.
Failure to check system safeguards / protection systems functioning correctly.
Fail to check all safety related document complete and signed.