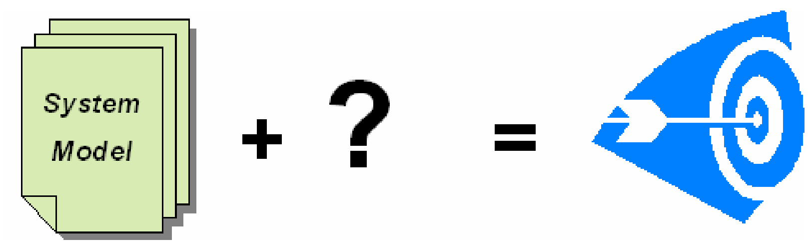
# Query Based UML Modeling

## *Validation and Verification of the System Model and Behavior for a Hydraulic Crane*

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**System Validation and Verification**
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**Fall 2006**

# TABLE OF CONTENTS

## 1.0 Introduction

This project report is a detailed case study on the development and use of a query based UML modeling tool. Throughout the last decade, UML along with its derivative, SysML have been used throughout the software and engineering communities to model system level architectures for various systems and subsystems. UML/SysML was designed to provide simple but powerful constructs for modeling a wide range of systems engineering problems. It is particularly effective in specifying requirements, structure, behavior, and allocations, and constraints on system properties to support engineering analysis. The language is intended to support multiple processes and methods such as structured, object-oriented, and others, but each methodology may impose additional constraints on how a construct or diagram kind may be used.

As flexible as UML/SysML may be, one of its drawbacks is that it is not very useful in an interactive dynamic format. Once a UML model is created, it is essentially a static system model that is little more than a "pretty picture". It would be greatly beneficial if it could be queried, and dynamically linked. Querying would enable an engineer to see how a particular element in a UML model is linked to another element, and also how changing one would alter the overall model. Currently this capability is lacking. Although relatively intuitive on small systems, the ability to query and dynamically link various UML models is of huge consequence on large and complex projects. This case study looks at a software algorithm model, the UML Query and Link Analysis Tool (UQLAT), for querying and dynamically linking UML models. Much of this work is done by me as part of an Independent Research and Development (IRAD) effort for my company, Raytheon. As a result of this, I am not allowed to disclose the actual algorithm or screenshots of the querying tool. However, this case study will discuss the data structure, general algorithm logic, and results of sample queries and dynamic links for a particular system.

For this case study, in addition to the UQLAT, a full Verification and Validation analysis was conducted on a hydraulic crane. The case study includes a full system architecture development, including use cases, scenario development, requirements generation, verification of the system, and finally validation using the UQLAT.

## 1.1 *Scope*

This case study focuses on the operational sequencing of an all-terrain hydraulic crane, using positive (nominal) and negative (off-nominal) use cases to model overall system behavior. The systems architecture describes crane operation across five distinct phases:

- Pre-Start Initiation
- Handling and Attaching the Load
- Lifting the Load
- Maneuvering the Load
- Ending Lift

These five phases describe the entire operational lifecycle of a stationary crane. This case study has chosen the route of using nominal and off-nominal use cases to describe overall system architecture[1]. Nominal and off-nominal use cases are described using activity diagrams in the Higraph style. Nominal use cases describe the crane system as it is intended to operate during a particular phase, whereas the off-nominal use cases describe how a nominal operation can be negatively affected, leading to either serious injury or fatality. To arrive at the off-nominal use cases, a separate failure analysis was conducted. The outcome of this failure analysis was the development of off-nominal use cases. There can theoretically be hundreds of off-nominal use cases. However to keep this case study manageable, only the most pertinent off-nominal use cases were included. Each nominal use case was matched up to no more than 3 off-nominal use cases for brevity.

Finally, only the nominal and off-nominal use cases presented in this case study are analyzed using UQLAT.

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[1] Reference 2

## 1.2 *Assumptions*

The analysis conducted for this report considers the hydraulic all-terrain mobile crane system commonly used at various construction sites. The analysis is kept at a general level without reference to a particular model.

Furthermore, the following conditions were used to bind and constrain the analysis of the crane system for this report:

- Crane Type: Only all-terrain mobile cranes are considered for this report. Crawlers, tower-cranes, floating platform cranes, derricks, lattice-structure cranes and truck-based “non-outrigger” cranes are not covered by the analysis in this report.
- Risk: Only safety-related risks are evaluated and analyzed for the failure analysis when developing off-nominal use cases. Safety related risks are injury and fatality. Mission assurance risk, financial risk, and any other non-safety risks are not evaluated in this report.
- Operation: Only stationary crane operations are considered for this report. There are additional crane safety requirements and conditions that exist for cranes when in motion. However these requirements are beyond the scope of this report.
- Analysis Extent: The level of analysis for this case study is constrained at the operational level. In other words, only the operational system architecture is studied here. The various lower level mechanical, software, and electrical functions are not discussed, unless there is a direct bearing on the operational phases.

## 1.3 *System Description*

Hydraulic cranes are very simple by design but can perform monumental tasks that would otherwise seem impossible. In a matter of minutes, these machines can raise multi-ton bridge beams on highways, heavy equipment in factories and even lift beachfront houses onto pilings. The hydraulic crane is based on a simple concept -- the transmission of forces from point to point through a fluid. Most hydraulic machines use some sort of incompressible fluid, a fluid that is at its maximum density. Oil is the most commonly used incompressible fluid for hydraulic machines, including hydraulic cranes. In a simple hydraulic system, when a piston pushes down on the oil, the oil transmits all of the original force to another piston, which is driven up.

A hydraulic pump creates the pressure that moves the pistons. Pressure in a hydraulic system is created by one of two types of hydraulic pumps: the variable-displacement pump, and the gear pump. Most hydraulic truck cranes use two-gear pumps that have a pair of inter-meshing gears to pressurize the hydraulic oil. When pressure needs to increase, the operator pushes the foot throttle to run the pump faster. In a gear pump, the only way to get high pressure is to run the engine at full power.

For this case study, a representative hydraulic crane model was chosen for comparative analysis. The model chosen was the 200 ton-capacity Link-Belt ATC 3200 hydraulic truck crane[2]. This crane uses a 388 $in^3$ diesel engine that generates up to 184 horsepower. The engine is connected to three two-gear pumps, including:

- Main pump - This pump operates the piston rod that raises and lowers the boom, as well as the hydraulic telescoping sections that extend the boom. The main pump is able to generate 170.7 gpm of pressure. It generates more pressure than the other two pumps because it is responsible for moving much more weight.
- Pilot pressure counterweight pump - A hydraulic truck crane uses counterweights on the back of the cab to keep it from tipping over. These are added and removed by a hydraulic lift that has its own pump. The counterweight gear pump can generate 1,400 psi.
- Steering/outrigger pump - One pump controls the steering and the outriggers. The outriggers are used to stabilize the truck during lifting operations. Because steering and outrigger operation are not performed simultaneously, they run off of the same pump. This pump generates 1,600 psi.

Some basic parts of a hydraulic truck crane include:

- Boom - The large arm mainly responsible for lifting
- Counterweights - Multi-ton weights placed on the back of the cab to prevent the crane from tipping during lifts
- Jib - Lattice structure that extends out of the boom
- Outriggers - Supports that keep the crane balanced
- Rotex gear - Large gear under the cab that allows the boom to be rotated

[2] Appendix B

- Boom Level Indicator - Array of lights located in the cab just above the operator's eye level; flashes if crane's lifting limits are reached
- Reinforced-steel cable
- Hook
- Clutch
- Joystick

The most recognizable part of any crane is the boom. This is the steel arm of the crane that holds the load. Rising up from just behind the operator's cab, the boom is the essential piece of a crane, allowing the machine to raise loads to heights of several dozen feet.

Reinforced-steel cable lines run from a winch just behind the operator's cab, extending up and over the boom and jib. The lines run up the boom and jib and attach to a metal ball that keeps the lines pulled taut when no load is attached to the hook.

To maneuver the load, the boom has to be able to move right and left, as well as up and down. Underneath the operator's cab is a Rotex gear on a turntable bearing that turns at 1.5 revolutions per minute (rpm). It is driven by a bidirectional, hydraulic motor mounted on the cab and housed in a metal cover to prevent injuries. The rotation is controlled by a foot-operated, hydraulic pedal in the cab.

Hydraulic truck cranes are used to lift heavy loads to tall heights, and it's important that the truck be completely stable during the lifting operation. The tires don't offer the necessary stability needed, so the truck employs outriggers that act as balances to keep the crane from leaning too much to one side or the other. The outriggers use hydraulics to lift the entire truck, tires and all, off the ground. The outriggers are comprised of the beam, which is the leg of the outrigger, and the pad, which is the foot. Sometimes, "floats" or “load distribution blocks” are placed under the pad to dissipate the force of the crane and the load over concrete or pavement. Floats are usually wood planks that are lined up to create a base that is larger than the pad itself.

The Link-Belt ATC 3200 hydraulic truck crane has two basic types of controls for maneuvering a load:

- Joysticks - There are two joysticks in the cab. One controls left-to-right movement of the boom, and the other controls forward and aft movement.
- Foot pedals - These pedals are responsible for retracting and extending the telescoping sections of the boom. They also control the amount of pressure being generated by the pump.

Joy sticks and foot pedals are connected to hydraulic hoses that connect various hydraulic rams to spool valves. The spool valve is connected to the hydraulic pump via a third hose that is placed between the two hoses that run from the spool valve to the hydraulic ram. When a joystick is pushed in one direction, it causes the valve to shut off one of the hydraulic hoses leading to the ram and open the other. Which way the joystick is pushed determines whether the piston in the hydraulic ram slides inward or out.

Prior to any lift, the operator enters data into a computer known as the boom level indicator located inside the cab, including the weight of the object to be lifted and the height to which it is to be lifted. This computer serves as the operator's backup, warning the operator if the crane is being pushed beyond its capability. Using a binder of load rating charts in the cab, the operator also determines the angle of lift and the radius of the boom. Once all of this is entered, the computer can track the progress of the lift and warn the driver if the crane is nearing its limitations. If the boom is lifted too high for the load amount, a series of lights and audible alerts just above the inside of the front window will begin to light up.

There are at least two other people needed to perform a lift properly, including the oiler and the signalman. These two people along with any other construction crew involved with the construction process comprise the “ground personnel”.  The oiler is responsible for making sure that all of the crane's parts are in place and secured prior to any lift. He or she also acts as a spotter during a lift to ensure that the lift is being performed properly. The signalman, as the name suggests, gives hand signals to the operator during the lift to make sure the load is being maneuvered correctly.

## 2.0 System Architecture

The operational sequence of a crane consists of five distinct phases that are conducted in order. Each of these five phases, in turn have many steps and actions that need to be completed. The proper sequencing of actions are:

1. Phase 1 Initiate pre-start inspection: these are a set of instructions and checklists that a crane operator must ensure are in place before turning on the engine
2. Phase 2 Handle and attach the load: this phase includes the placement and positioning of the load onto the crane hook
3. Phase 3 Lift the load: this phase is the actual raising of the crane boom with the load fully attached (vertical movement)
4. Phase 4 Maneuver the load: this phase is when the load is cleared for horizontal movement, and any subsequent vertical movements
5. Phase 5 End lifting: this phase includes the lowering of a load, and all post landing operations

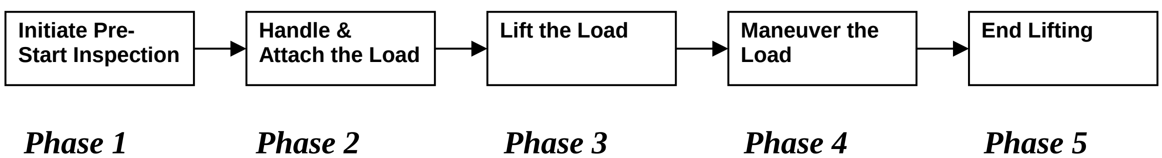



***Fig. 1 Crane Operational Phase***

## 2.1 *Inheritance View Diagram*

The inheritance view shows a detailed view of the attributes and functions of the crane system. The attributes and functions are split between the main system and the subsystem of the crane.

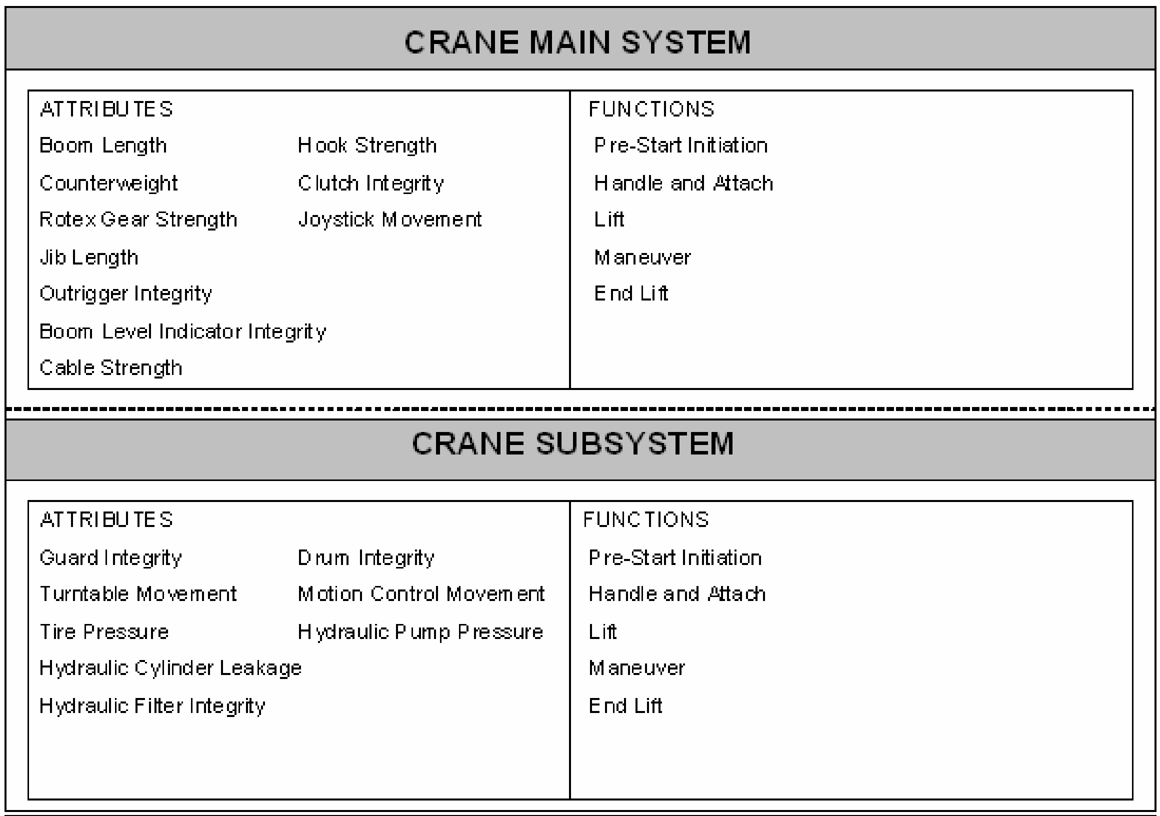



***Fig. 2  Inheritance View Diagram***

## 2.2 *Class Diagram*

The class diagram depicts the overall structural breakdown of the crane along with its subsystems. Each subsystem is shown with its major function.

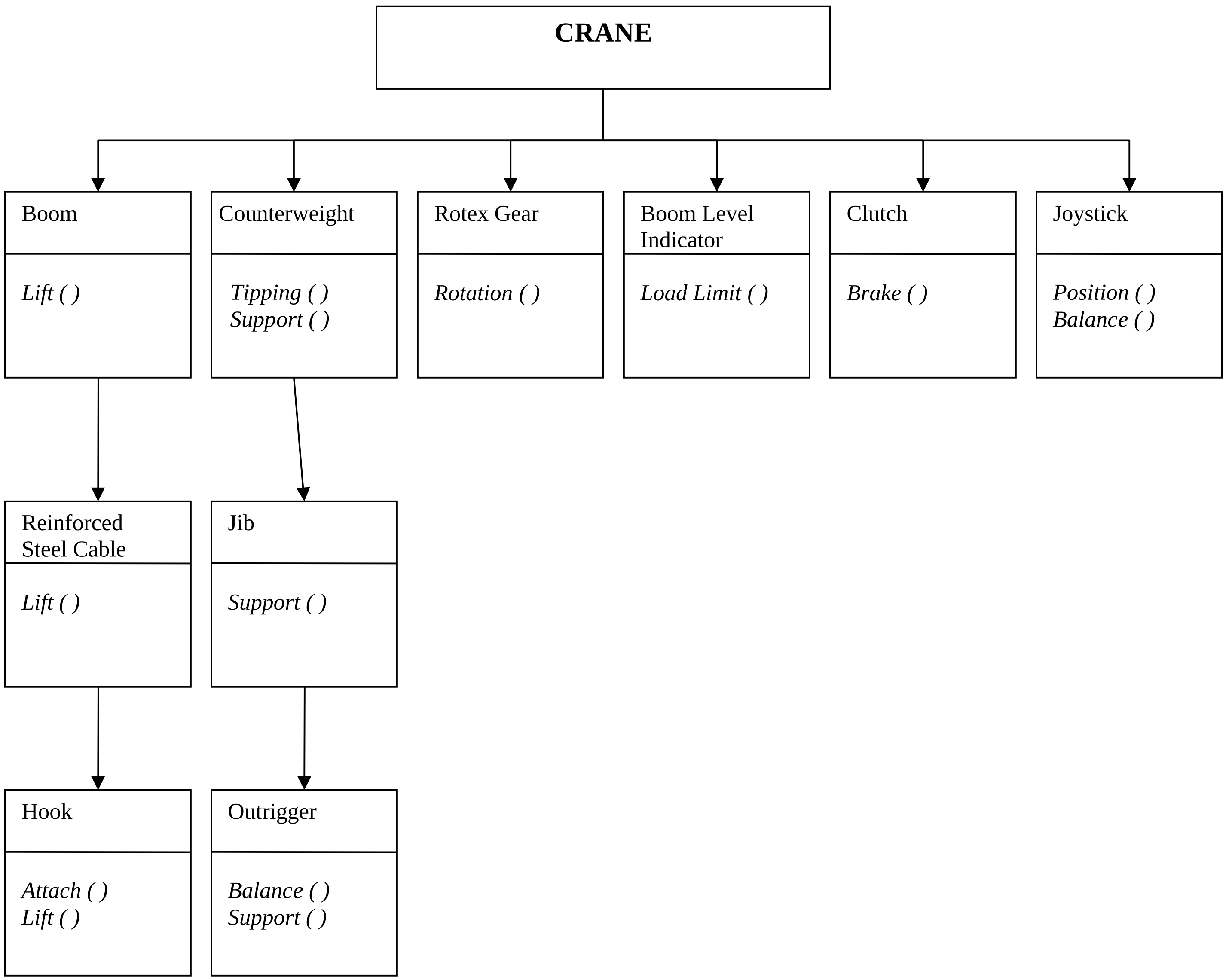



***Fig.3 Crane Class Diagram***

## 2.3 *Initial Use Case Diagram*

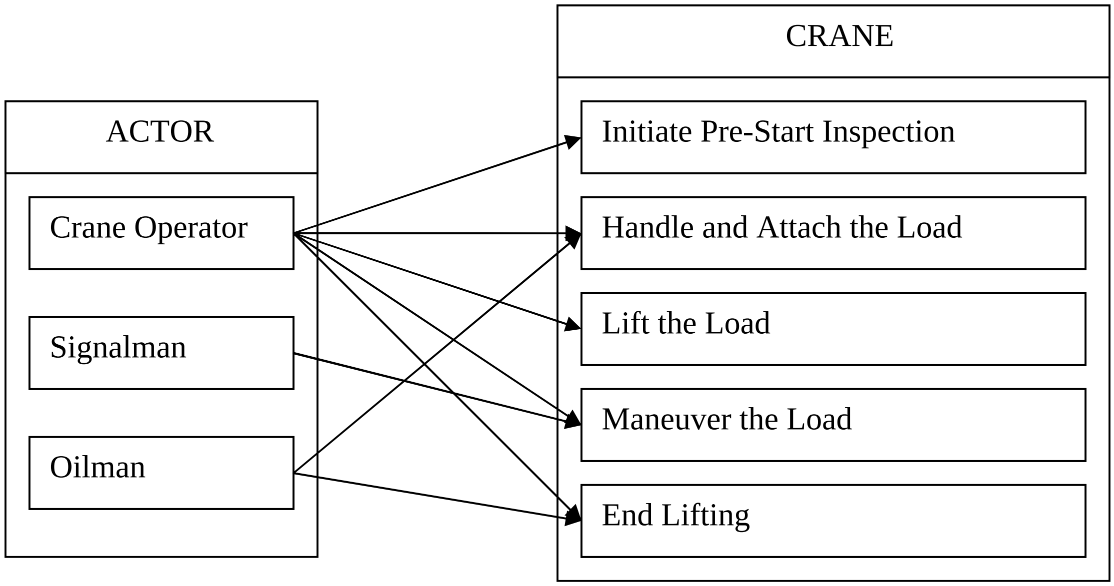



***Fig.4 Initial Use Case***

## 2.4 *Nominal Phase Use Cases*

This section describes the nominal use cases for the five operational phases of the crane. Activity diagrams using the Higraph notation is employed to show the time sequence and order of the various functions and actions within each phase. The Activity diagrams describe how a particular phase is supposed to properly execute its operations. The rectangular boxes are action elements, whereas the rounded boxes are state elements. Action elements represent events that require user input (ex. pressing a button or typing in a number). State elements represent events that are an outcome of a particular Action element. State elements represent conditions, and do not need to be acted upon.

**Use Case 1 - Phase 1: Initiate Pre-Start Inspection**
Description: The crane operator goes through a pre-start checklist for safety
Primary Actor: Crane Operator
Pre-Conditions: Crane Operator has access to the crane

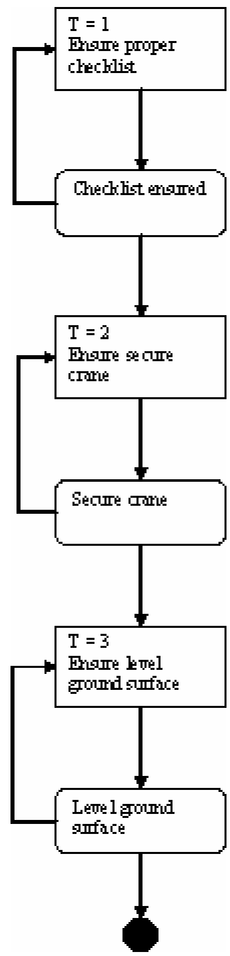



*Fig. 5 Phase 1 Activity Diagram*

**Use Case 2 - Phase 2: Handle and Attach the Load**
Description: Load is measured, calibrated and put onto the crane hook
Primary Actor: Crane Operator, Oilman
Pre-Conditions: Pre-Inspection checklist was conducted

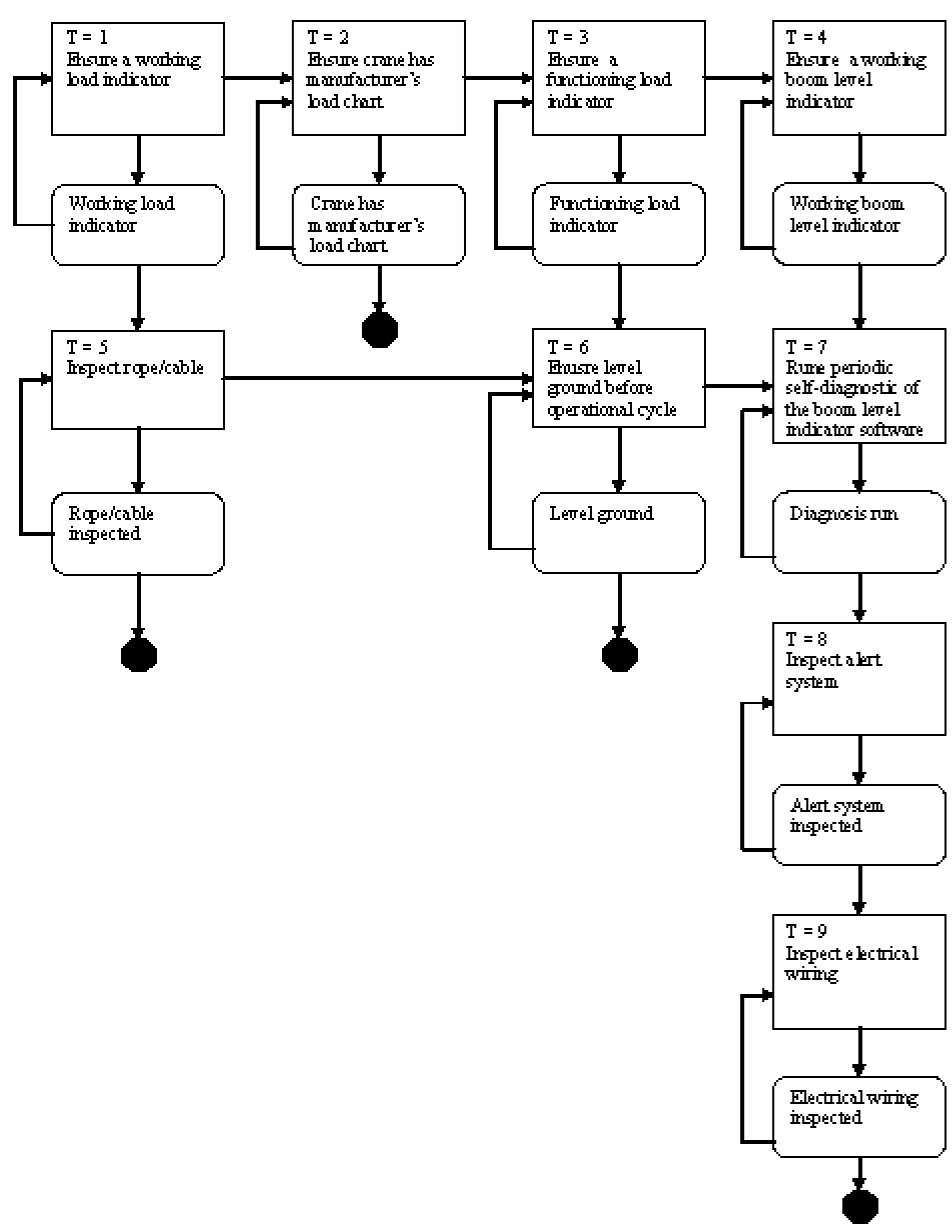



***Fig 6 Phase 2 Activity Diagram.***

**Use Case 3 – Phase 3: Lift the Load**

Description: Crane lifts the load after it has been attached

Primary Actor: Crane Operator

Pre-Conditions: Pre-Inspection checklist was conducted,
The load has been handled and attached

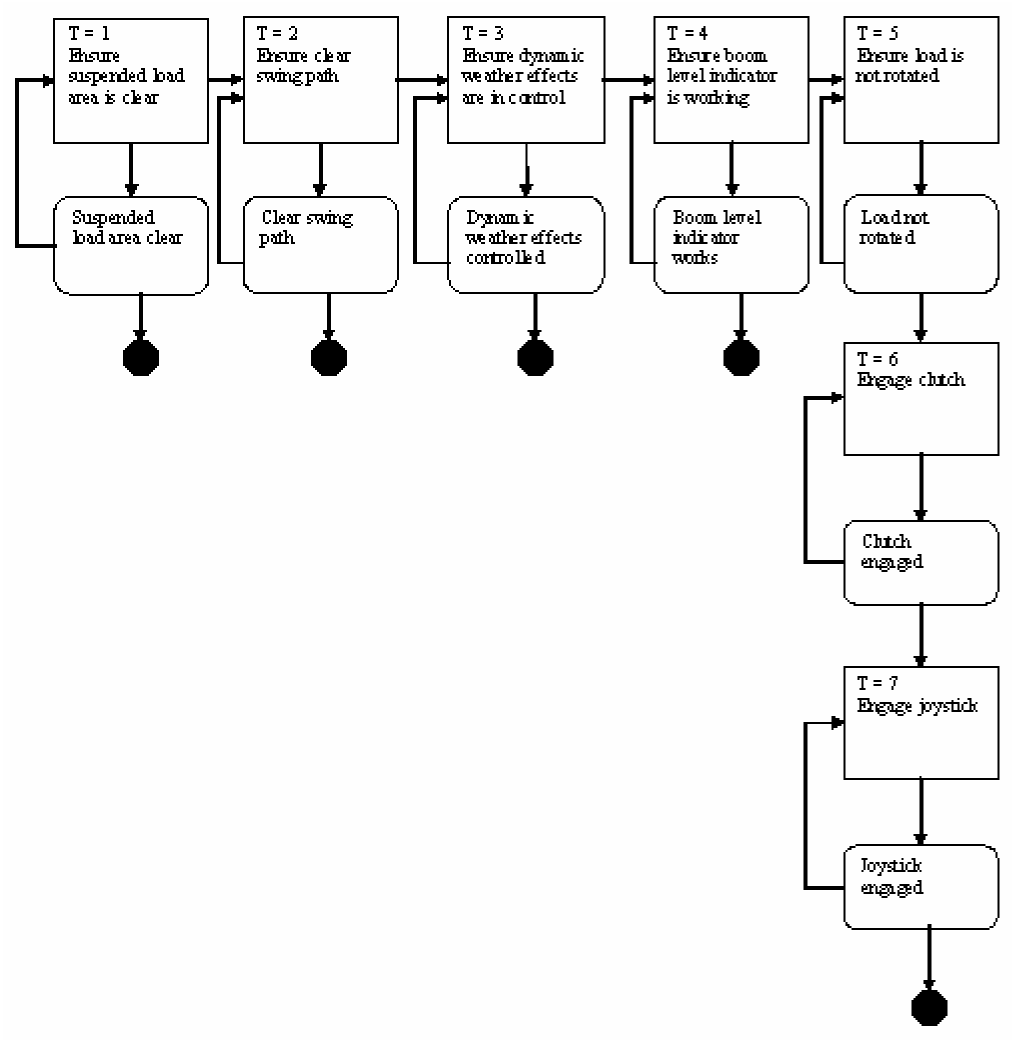



***Fig.7 Phase 3 Activity Diagram***

**Use Case 4 - Phase 4: Maneuver the Load**

Description: Crane moves the load to the desired position

Primary Actor: Crane Operator, Signalman

Pre-Conditions: Pre-Inspection checklist was conducted,
The load has been handled and attached
The load has been lifted successfully

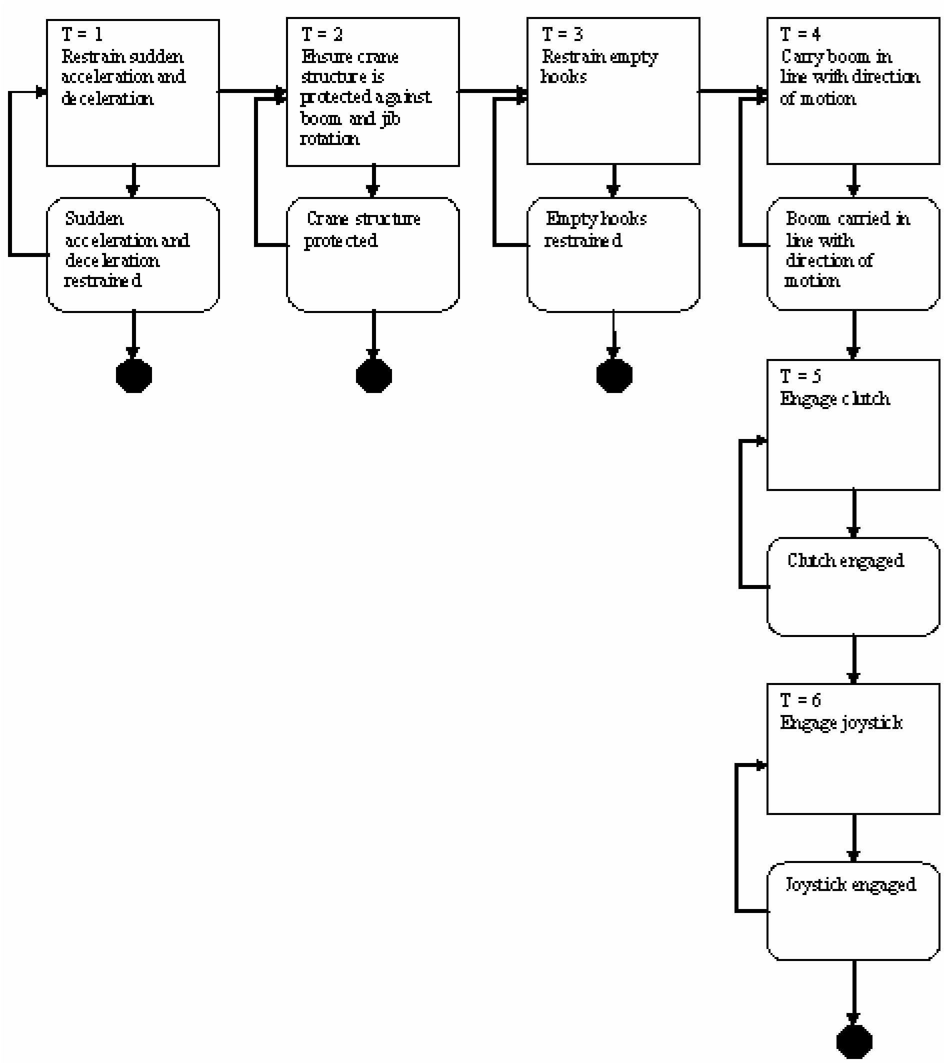



*Fig.8 Phase 4 Activity Diagram*

**Use Case 5 - Phase 5: End Lifting**

Description: Crane lands the load, and lifting is brought to an end.

Primary Actor: Crane Operator, Oilman

Pre-Conditions: Pre-Inspection checklist was conducted,
The load has been handled and attached
The load has been lifted successfully
The load has been maneuvered successfully

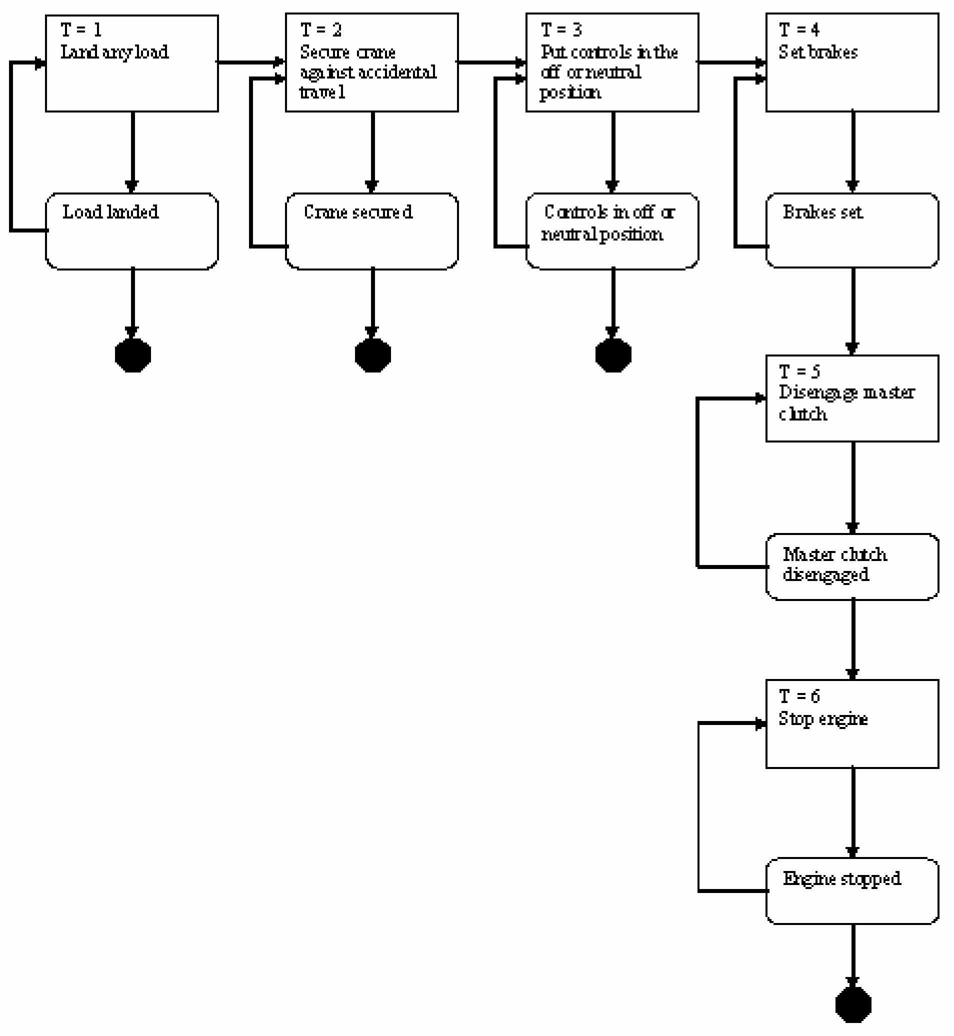



***Fig.9 Phase 5 Activity Diagram***

## 2.5 *Off-Nominal Use Cases using Scenario Development*

Off-Nominal use cases were developed for the five crane operational phases. The nominal use cases described in section 2.4 depict the sequence of events that are expected to occur during the normal execution of a particular phase. It does not factor in unexpected events, failure events, and other disturbances. However, these events are important in understanding how a system fails, and consequently lead to fatalities. Off-Nominal use cases can be developed using Failure Mode and Error Analysis (FMEA) techniques, and in particular Cause and Effect Hazard Analysis (CEHA). Furthermore, this design project extends the idea presented by Uchitel, Kramer, and Magee in using behavior models by using implied scenarios, as well as correlating positive and negative use cases[3]. CEHA analysis involves the identification of all possible initiating and contributory hazards that lead to an adverse event flow leading to harm. For this project, a separate CEHA analysis was conducted to identify the major failure points and events, as well as their criticality and consequence levels. These were then combined to form negative or off-nominal use cases in the form of implied scenarios. That work is beyond the scope of this report, but the end results of the CEHA is summarized in Table 1. For each nominal use case, there can be tens of hundreds of off-nominal use cases. However, to keep this project manageable, only the most pertinent off-nominal use cases are discussed for each phase. Finally, each nominal use case is matched up to its corresponding off-nominal use case, by analyzing which off-nominal and nominal use cases have the strongest cause and effect relationship. Some nominal use cases only have one off-nominal use case, while others have many. Some off-nominal use cases are also repeated by other nominal use cases.

It is important to realize that the off-nominal use cases presented in this report are just few of the possible scenarios that exist for each nominal use case. It is by no means an exhaustive list. It should be evident that nominal use cases represent the way a system is intended and expected to work ( a positive), whereas the off-nominal use cases depict the undesired flow of events (a negative). As described by Uchitel, Kramer, and Magee [4], the use of positive and negative implied scenarios are extremely beneficial in discovering system weakness and pitfalls when designing a system, that may not be as easily discovered by simply using UML/SysML or other modeling tools. This in turn, helps one design a more robust and error proof nominal system architecture.

[3] Reference 2
[4] Reference 2

| Failure # | Primary Hazard | Definition | Contributor | Consequence |
|---|---|---|---|---|
| 1 | Poor Startup | Crane's inability to startup in accordance with established safety procedures | - LTA Training<br>- LTA Physical and Mental Coordination<br>- LTA Procedural Checklist | Injury |
| 2 | Forward and backward Instability | Crane's ability to resist overturning in the direction opposite the boom point while in the unloaded condition | - Crane not designed with shortest allowable boom<br>- Insufficient outrigger structural integrity<br>- Imbalanced weight distribution on all wheels<br>- Excessive design margin between center of gravity and the axis of rotation | Fatality |
| 3 | Boom Hoist Mechanism Instability | Boom hoist mechanism supports the boom and controls the boom angle | - Insufficient rope capacity in the boom hoist drum to cover all positions<br>- Insufficient rope strength in the boom hoist drum<br>- LTA braking mechanism to prevent accidental boom lowering<br>- Failure of load-hold check valve | Fatality |
| 4 | Load Hoist Mechanism Instability | Load hoist mechanism is a hoist drum and reeving system used for lifting and lowering loads | - Load hoist drums with LTA power<br>- Insufficient thermal rating for load hoist drum brake and clutch<br>- Insufficient rope strength in load hoist drums<br>- Lack of anti-drum rotation controller<br>- Lack of anti-drum rotation hold-check valve mechanism<br>- Improper foot rest | Fatality |
| 5 | Swing Mechanism Instability | The swing mechanism rotates | - Lack of boom support | Fatality |

| | | | | |
|---|---|---|---|---|
| | | the boom and cab to position it over a desired location | - LTA rotational Brake hold<br>- Differential rotational braking | |
| 6 | Manual Control Inaccessibility | Controls include manual levers, switches, and buttons that are used to maneuver and position various parts of the crane | - LTA ergonomics<br>- Lack of neutral positions for control levers<br>- Excessive loading on hand-levers<br>- Excessive travel distance on hand levers | Fatality |
| 7 | Rope and Cable Slippage | Ropes and cables provide the means to hold and carry loads, as well as secure various parts of the boom and jib | - LTA design factor for ropes and cables<br>- Use of fiber-core ropes<br>- Use of rotation resistant ropes<br>- Non-smooth sheave grooves<br>- Non form-fitting sheave grooves<br>- LTA sheave bearing lubrication port | Injury |
| 8 | Poor Cab Design | Cab is the enclosed housing for the operator and the control station | - Inadequate protection from the weather<br>- Shrouded visibility from inside the cab<br>- Inadequate egress and ingress<br>- Exhaust gas leakage into the cab<br>- Improper seating arrangement | Fatality |
| 9 | Poor Boom Design | Boom is the main lifting structure on the crane, and includes the additional jib structure | - LTA boom stop structural strength<br>- LTA jib stop structural strength<br>- Lack of automatic boom hoist shut-off | Fatality |
| | | | | |

***Table 1  FMEA – Cause and Effect Hazard Analysis***

2.6 *Nominal vs. Off-Nominal Use Cases*

**Off-Nominal Use Case 1**
Reference: Failure # 1
Description: The crane operator creates an operational hazard due to poor startup procedures

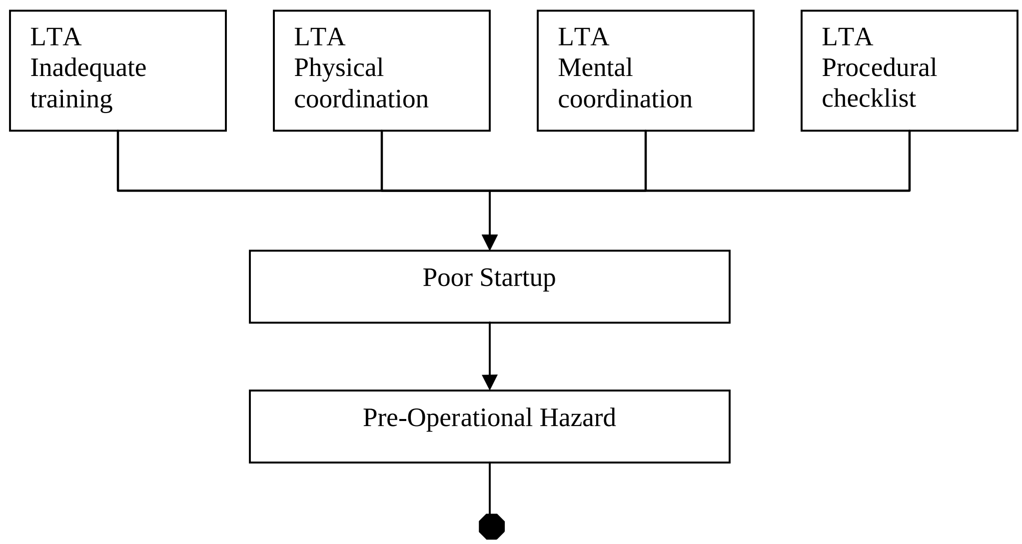



***Fig. 10  Off-Nominal Use Case 1***

**Off-Nominal Use Case 2**
Reference: Failure # 2
Description: Forward and backward instability of the crane leads to tipping

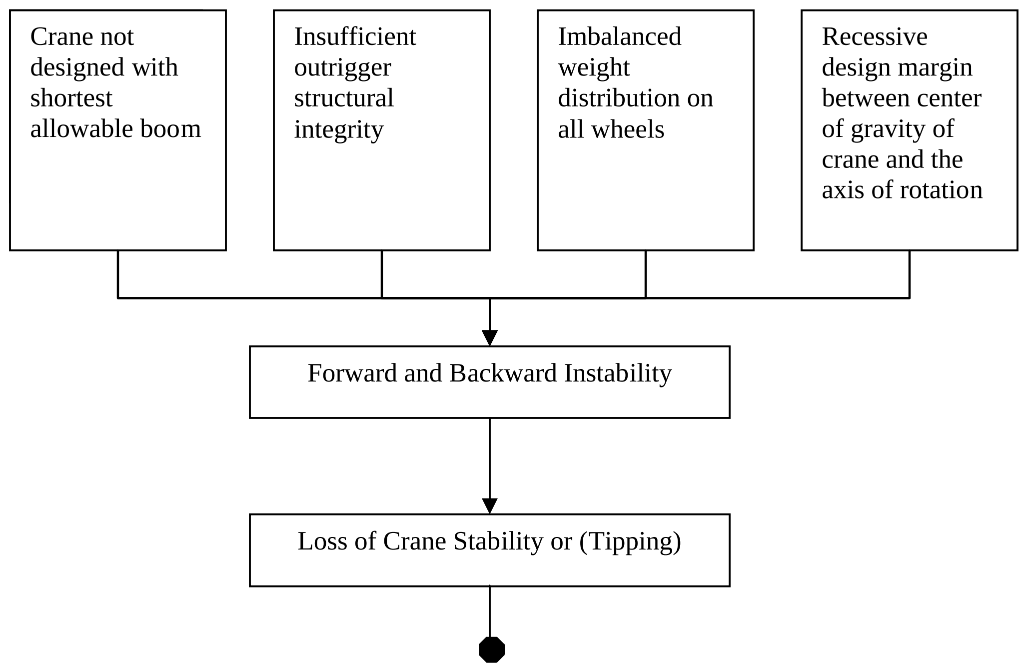



***Fig. 11  Off-Nominal Use Case 2***

**Off-Nominal Use Case 3**
Reference: Failure # 3
Description: Poor boom and rope conditions lead to loss of boom hoist stability

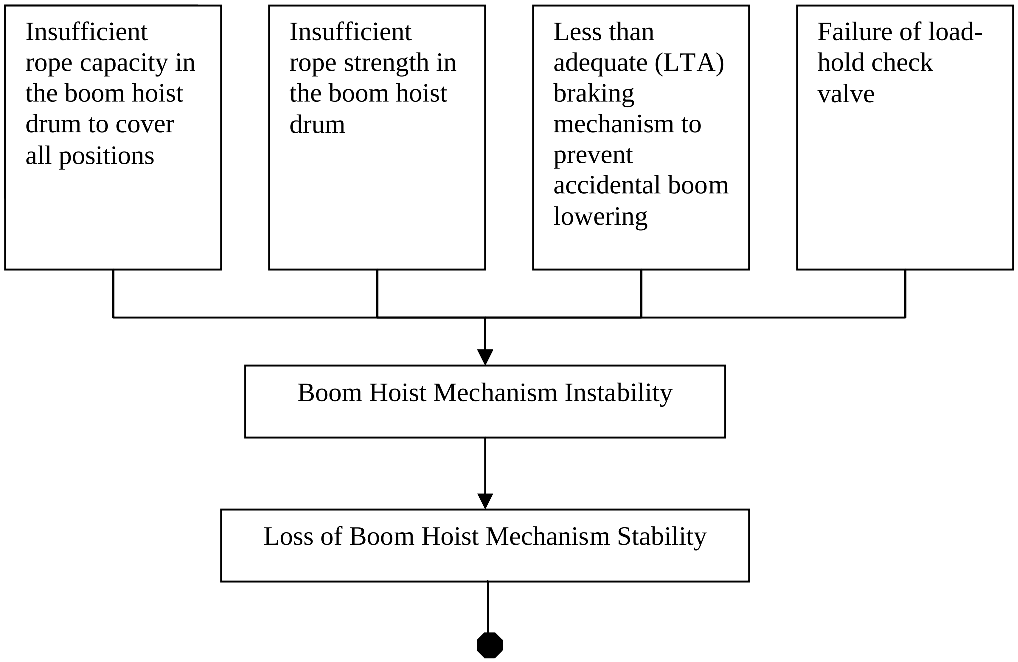



***Fig. 12 Off-Nominal Use Case 3***

**Off-Nominal Use Case 4**
Reference: Failure # 4
Description: Poor drum and rope conditions lead to loss of load hoist stability

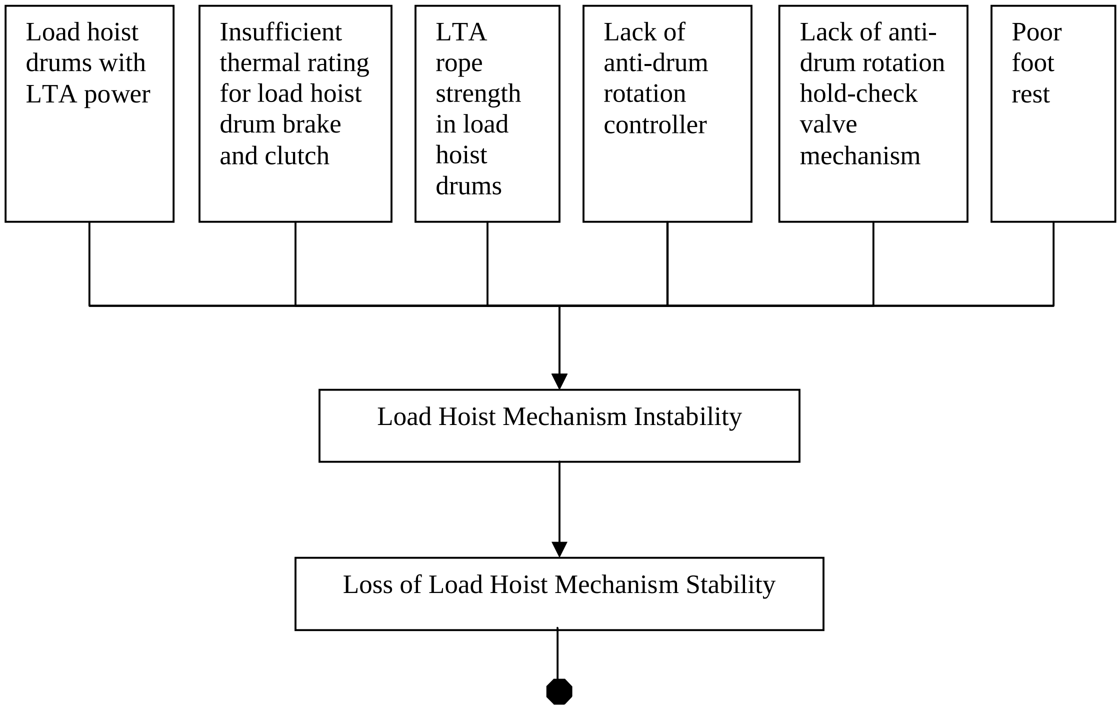



***Fig. 13 Off-Nominal Use Case 4***

**Off-Nominal Use Case 5**
Reference: Failure # 5
Description: Poor brake hold and boom support lead to erratic swinging

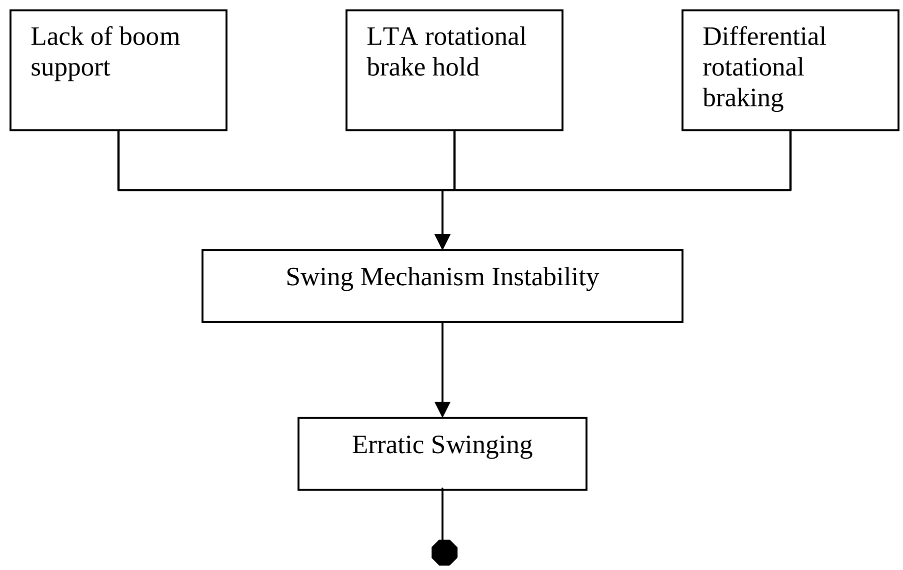



***Fig. 14 Off-Nominal Use Case 5***

**Off-Nominal Use Case 6**
Reference: Failure # 6
Description: Poor ergonomics lead to positional errors

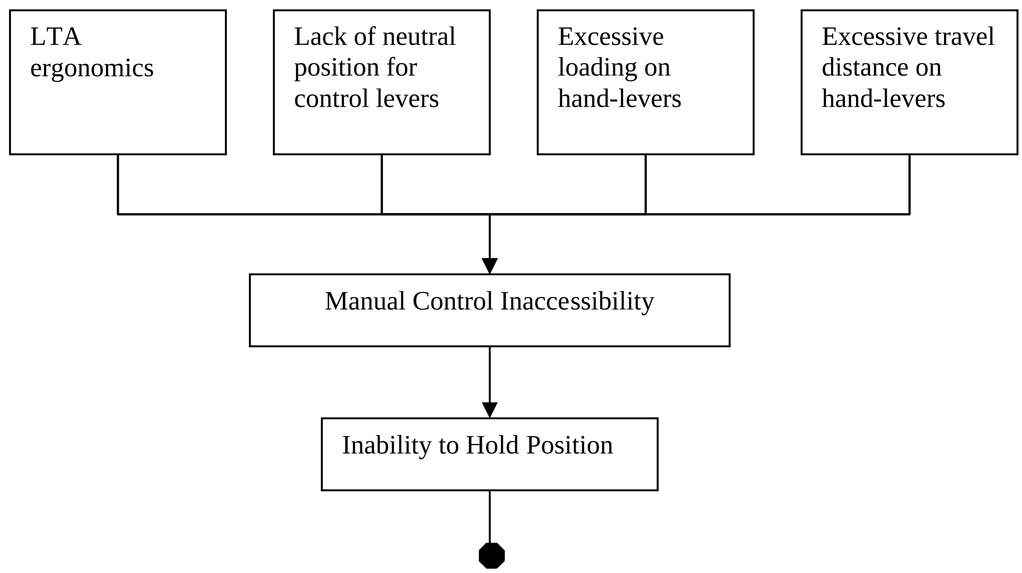



***Fig. 15 Off-Nominal Use Case 6***

**Off-Nominal Use Case 7**
Reference: Failure # 7
Description: Poor rope and cable strength leads to premature lifting and landing

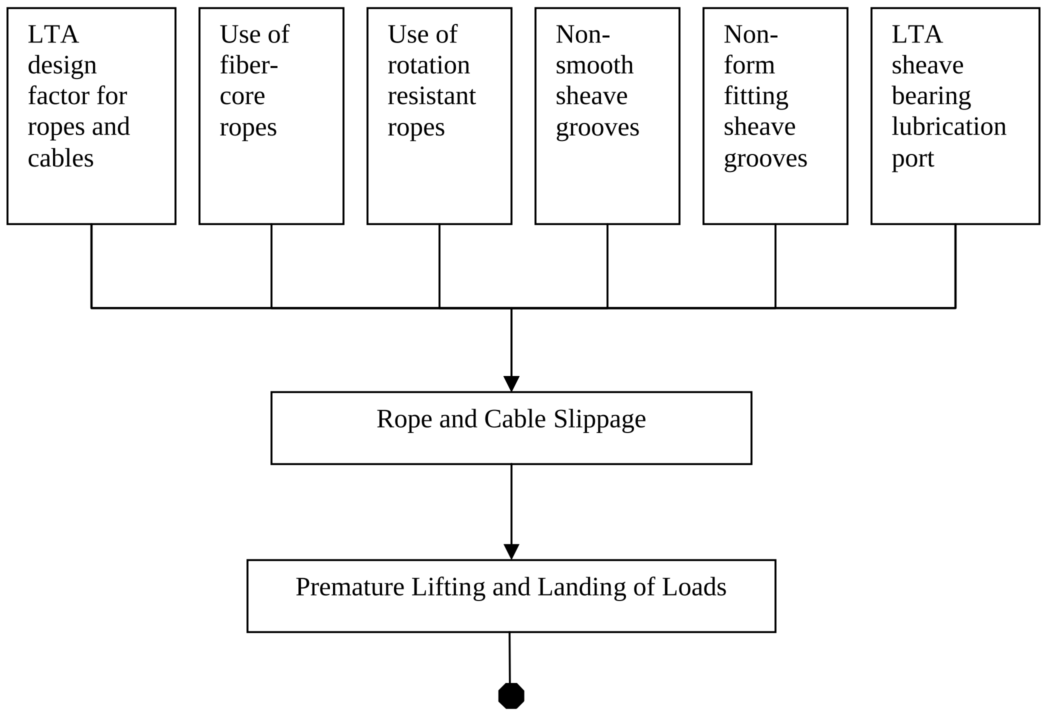



***Fig. 16  Off-Nominal Use Case 7***

**Off-Nominal Use Case 8**
Reference: Failure # 8
Description: Poor ergonomic and cab design issues lead to operator errors

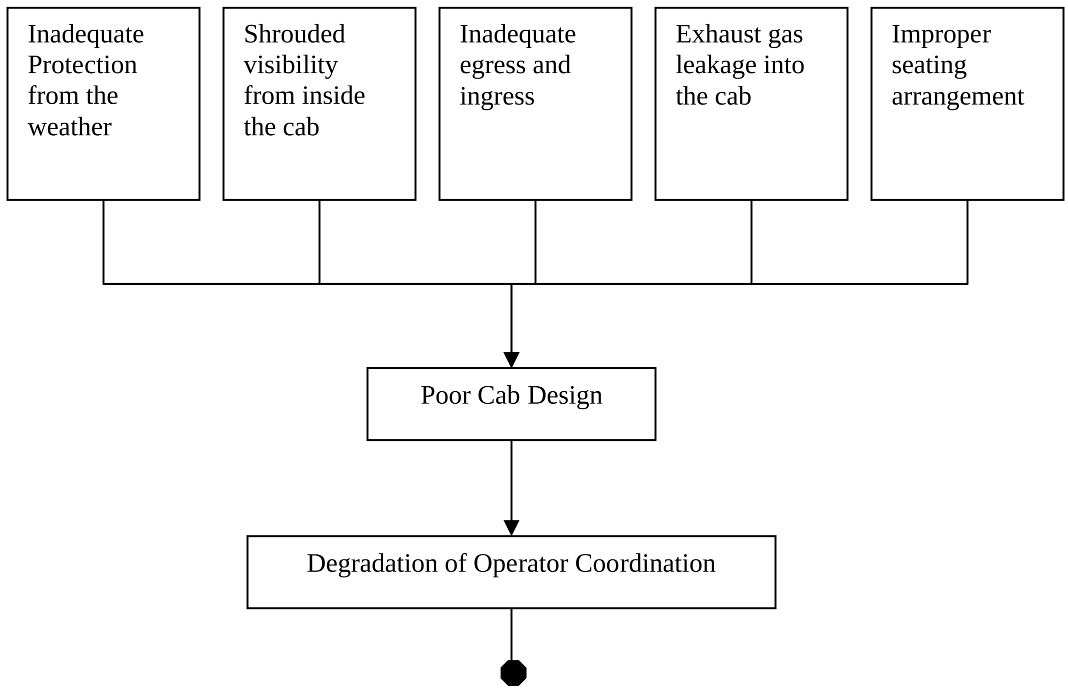



***Fig. 17  Off-Nominal Use Case 8***

**Off-Nominal Use Case 9**
Reference: Failure # 9
Description: Poor boom design leads to boom overturning

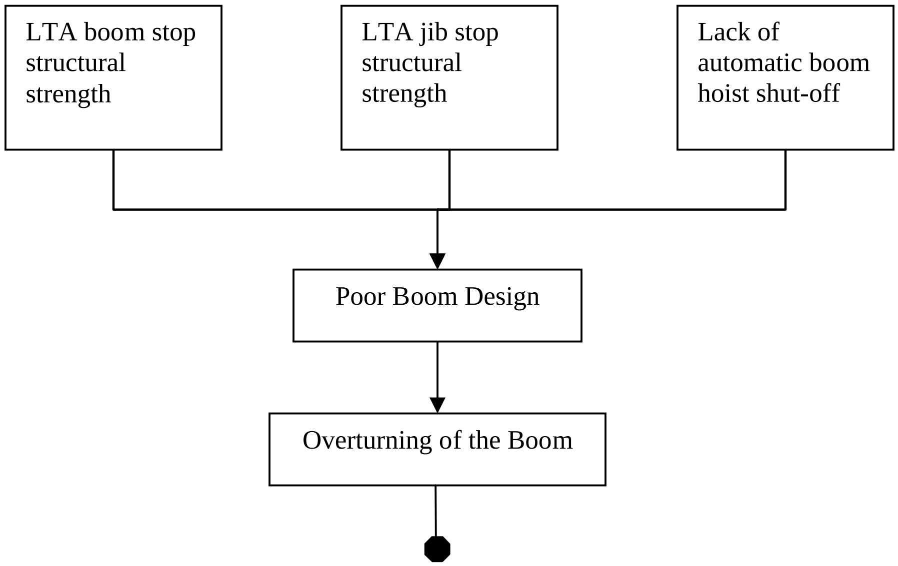



***Fig. 18  Off-Nominal Use Case 9***

Allocation of Nominal to Off-Nominal Use Cases:

| **Phase (Nominal)** | **Failure (Off-Nominal)** |
|---|---|
| 1: Initiate Pre-Start Inspection | 1 |
| 2: Handle and Attach the Load | 2, 9 |
| 3: Lift the Load | 3, 4, 6, 8, 9 |
| 4:  Maneuver the Load | 3, 5, 6, 7, 8, 9 |
| 5: End Lifting | 4, 6, 8 |

***Table 2  Use Case Allocation***

## 3.0 Requirements

The requirements generated for this report are done by extensive research of hydraulic cranes. These operational and design requirements are gathered by researching various crane manufacturing operational specifications, and design specifications. The requirements presented here are pertinent and applicable to the five operational phases of a crane. Verification and Validation of these requirements, however, require that a specific hydraulic crane model be chosen. For the purposes of this report, the Link-Belt ATC 3200 hydraulic truck crane was chosen. Operational and Design specifications were obtained from the manufacturer [5], and a full requirement verification and validation was conducted for this particular crane model.

### 3.1 *Generation of Crane Operational Requirements*

| Req. # | Main Requirement | Derived Requirement |
|---|---|---|
| 1 | To protect against tipping due to excessive moment loading | 1.1 Utilize only cranes with appropriately designed booms |
| 2 | To protect against accidental lowering of boom | 2.1 Install new braking system<br>2.2 Test load-hold valve<br>2.3 Install load-hold valve<br>2.4 Test complete braking hydraulic system<br>2.5 Test braking and valve at the extremes of load and range |
| 3 | To prevent backward crane tipping | 3.1 Adequate boom structural design<br>3.2 Install jib stop mechanism<br>3.3 Install boom hoist shutoff mechanism |
| 4 | To prevent buckling of outriggers | 4.1 Reinforce weak outriggers with tension cables |
| 5 | To prevent crane tilt | 5.1 Test crane unloaded before utilizing it with loads on level surface<br>5.2 Change wheels and tires<br>5.3 Check suspension system |
| 6 | To prevent rope damage | 6.1 Ensure enough rope length to support all maximum boom extensions |
| 7 | To prevent accidental load crashing | 7.1 Install adequate power supply for drum<br>7.2 Install new rope<br>7.3 Install properly thermal rated brakes and clutch<br>7.4 Ensure adequate ergonomics (foot rest, seating, etc…)<br>7.5 Install new anti-drum rotation controller<br>7.6 Install anti-drum rotation mechanism |
| 8 | To prevent non-smooth rotation of turntable | 8.1 Install rotational brake hold that prevents accidental and differential braking related movements |
| 9 | To permit reliable and smooth physical coordination of the operator in conducting crane operations. | 9.1 Install or modify cab area for each operator<br>9.2 Ensure engine exhaust is prevented from entering the cab |
| 10 | To ensure Operator and Ground Personnel can communicate | 10.1 Ensure there is a built-in communication channel between the Crane Operator and Ground Personnel |

[5] Reference 5

| | | |
|---|---|---|
| 11 | To ensure boom structural integrity is maintained | 11.1 Protect boom against environmental degradation<br>11.2 Ensure monthly inspections on boom structural integrity<br>11.3 Ensure proper boom coating to protect against corrosion<br>11.4 Use cranes designed for the proper weather conditions |
| 12 | To ensure boom structural integrity is maintained | 12.1 Protect against loose boom bolts and rivets |
| 13 | To prevent crane tipping | 13.1 Check for counterweight attachment connections<br>13.2 Check for structural (i.e. cracks) within the counterweights |
| 14 | To prevent rope/cable slippage | 14.1 Inspect drum/sheave weekly to ensure smoothness<br>14.2 Use proper drum lubrication to ensure minimum damage from nominal rope/cable shear stress |
| 15 | To prevent load slippage from hook | 15.1 Ensure proper monthly maintenance and inspection of hook assembly<br>15.2 Do not use loads greater than the hook rating<br>15.3 Avoid harsh impact landing of hook and load hoist assembly |
| 16 | To give operator knowledge of crane capabilities and limitations | 16.1 Ensure load rating charts are always present before any operation<br>16.2 Ensure periodic inspections check for updated and clearly legible load rating charts |
| 17 | To prevent erratic spin of the turntable | 17.1 Ensure turntable guard is in place<br>17.2 Inspect turntable gear mechanisms weekly for wear |
| 18 | To ensure smooth movement of boom, jib, and load | 18.1 Conduct monthly inspection of all levers and joysticks, including travel and response adjustments<br>18.2 Proper lubrication of connecting parts |
| 19 | To protect moving parts against environmental damage | 19.1 Ensure guards to protect moving parts are in place before crane operation<br>19.2 Conduct weekly inspections to determine condition of guard<br>19.3 Conduct weekly inspections to determine firm placement of guard (including the bolts and rivets holding it in place) |
| 20 | To protect connecting parts (pins, bearings, rods, rivets) against environmental damage | 20.1 Conduct weekly inspections to assess connecting part condition<br>20.2 Ensure guard is in place to protect connecting parts |
| 21 | To protect crane from tipping during heavy lifting | 21.1 Inspect tire condition before every operational cycle<br>21.2 Maintain proper air pressure in the tires |
| 22 | To prevent loss of hydraulic pressure due to ruptured hose | 22.1 Conduct weekly Inspections for hydraulic hose leakage<br>22.2 Replacement of hoses that exceed minimum threshold thickness<br>22.3 Proper placement of hoses to avoid scrubbing from other mechanical parts<br>22.4 Ensure guard is in place |
| 23 | To prevent loss of hydraulic pressure due to hydraulic pump failure | 23.1 Monthly Inspections for hydraulic pump pressure<br>23.2 Ensure all leakages are fixed prior to operation<br>23.3 Minimize vibration by using appropriately rated dampeners<br>23.4 Ensure pump casing is not dented and is free from ruptures prior to operation |

| | | |
|---|---|---|
| | | |
| 24 | To prevent loss of hydraulic pressure due to hydraulic cylinder damage | 24.1 Monthly Inspections for hydraulic pump pressure<br>24.2 Ensure all leakages are fixed prior to operation<br>24.3 Minimize vibration by using appropriately rated dampeners<br>24.4 Ensure pump casing is not dented and is free from ruptures prior to operation |
| 25 | To prevent loss of hydraulic pressure due to broken hydraulic filter | 25.1 Weekly to monthly replacement of hydraulic filter, as needed, depending on operation cycles<br>25.2 Ensure properly recommended filter is used |
| | | |

***Table 3 Crane Operational Requirements***

### 3.2 *Requirements Verification Matrix*

A Requirements Verification Matrix allows one to formally verify if and how the top-level requirements are met through a specific design implementation. For this report, the Link Belt crane design and operational specifications were matched up against acceptable standard practice and design for hydraulic cranes as designated by the American Society of Mechanical Engineers (ASME) and American National Standards Institute (ANSI). The end result of the verification matrix is to find requirements that cannot be verified or have not been implemented.

***Table 4 Requirements Verification Matrix***

| Req. # | Main Requirement | System Requirement Reference | Verified |
|---|---|---|---|
| 1 | To protect against tipping due to excessive moment loading | Crane is designed in compliance with ASME/ANSI B30 design standard *(Ref. Link-Belt A:4.5)* | Yes |
| 2 | To protect against accidental lowering of boom | *(Manufacturer needs to address)* | No |
| 3 | To prevent backward crane tipping | Crane is designed in compliance with ASME/ANSI B30 design standard *(Ref. Link-Belt A:4.5)* | Yes |
| 4 | To prevent buckling of outriggers | Crane is designed in compliance with ASME/ANSI B30 design standard *(Ref. Link-Belt A:4.5)* | Yes |
| 5 | To prevent crane tilt | Crane is designed in compliance with ASME/ANSI B30 design standard *(Ref. Link-Belt A:4.5)*<br><br>Crane is given a final check down of its wheel and suspension system before delivery to operator *(Ref. Link-Belt A:7.13)* | Yes |
| 6 | To prevent rope damage | Crane is designed in compliance with ASME/ANSI B30 design standard *(Ref. Link-Belt A:4.5)*<br><br>Crane is given a final check down for adequate rope length and quality before delivery to operator *(Ref. Link-Belt A:8.1)* | Yes |
| 7 | To prevent accidental load crashing | Crane is designed in compliance with ASME/ANSI B30 design standard *(Ref. Link-Belt A:4.5)*<br><br>Crane is given a final check down for adequate<br>Drum *(Ref. Link-Belt A:4.1)*<br>Rope *(Ref. Link-Belt A:8.1)*<br>Thermal rating *(Ref. Link-Belt A:7.1)*<br>Ergonomics *(Ref. Link-Belt A:10.5)*<br>Power supply*(Ref. Link-Belt A:5.1)* | Yes |

| | | | |
|---|---|---|---|
| 8 | To prevent non-smooth rotation of turntable | Crane is given a final check down for adequate Brakes *(Ref. Link-Belt A:4.2)* | Yes |
| 9 | To permit reliable and smooth physical coordination of the operator in conducting crane operations. | Crane is designed in compliance with ASME/ANSI B30 design standard *(Ref. Link-Belt A:4.5)*<br><br>Crane is given a final check down for adequate Ergonomics *(Ref. Link-Belt A:10.7)* | Yes |
| 10 | To ensure Operator and Ground Personnel can communicate | *(Manufacturer needs to address)* | No |
| 11 | To ensure boom structural integrity is maintained | Crane Inspection Procedure<br>*Environmental Protection and Maintenance (Ref. Link Belt B: 5.1)*<br>*Boom Inspection and Maintenance (Ref. Link Belt B:4.1)* | Yes |
| 12 | To ensure boom structural integrity is maintained | Crane Inspection Procedure<br>*Boom Inspection and Maintenance (Ref. Link Belt B:4.1.5)* | Yes |
| 13 | To prevent crane tipping | Crane Inspection Procedure<br>*Counterweight Inspection and Maintenance (Ref. Link Belt B:8.5.3)* | Yes |
| 14 | To prevent rope/cable slippage | Crane Inspection Procedure<br>*Drum/Sheave Inspection and Maintenance (Ref. Link Belt B:9.5.5)* | Yes |
| 15 | To prevent load slippage from hook | Crane Inspection Procedure<br>*Hook Assembly Inspection and Maintenance (Ref. Link Belt B:3.8)* | Yes |
| 16 | To give operator knowledge of crane capabilities and limitations | *Lin Belt ATC 3200 All-Terrain Mobile Crane (Manufacturer's Specification and Data Sheet)* | Yes |
| 17 | To prevent erratic spin of the turntable | *Turntable (Rotex)Assembly Inspection and Maintenance (Ref. Link Belt B.16.5)* | Yes |
| 18 | To ensure smooth movement of boom, jib, and load | *Motion Control Assembly Inspection and Maintenance (Ref. Link Belt B:12.3)* | Yes |
| 19 | To protect moving parts against environmental damage | *(Manufacturer needs to address)* | No |
| 20 | To protect connecting parts (pins, bearings, rods, rivets) against environmental damage | *Connecting Parts Assembly Inspection and Maintenance (Ref. Link Belt B:19.5)* | Yes |
| 21 | To protect crane from tipping during heavy lifting | *Tire and Wheel Assembly Inspection and Maintenance (Ref. Link Belt B:18.5)* | Yes |
| 22 | To prevent loss of hydraulic pressure due to ruptured hose | *Hydraulic System Assembly Inspection and Maintenance (Ref. Link Belt B:15.5.2)* | Yes |
| 23 | To prevent loss of hydraulic pressure due to hydraulic pump failure | *Hydraulic System Assembly Inspection and Maintenance (Ref. Link Belt B:15.5.3)* | Yes |
| 24 | To prevent loss of hydraulic pressure due to | *Hydraulic System Assembly Inspection and* | Yes |

| | | | |
|---|---|---|---|
| | hydraulic cylinder damage | *Maintenance (Ref. Link Belt B:15.5.4)* | |
| 25 | To prevent loss of hydraulic pressure due to broken hydraulic filter | *Hydraulic System Assembly Inspection and Maintenance (Ref. Link Belt B:15.5.7)* | Yes |

Using the Requirements Verification Matrix, the following three requirements were not met by the Link Belt design and operational specifications:

| Req. # | Main Requirement | System Requirement Reference | Verified |
|---|---|---|---|
| 2 | To protect against accidental lowering of boom | *(Manufacturer needs to address)* | No |
| 10 | To ensure Operator and Ground Personnel can communicate | *(Manufacturer needs to address)* | No |
| 19 | To protect moving parts against environmental damage | *(Manufacturer needs to address)* | No |

***Table 5  Unmet Requirements***

### 3.3 *Requirements Constraint and Analysis*

Requirements Constraint and Analysis (RCA) checks for important safety critical requirements and then analyzes them for limitations, feasibility, and ease of implementation. The purpose of RCA is to see how well the requirements are developed and the extent to which they can be realistically and practically implemented. The following are some of the more important safety critical hydraulic crane requirements analyzed using RCA.

| Req. # | Derived Requirement | RCA |
|---|---|---|
| 2 | - Install new braking system<br>- Test braking at the extremes of load and range<br>- Test complete braking hydraulic system | - New braking system might have inadequate life-cycle.<br>- Accelerated testing of brakes does not capture random environmental conditions experienced during operational use.<br>- Hydraulic braking system testing might only be exposed to smooth linear loadings, whereas operational load movements are often abrupt.<br>- New braking system may not have gone through adequate independent testing, especially if it is obtained through a subcontractor. |
| 3 | - Install jib stop mechanism<br>- Install boom hoist shutoff mechanism | - New shutoff/stop system might have inadequate life-cycle.<br>- Accelerated testing of shutoff/stop system does not capture random environmental conditions experienced during operational use.<br>- Installation of shutoff/stop system may not have factored in the need of the operator to later modify the system for operational flexibility.<br>- New shutoff/stop system may not have gone through adequate independent testing, especially if it is obtained through a subcontractor. |
| 4 | - Reinforce weak outriggers with tension cables | - Tension cables can be easily removed or damaged by the operator.<br>- Tension cables are a less than satisfactory means of compensating for a poorly designed outrigger.<br>- Tension cables might induce excessive buckling stress beyond the buckling strength of outriggers. |

| | | |
|---|---|---|
| 5 | - Change wheels and tires | - Wheels and tires may not have gone through adequate independent testing, especially if it is obtained through a subcontractor.<br>- Wheels and tires may not have gone through adequate environmental and road condition testing<br>- Operator may have modified wheel and tire attachment system without adequately understanding its impact on the crane structure, before transferring to a new operator. |
| 7 | - Ensure adequate ergonomics (foot rest, seating, etc…)<br>- Adjust ergonomics for each operator | - Manufacturer may only have considered ergonomics for a limited physical subset or size.<br>- Operator may have modified ergonomics irrecoverably before transferring it to a new operator. |
| 7 | - Install new anti-drum rotation controller<br>- Install anti-drum rotation mechanism | - New rotation mechanism and controller might not capture random environmental conditions experienced during operational use.<br>- Installation of new rotation mechanism and controller may not have factored in the need of the operator to later modify the system for operational flexibility.<br>- New rotation mechanism and controller system may not have gone through adequate independent testing, especially if it is obtained through a subcontractor. |
| 8 | - Install rotational brake hold that prevents accidental and differential braking related movements | - Brake hold may not be designed to withstand brake holds for excessively long periods of time and excessive loads.<br>- Availability of brake hold may cause operator to develop the habit of periodically leaving the crane to go outside, exposing ground personnel to the dangerous condition of a hanging load. |

| | | |
|---|---|---|
| 10 | - Communication channel between Ground Personnel and Crane Operator | - Wireless communication channel between ground personnel and operator can be degraded by signal interference<br>- A secondary communication channel between the operator and ground personnel would minimize signal interference. |
| | | |

***Table 6  Requirements Constraint and Analysis***

## 4.0 Query Modeling and Validation

Traditional UML/SysML is not very useful in an interactive dynamic format. In another words, once a system model has been created in UML, it is essentially a static model, with limited or nonexistent ability to be queried and modified dynamically. It would be greatly beneficial if a system model that has been created can be queried to see how one element is related to another and to see all its dependencies and hierarchy. Querying would enable an engineer to see how a particular element in a UML model is linked to another element, and also how changing one would alter the overall model. Currently this capability is lacking. Although relatively intuitive on small systems, the ability to query and dynamically link various UML models is of huge consequences on large and complex projects.

This report looks at a software algorithm model, the UML Query and Link Analysis Tool (UQLAT), for querying and dynamically linking UML models. Much of this work is done by me as part of an Independent Research and Development (IRAD) effort for my company, Raytheon. As a result of this, I am not allowed to disclose the actual algorithm or screenshots of the querying tool, due to UQLAT being currently used for a Bid Proposal. The UQLAT tool will however be openly disclosed and formally presented at the 2007 INCOSE International Symposium to be held from June 24 – June 28, as part of Raytheon's demonstration. UQLAT will also be freely available for DOD projects. However, this case study will discuss the data structure, and general algorithm of UQLAT, as well as results of sample queries for the hydraulic crane system presented in this report.

The system model that was used for this report includes the nominal and the off-nominal use cases that were developed in Sections 2.4 and 2.5. Here nominal and off-nominal use cases were modeled using UML type block structures. The particular UML diagram that was used was the Activity diagram. UQLAT has been developed to see the link and relationship between the various elements within the Activity diagrams, both for the nominal and off-nominal use cases. The following six types of queries can be conducted in UQLAT:

1) Query any one element within one phase
2) Query one element independently across many phases simultaneously
3) Query all the inputs from any one element within one phase
4) Query all the outputs from any one element within one phase
5) Query the link between any one element and other elements within one phase
6) Query the level of any element within any phase

UQLAT is a multi-year program, and therefore is still evolving. As a result, the following are the current limitations of the tool:

- UQLAT is limited to Activity diagrams currently
- UQLAT is not capable of linking elements across multiple phases (i.e. how is this element related to another element across all phases)
- UQLAT only dynamically updates individual phases. So if one element changes in one phase, the change is only reflected for that phase

4.1 *Algorithm*

UQLAT is a UML query tool that was designed and built using a combination of three primary software tools:

ORACLE – A backend ORACLE database serve is used for the storage organization of UML diagrams and all data
ORACLE Forms – A GUI is created using Forms to query UQLAT, as well as display the results of a particular query
Python/SQL – Python and SQL are used to implement the algorithm used for querying and processing

The general sequence of events for a query execution is shown and described below.

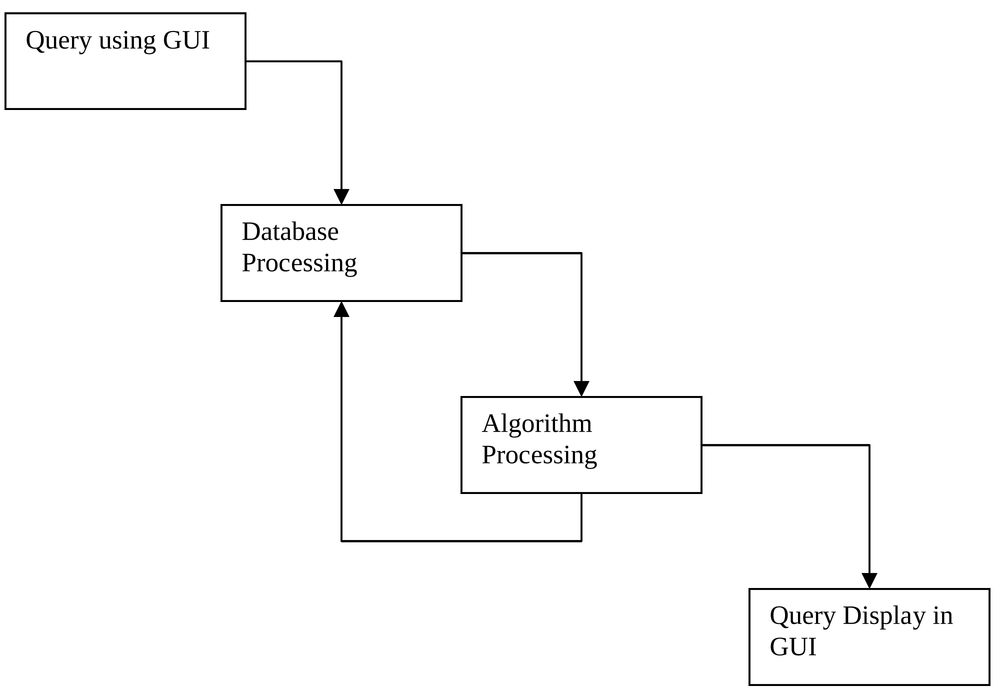



***Fig. 17 Query Sequence of Events***

*Step 1* – User enters a query against UQLAT using the custom GUI, by choosing one or more parameters from the GUI window. All parameters, except one, are drop down menu type lists that have their values pre-loaded into the GUI from the ORACLE database, as the UML diagrams were being created. The only non pre-loaded parameter is the Name box. This is a free text search box that will search the entire database for specific keywords.
*Step 2*- The query will be passed onto the ORACLE database that houses the entire UML diagram blocks, connections, text, etc…
*Step 3* - Here a residing algorithm created in Python/SQL will execute automatically to process the user's input. The algorithm will continually search the database until it has satisfied all the parameter inputs of the user.
*Step 4* – Finally, the algorithm will provide the desired output, which will then be displayed in a GUI format back to the end user.

## 4.2 <u>*Data Structure*</u>

The key ingredient to UQLAT's algorithm is the creation of a unique data structure that makes it conducive to be queried and linked. Every time an UML diagram is created in UQLAT's GUI, it stores each element (a block), connecting arrows, text descriptions, time, hierarchy level, and inputs into the ORACLE database. The basic building block in UQLAT is the block element, which are the rectangular boxes used to describe actions or states in an UML diagram. These block elements, which are stored in the database using the data structure are then processed by the UQLAT algorithm. The algorithm is essentially a structured query mechanism that processes the user's inputs based on the closest search result and the closest relationship it has to any particular block element. The current capability of UQLAT is limited to activity diagrams. The following table fully describes the data structure used in UQLAT.

| Data Element | Type | Description | Comments |
|---|---|---|---|
| Block ID | Mixed Numeric | UQLAT automatically assigns each block element a computer generated ID making each block element an unique entity within the UQLAT database | Block ID serves as the primary key for the entire UQLAT database |
| Name | Text | Textual description of a particular block element | Has to be text string only |
| Level | Integer | The hierarchy level at which a particular block exists | For this report, no more than 3 levels are considered to keep UQLAT manageable |
| Phase | Integer | The function that is being performed | For this report, this corresponds to Phases 1 through 5 |
| Time Element | Integer | The sequence of events taking place. This need not be in perfect sequence, but its primary purpose is to tell where one event exists spatially with respect to another | |
| Action/State | Binary | Action – an event that requires execution<br>State – an event that is the outcome of an execution | A: action<br>S: state |
| Input | Binary | Does a block element have an input | 0: no |

| | | | |
|---|---|---|---|
| | | | 1: yes |
| Output | Binary | Does a block element have an output | 0: no<br>1: yes |
| NOI | Integer | Number of inputs | |
| NOO | Integer | Number of outputs | |
| Recursive | Binary | Does a block have a feedback loop | 0: no<br>1: yes |
| Pointer | Mixed Numeric | The block element address of where one block points towards | Recursive pointers point to themselves |
| | | | |

***Table 7 UQLAT Data Structure***

## 4.3 *Tool Description*

The user interface for UQTAL consists of two different GUI screens that are accessible once UQTAL has been installed along with the entire database and source code elements. The first GUI screen is for the initiation of a query, while the second one displays the results of a query. The user selects an input parameter by selecting them from the drop down menu list or typing in a keyword in the Search Name Box. Once the parameters have been selected, the user can Preview his selections to make sure they are accurate, save the search as a template, or execute the query. The results are displayed in a Query Results Form. The query results form will list the input parameter primary and secondary keys, followed by the query results in the Output section. A clickable diagram link will also take you directly to the UML diagram that the output references.

## 4.4 *Test Query Cases*

Five different test query samples are presented here. These five samples are selected to represent a broad spectrum of the type of queries that are possible with the UQLAT software.

Query 1: How many block elements are there in Phase 2?
Solution: 18 total - 9 action and 9 state

Query 2: List all the block elements within one level of block element “Running Periodic Self Diagnostic”
Solution: “Ensure Boom Level Indicator is Working” and
“Ensure Ground is Level before an Operational Cycle”

Query 3: List all Phases that have the block element “Level Ground Surface”
Solution: Phase 1 and Phase 2

Query 4: What phases have the block elements “Secure Crane”?
Solution: Phase 1 and Phase 5,

Query 5: What block element is common across Phase 3 and Phase 4?
Solution: "Engage Clutch" and "Engage Joystick"

## 4.5 *Test Query Case Results*

Query Initiation Form:

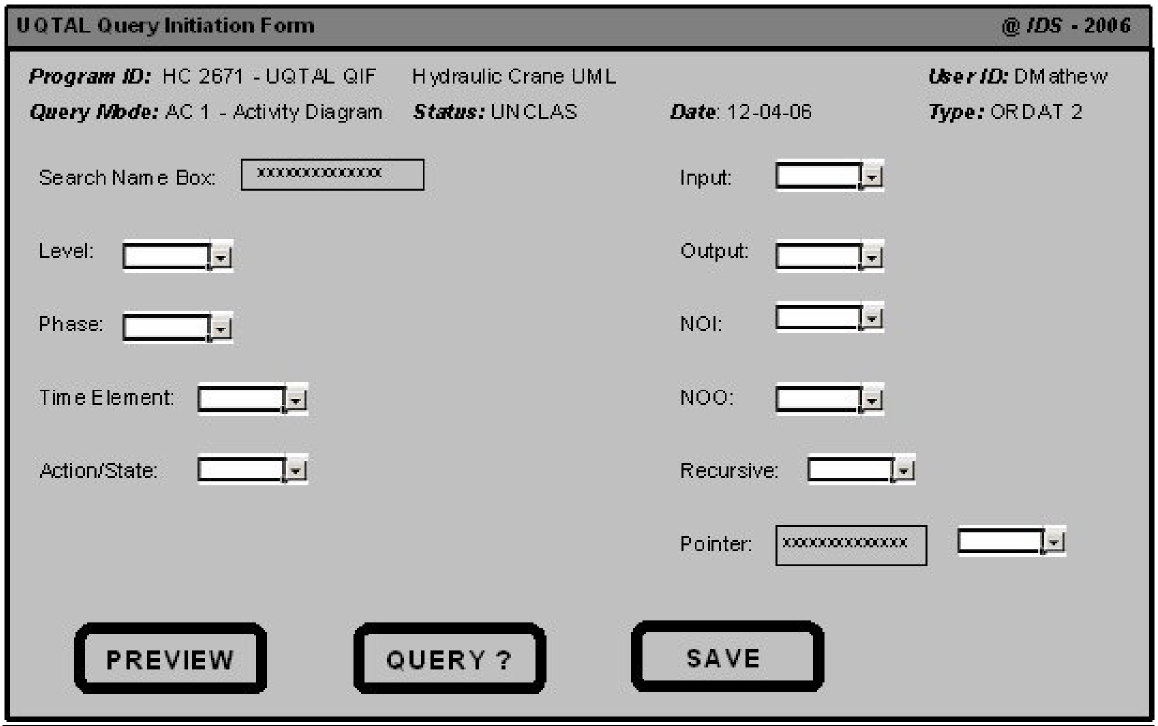
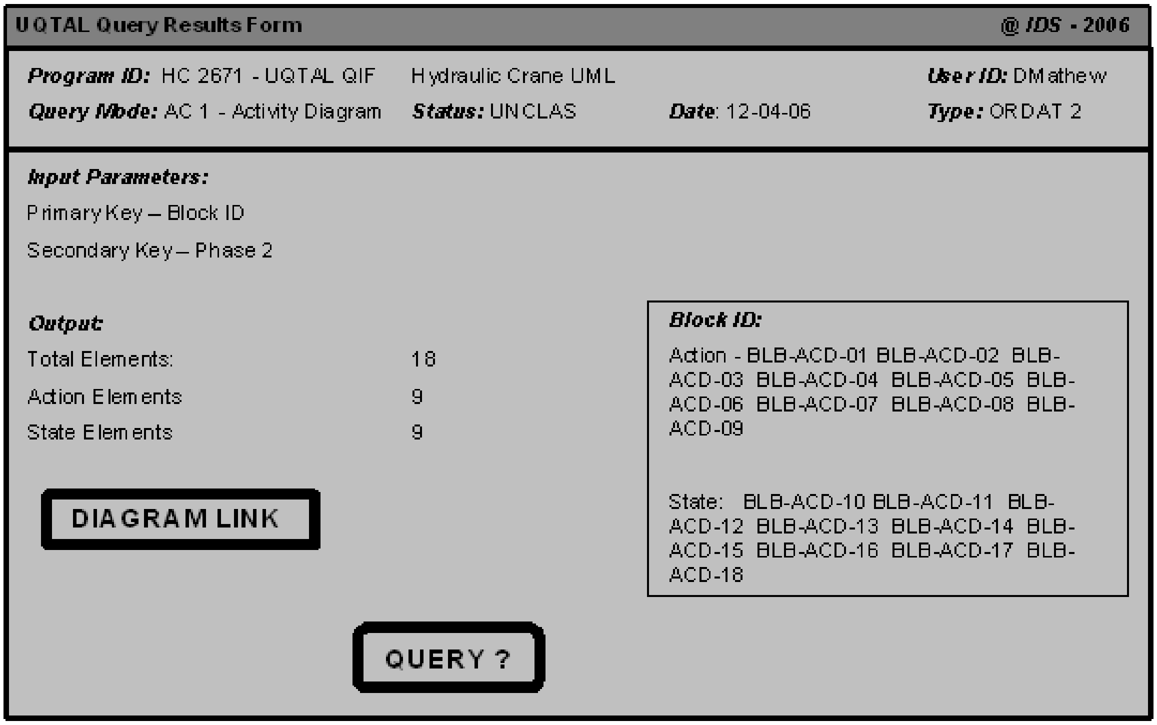



***Fig. 18 Query Initiation Form***

Query 1 Results Form:


UQTAL Query Results Form @ IDS - 2006

***Program ID:*** HC 2671 - UQTAL QIF Hydraulic Crane UML ***User ID:*** DMathew

***Query Mode:*** AC 1 - Activity Diagram ***Status:*** UNCLAS ***Date***: 12-04-06 ***Type:*** ORDAT 2

***Input Parameters:***

Primary Key – Block ID

Secondary Key – Phase 2

***Output:***

Total Elements: 18

Action Elements 9

State Elements 9

DIAGRAM LINK

***Block ID:***

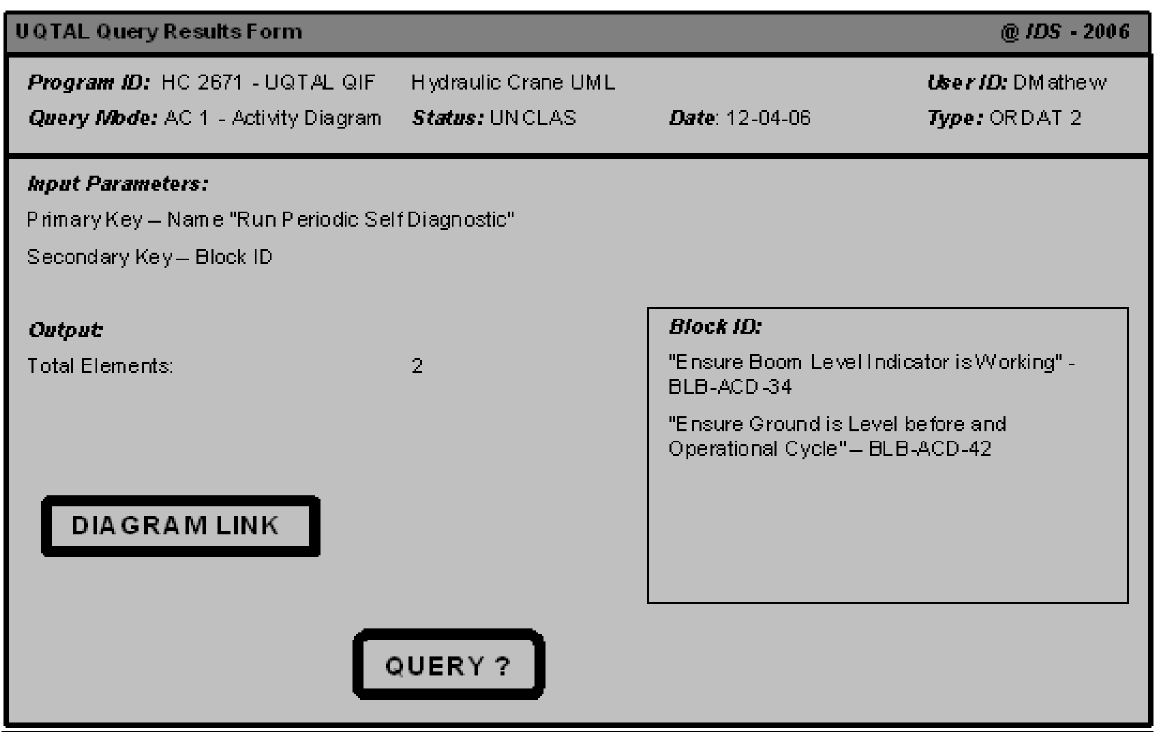
Action - BLB-ACD-01 BLB-ACD-02 BLB-ACD-03 BLB-ACD-04 BLB-ACD-05 BLB-ACD-06 BLB-ACD-07 BLB-ACD-08 BLB-ACD-09

State: BLB-ACD-10 BLB-ACD-11 BLB-ACD-12 BLB-ACD-13 BLB-ACD-14 BLB-ACD-15 BLB-ACD-16 BLB-ACD-17 BLB-ACD-18

QUERY ?

***Fig. 19***

Query 2 Results Form:


UQTAL Query Results Form @ IDS - 2006

***Program ID:*** HC 2671 - UQTAL QIF Hydraulic Crane UML ***User ID:*** DMathew

***Query Mode:*** AC 1 - Activity Diagram ***Status:*** UNCLAS ***Date***: 12-04-06 ***Type:*** ORDAT 2

***Input Parameters:***

Primary Key – Name "Run Periodic Self Diagnostic"

Secondary Key – Block ID

***Output:***

Total Elements: 2

DIAGRAM LINK

***Block ID:***

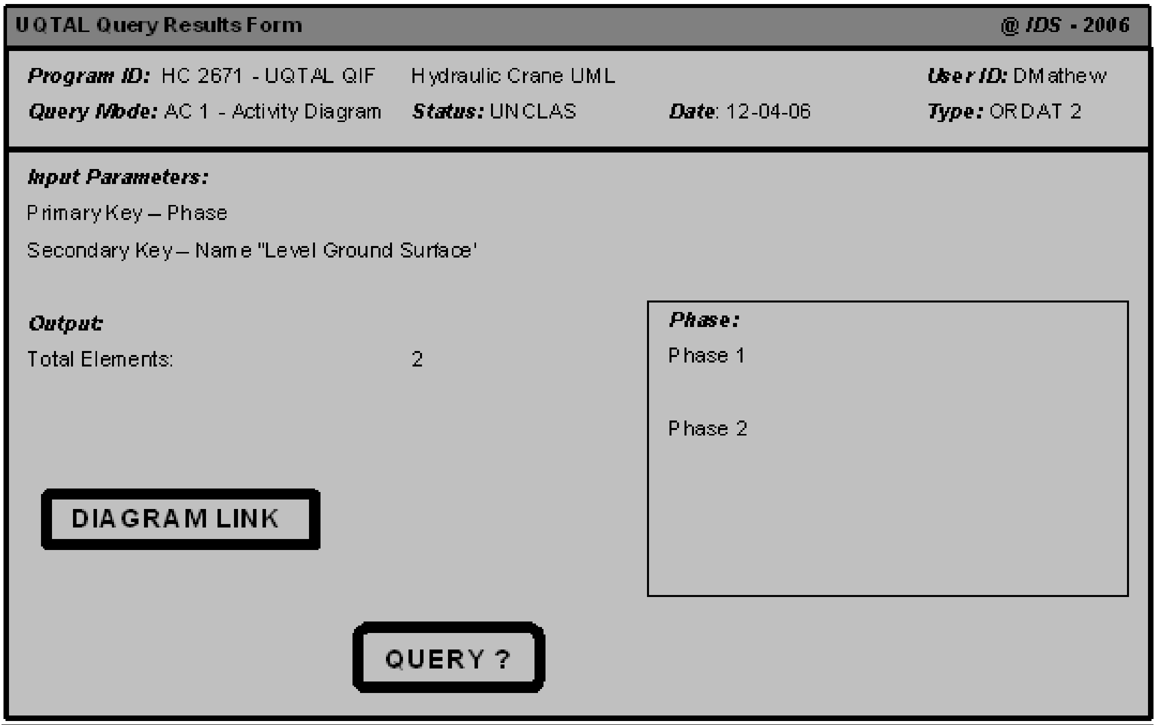
"Ensure Boom Level Indicator is Working" - BLB-ACD-34

"Ensure Ground is Level before and Operational Cycle" – BLB-ACD-42

QUERY ?

***Fig.20***

Query 3 Results Form:


UQTAL Query Results Form @ IDS - 2006

**Program ID:** HC 2671 - UQTAL QIF Hydraulic Crane UML **User ID:** DMathew

**Query Mode:** AC 1 - Activity Diagram **Status:** UNCLAS **Date**: 12-04-06 **Type:** ORDAT 2

**Input Parameters:**

Primary Key – Phase

Secondary Key – Name "Level Ground Surface'

**Output:**

Total Elements: 2

**Phase:**

Phase 1

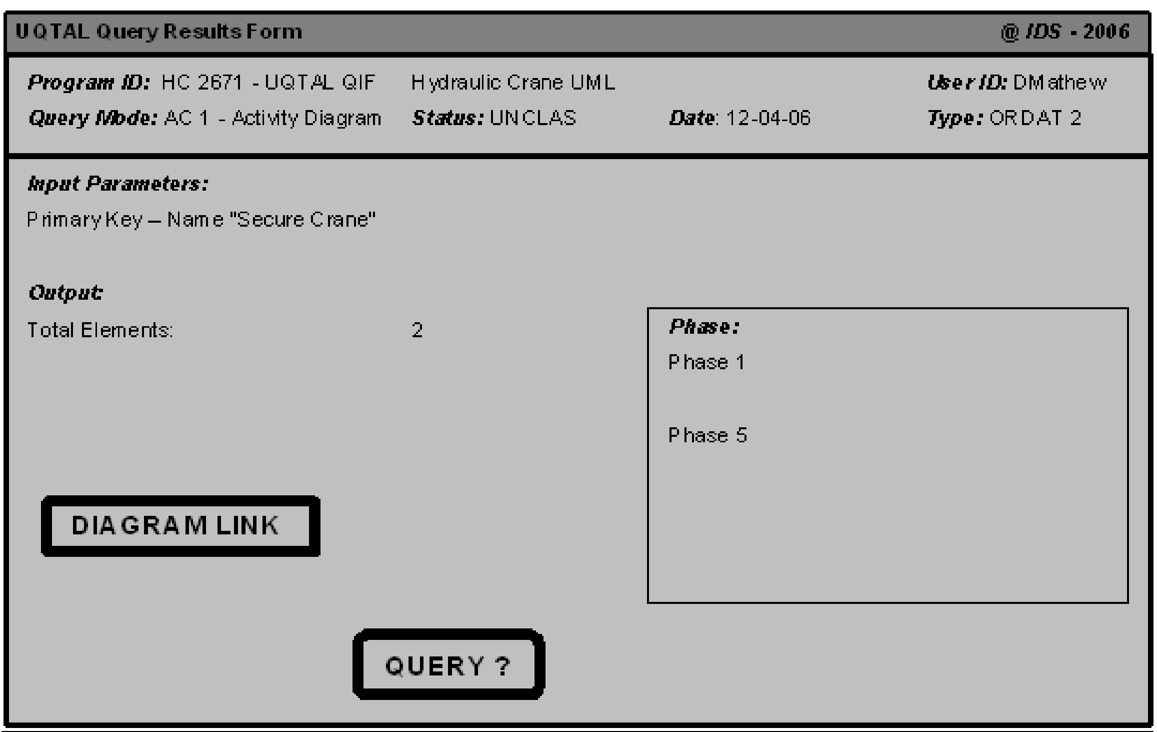
Phase 2

DIAGRAM LINK

QUERY ?

***Fig.21***

Query 4 Results Form:


UQTAL Query Results Form @ IDS - 2006

**Program ID:** HC 2671 - UQTAL QIF Hydraulic Crane UML **User ID:** DMathew

**Query Mode:** AC 1 - Activity Diagram **Status:** UNCLAS **Date**: 12-04-06 **Type:** ORDAT 2

**Input Parameters:**

Primary Key – Name "Secure Crane"

**Output:**

Total Elements: 2

**Phase:**

Phase 1

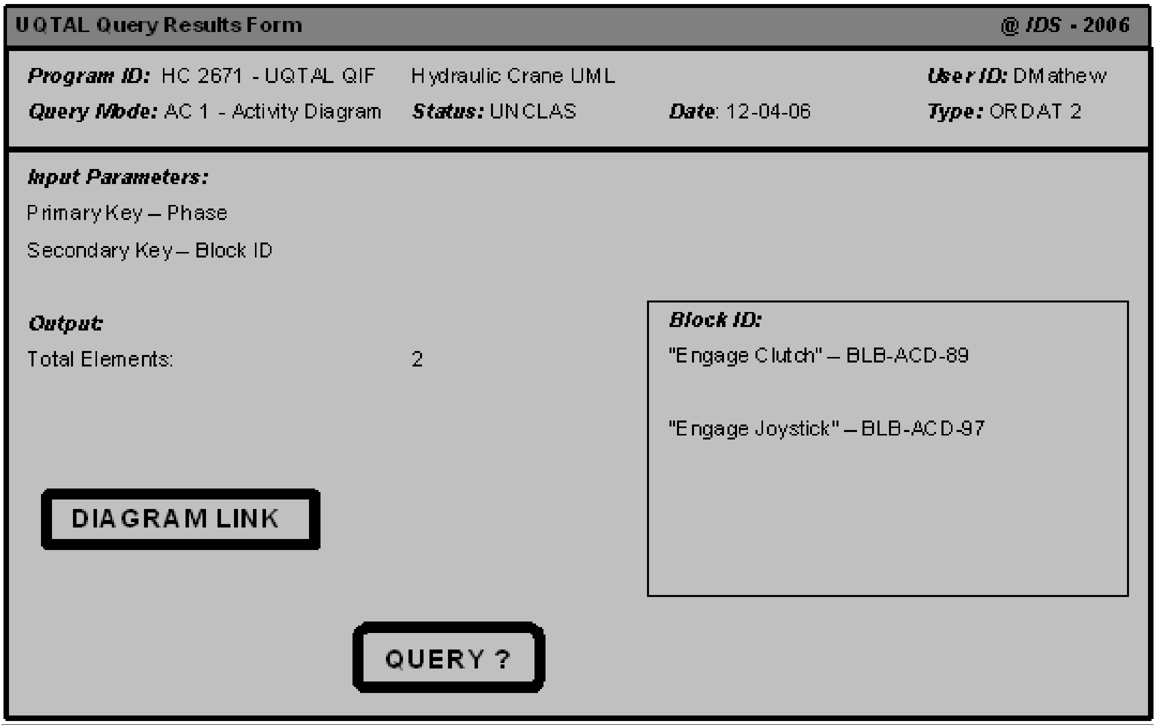
Phase 5

DIAGRAM LINK

QUERY ?

***Fig. 22***

Query 5 Results Form:


UQTAL Query Results Form @ IDS - 2006

**Program ID:** HC 2671 - UQTAL QIF Hydraulic Crane UML **User ID:** DMathew

**Query Mode:** AC 1 - Activity Diagram **Status:** UNCLAS **Date**: 12-04-06 **Type:** ORDAT 2

**Input Parameters:**

Primary Key – Phase

Secondary Key – Block ID

**Output:**

Total Elements: 2

**Block ID:**

"Engage Clutch" – BLB-ACD-89

"Engage Joystick" – BLB-ACD-97

DIAGRAM LINK

QUERY ?

***Fig. 23***

## 5.0 CONCLUSION

A detailed system engineering effort goes through system requirements, architecture development, verification, and validation. The current modeling efforts used for systems modeling is not very dynamic and cannot be queried. Without the ability to query and dynamically observe changes, a model does not go very far in aiding a systems engineer. UQLAT has proven itself to be such a tool, and very effective in its ability to transcribe UML models into dynamic and query capable models. Although there are limitations to UQLAT in its current format, primarily in its inability to dynamically link across multiple phases and being limited to activity diagram only, future additions to UQLAT will make it a very versatile tool for systems modeling and analysis.

## 6.0 REFERENCES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4) Magee, Jeff. *LTSA: Labeled Transition System Analyser.*1999. http://www.doc.ic.ac.uk/~jnm/book/ltsa/LTSA.html

*5)* *Technical Data Specifications and Capacities*: Link-Belt ATC 3200 Telescopic Boom All Terrain Crane, March, 2005

# Appendix A – Definitions

| | |
|---|---|
| **Auxiliary Hoist** | A supplemental hoisting unit, usually of lower load rating and higher speed than the main hoist. |
| **Axis of Rotation** | The vertical axis around which the crane's superstructure rotates. |
| **Boom** | In cranes and derricks, an inclined spar, strut, or other long member supporting the hoisting tackle. Also defined as a structural member attached to the revolving superstructure used for guiding and acting as a support for the load. |
| **Boom Angle Indicator** | An accessory device that measures the angle of the boom base section centerline to horizontal. |
| **Boom Stops** | A devise used to limit the angle of the boom at its highest position. |
| **Brake** | A device used for retarding or stopping motion by friction or power means. |
| **Block** | Sheaves or grooved pulleys in a frame provided with hook, eye, and strap. |
| **CEHA** | Cause and Effect Hazard Analysis |
| **Crane** | A machine consisting of a rotating superstructure for lifting and lowering a load and moving it horizontally on either rubber tires or crawler treads. |
| **Counterweight** | Weights used for balancing loads and the weight of the crane in providing stability for lifting. |
| **Deck** | The revolving superstructure or turntable bed. |

| | |
|---|---|
| **Drum** | The spool or cylindrical member around which cables are wound for raising and lowering loads. |
| **Gantry** | A structural frame work (also known as an A Frame) mounted on the revolving superstructure of the crane to which the boom supporting cables are reeved. |
| **Headache Ball** | A heavy weight attached above the hook on a single line or whip line to provide sufficient weight to lower the hook when unloaded. |
| **Holding Brake** | A brake that automatically sets to prevent motion when power is off. |
| **IMHA** | Inspection and Maintenance Hazard Analysis |
| **Jib** | An extension attached to the. boom point to provide added boom length for lifting specified loads. |
| **Load** | The weight of the object being lifted or lowered, including load block, ropes, slings, shackles, and any other ancillary attachment. |
| **Load Block** | The assembly of the hook or shackles, swivel, sheaves, pins, and frame suspended from the boom point. |
| **Main Hoist** | Hoist system or boom used for raising and lowering loads up to maximum rated capacity. |
| **Mechanical Load Brake** | An automatic type of friction brake used for controlling loads in the lowering direction. This device requires torque from the motor to lower a load but does not impose additional loads on the motor when lifting a load. |
| **OHA** | Operation Hazard Analysis |

| | |
|---|---|
| **Outriggers** | Support members attached to the crane's carrier frame which are used to the crane and may be blocked up to increase stability. |
| **Radius** | The horizontal distance from the axis of rotation of the crane's superstructure to the center of the suspended load. |
| **Reeving** | The path that a rope takes in adapting itself to all sheaves and drums of a piece of equipment. |
| **Running Sheave** | Sheaves that rotate as the hook is raised or lowered |
| **SDHA** | Scenario Driven Hazard Analysis |
| **Two-Block** | The condition in which the lower load lock or hook assembly comes in contact with the upper load block or boom point sheave assembly. |
| | |

# Appendix B – Link Belt ATC 3200 Technical Data and Specifications

## PRELIMINARY SPECIFICATIONS

- 43.3-196.9 ft *(13.2-60.0m)* six section boom
- 17.7 ft - 43.3 ft *(5.4 - 13.2m)* two piece offsettable fly
- Four 19.7 ft *(6.0m)* fly insert plus 43.3 ft *(13.2m)* two-piece offsettable fly [Total attachment length is 122.1 ft *(37.2m)*]
- 331 ft *(101.0m)* maximum tip height
- Height: 13 ft 1in *(4.0m)*
  Width: 9 ft 10 in *(2.97m)*
  Length: 52 ft 4 in *(16.0m)*
- 52.8 mph *(85.0km/hr)* travel speed
- 27 ft 10 in *(8.49m)* wheel base
- 20.5R25 tires
- Mercedes Benz diesel engines:
  Upper – OM906LA 6.4L 184 hp *(135kW)*;
  lower – OM502LA 15.9L 517 hp *(380kW)*
- ZF AS-Tronic automated 16-speed transmission
- 27 ft - 3 in *(8.30m)* outrigger spread,
  29 ft – 6 in *(8.98m)* outrigger base
- 21,010 lbs *(9 530.0kg)* maximum winch line pull
- 526 fpm *(160.21m/min)* maximum winch line speed

## PRELIMINARY KEY FEATURES

- Tested to meet SAE structural and stability requirements
- Automatic load compensator maintains a consistent radius during load lift-off
- Crane instrumentation and operational documents have North American units of measure
- Multiple steering modes that can be controlled from the carrier cab
- Boom dolly provisions
- Free and automatic swing brake modes
- Tilting interior within the operator's cab
- Air conditioning in the carrier and operator's cabs
- Outrigger controls in the operator's cab
- Central lubrication system for the upper and carrier
- 10x8x8 Drive/Steer
- Third axle lift system
- Engine compression brake and intarder
- Cruise control

Link-Belt Construction Equipment Company | Lexington, Kentucky | www.linkbelt.com



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Link-Belt
CRANES

5449–0505–P6

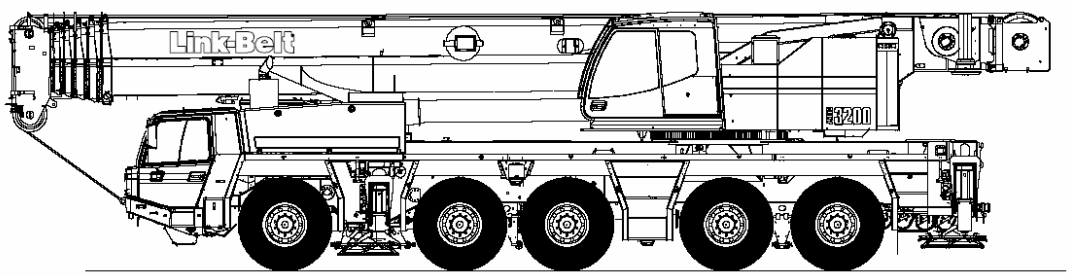
# Technical Data

Specifications & Capacities

ATC 3200

Telescopic Boom All Terrain Crane

200 ton *(181.44 metric ton)*



# Boom, Attachments, and Upper Structure

## ■ Boom

**Design** – Six section, formed construction of extra high tensile steel consisting of one base section and five telescoping sections. The two plate design of each section has multiple longitudinal bends for superior strength. Each telescoping section extends independently by means of one double–acting, single stage hydraulic cylinder with an integrated holding valve.

### Boom

- 43.3–196.9 ft (*13.2–60.0m*) six section boom
- Four pinned positions of 0%, 46%, 93%, and 100% on each boom section provide twenty–nine extend combinations for superior capacities when varying the extension of the telescoping sections, controlled from the operator's cab.
- Integral boom dolly connection
- Mechanical boom angle indicator
- Wind speed indicator
- Maximum tip height for the following boom lengths are:

| Boom Length (Pinned Positions) | | Tip Height | |
|---|---|---|---|
| ft | *m* | ft | *m* |
| 196.9 | *60.0* | 208.3 | *63.5* |
| 186.0 | *56.7* | 197.5 | *60.2* |
| 171.9 | *52.4* | 183.5 | *55.9* |
| 157.5 | *48.0* | 169.2 | *51.6* |
| 143.3 | *43.7* | 155.0 | *47.3* |
| 128.9 | *39.3* | 140.8 | *42.9* |
| 114.8 | *35.0* | 126.7 | *38.6* |
| 100.4 | *30.6* | 112.4 | *34.2* |
| 86.3 | *26.3* | 98.3 | *30.0* |
| 71.9 | *21.9* | 84.0 | *25.6* |
| 57.7 | *17.6* | 69.9 | *21.3* |
| 43.3 | *13.2* | 55.6 | *16.9* |

### Boom Head

- Seven 18.2 in (*46.2cm*) root diameter nylon sheaves to handle up to fourteen parts of line
- Easily removable wire rope guards
- Rope dead end lugs on one side of the boom head
- Boom head is designed for quick–reeve of the hook block

### Boom Elevation

- One double acting hydraulic cylinder with integral holding valve
- Boom elevation: –1.5° to 84°
- **Load Com** – Load compensator maintains a consistent radius during load lift–off by automatically elevating boom hoist cylinder. Operated by a switch from the operator's cab.

### Auxiliary Lifting Sheave – Optional

- Single 18.2 in (*46.2m*) root diameter nylon sheave
- Easily removable wire rope guards
- Does not affect erection of the fly or use of the main head sheaves

### Hook Blocks and Balls – Optional

- 27.6 ton (*25.0mt*) 1 sheave quick–reeve hook block with safety latch
- 88.2 ton (*80.0mt*) 5 sheave quick–reeve hook block with safety latch
- 200 ton (*181.4mt*) 11 sheave quick–reeve hook block with safety latch
- 11 ton (*10.0mt*) swivel hook ball with safety latch

### Fly – Optional

- 17.7 ft–43.3 ft (*5.4–13.2m*) two piece telescoping lattice fly, stowable, offsettable to 0°, 20°, and 40°. Maximum tip height is 251.4 ft (*76.6m*).

### Fly Inserts – Optional

- Four 19.7 ft (*6.0m*) lattice inserts to be mounted between the 17.7 ft (*5.4m*) lattice fly base and the 25.6 ft (*7.8m*) lattice fly tip option. Maximum tip heights for the following fly lengths are:

| Fly Length | | Tip Height | |
|---|---|---|---|
| ft | *m* | ft | *m* |
| 63.0 | *19.2* | 271.0 | *82.6* |
| 82.7 | *25.2* | 290.5 | *88.5* |
| 102.4 | *31.2* | 310.1 | *94.5* |
| 122.1 | *37.2* | 329.7 | *100.5* |

## ■ Upper Operator's Cab and Controls

**Environmental Cab** – Fully enclosed, one person cab of galvaneal steel structure with acoustical insulation. Equipped with:

- Tilting interior where the operator's seat, joystick controllers, floor controls and pedals, and main console tilt within the cab
- Tinted and tempered glass windows
- Extra–large power up/power down front window with windshield wiper and washer
- Fixed roof window with windshield wiper
- Sliding left side door with large fixed window
- Fold out rear window for ventilation
- Fixed right side window
- Six way adjustable, cushioned seat with headrests, adjustable lumbar support, and seat belt
- Engine dependent warm–water heater with air ducts for front windshield defroster and cab floor
- AM/FM stereo with single disc CD player
- 12 volt and 24 volt power connections
- Engine hourmeter
- Rated capacity limiter override
- Adjustable sun visor
- Dome light
- Cup holder
- Fire extinguisher
- Left side viewing mirror
- Integral recessed cabwalks
- One position travel swing lock

**Air Conditioning – Optional** – Integral with cab heating system utilizing the same ventilation outlets

**Armrest Controls** – Two dual axis electronic joystick controllers for:

- Swing
- Boom hoist
- Boom telescope
- Main rear winch
- Auxiliary front winch – optional
- Counterweight handling
- Drum rotation indicator(s)
- Winch high/low speed and disable switch(es)
- Free swing/automatic swing brake switch
- Auxiliary winch/telescope/counterweight handling switch
- High speed function button
- Boom pinning location stop button
- Warning horn

**Foot Controls**

- Boom telescope
- Swing brake
- Engine throttle

**Front Main Console** – Controls and indicators for:

- Emergency shut down switch
- Central warning indication

**Right Side Console** – Controls and indicators for:

- Auxiliary winch disable switch
- Swing override switch
- Drum rotation indicator activation switch
- Telescopic override switches
- Engine shutdown switch
- Anti–two block override switch

**Right Side Overhead Console** – Controls and indicators for:

- Central lubrication system switch
- Boom and cab floodlight switches
- Top windshield wiper switch
- Front windshield wiper and washer switch
- Power up/power down front windshield switch
- Tilting interior switch
- Battery main shutoff switch
- Supplementary heater controls

**Cockpit Graphic Control (CGC)** – Ergonomically positioned on the front main console, digital instrumentation, and control for crane operations including:

- Engine coolant temperature
- Electronic bubble level and levelness readout
- CAN–BUS diagnostic and engine electronic fault indicator
- Swing lock indicator
- Hydraulic oil and air cleaner filter indicator
- Hydraulic oil temperature
- Low engine oil pressure indicator
- Low voltage indicator
- Fuel level
- Carrier park brake indicator
- Suspension lock indicator
- Axle lift indicator
- Outrigger operation
- Outrigger force readout – optional

**Rated Capacity Limiter** – Color graphic audio–visual warning system integrated into the front main console with anti–two block and function limiter. Operating data available includes:

- Crane configuration
- Boom length and angle
- Boom head height
- Allowed load and % of allowed load
- Boom angle
- Radius of load
- Actual load
- Counterweight handling
- Wind speed
- Operator settable alarms (include):
  - Maximum and minimum boom angles
  - Maximum and minimum tip height
  - Maximum boom length
  - Left/right swing positions
  - Operator defined area (imaginary plane)

## ■ Swing

**Motor/Planetary** – Bi–directional hydraulic swing motor mounted to a planetary reduction unit for 360° continuous smooth swing at 1.5 rpm. Free swing capable when controller within the operator's cab is in the neutral position.

**Swing Park Brake** – 360°, electric over hydraulic, (spring applied/hydraulic released) multi–disc brake mounted on the reduction unit. Operated by a switch from the operator's cab.

**Swing Brake** – 360°, foot operated, hydraulic applied disc brake mounted to the reduction unit.

**Swing Lock** – One–position swing lock (boom over rear) operated from the operator's cab.

**Automatic Swing Brake Mode** – Swing brake applies when controller within the operator's cab is in the neutral position. Operated by a switch from the operator's cab.

**360° Positive Swing Lock – Optional** – Meets New York City requirement.

## ■ Central Lubrication System

Automated lubrication unit that injects grease into the turntable bearing, boom hoist cylinder pins, boom foot pin, and the main (front) and auxiliary (rear) winch. Operated by a switch from the operator's cab.

## ■ Electrical

Two batteries provide 24–volt operation and starting. CAN bus wiring and components, and integral self–test CSS (Control & Service System).

**Swing Alarm** – Audio warning device signals when the upper is swinging.

**Lights**

- Two working lights on front of the cab
- One rotating amber beacon on the right side of the main winch
- One boom floodlight on the boom base section
- Two side marker lights on the boom head

## ■ Hydraulic System

**Main Pumps**

- Two variable displacement piston pumps for the main and auxiliary winches, boom hoist and telescope
- One fixed displacement piston pump for the counterweight removal, and swing
- One fixed displacement gear pump for pilot pressure
- One fixed displacement gear pump for telescope pinning
- The upper engine powers the pumps. Combined pump capacity of 170.7 gpm (*645Lpm*).
- Remote mounted, auxiliary hydraulic oil cooler

**Pump Control "fine inching" Mode** – Special fine metering pump settings, selectable from the operator's cab, allows very slow movements to the main and auxiliary winches, boom hoist, and swing for precision work.

**Pump Control "high speed" Mode** – Boosts hydraulic oil flow by combining the two variable displacement piston pumps for the main and auxiliary winches, boom hoist up, and telescope extend. Operated by a button on the right joystick controller from the operator's cab.

**Hydraulic Reservoir** – 268 gal (*1 014L*) capacity equipped with sight level gauge. Diffusers built in for deaeration.

**Filtration** – One 12 micron, full flow, line filter in the control circuit. All oil is filtered prior to return to sump tank. Accessible for easy filter replacement.

**Counterbalance Valves** – All hoist motors, boom extend cylinders, and boom hoist cylinders are equipped with counterbalance valves to provide load lowering and prevents accidental load drop when hydraulic power is suddenly reduced.

**Boom Hoist Float Valves** – For transporting the boom over the rear of the crane with a boom dolly. Allows hydraulic oil within the boom hoist cylinder to flow between piston side and case side.

**Swing Brake Release Valve** – For transporting the boom over the rear of the crane with a boom dolly. Holds the 360° swing park brake in the release position allowing free rotation of the upperstructure.

## ■ Pump Drive

All functions are hydraulically powered allowing positive, precise control with independent or simultaneous operation of all functions.

## ■ Fuel Tank

One 66.0 gal (250L) capacity tank.

## ■ Engine

| Specification | Mercedes Benz OM 906 LA |
|---|---|
| Numbers of cylinders | 6 |
| Cycle | 4 |
| Bore and Stroke: inch (mm) | 4.02 x 5.12 (102x130) |
| Piston Displacement: $in^3$ ($cm^3$) | 388.72 (*6 374*) |
| Max. Brake Horsepower: hp (kW) | 184 (135) @ 1,800 rpm |
| Peak Torque: ft lb (Nm) | 553 (750) @ 1,200 rpm |
| Alternator: volts – amps | 24 – 90 |
| Crankcase Capacity: qt (L) | 30.64 (29) |

- Webasto Engine/Cab Heater – Diesel fired heating unit that can be used for preheating of the engine, or for engine preheating combined with heating of the operator's cab.