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RISK ASSESSMENT IN WIND GENERATOR ASSEMBLY ACTIVITIES IN WIND FARMS

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Abstract: With the increase in demand for renewable energy, there has been a boom in wind farms in Brazil. With this, it was also observed the need for work safety procedures that guarantee worker health. One of the procedures used during the pre-installation phase is the Preliminary Hazard Analysis - APP, which determines the degree of risk of a sub-activity. Using the APP procedure for the sub-stages of wind turbine assembly, it was found that the average degree of risk was equal to 3, which corresponds to "moderate". However, one of the determining factors for this conclusion is the frequency in which the accident occurs. This frequency was not based on a historical series because this data is not widely disseminated.
Keywords: Wind Farms; Preliminary Hazard Analysis; Wind turbine assembly; Renewable energy.

INTRODUCTION

Brazil is the largest producer of wind energy in Latin America and the 6th in the world in installed capacity, recently surpassing the 25 GW mark (data from February 2023) of installed capacity, with emphasis on the Northeast and extreme South regions of Brazil. country, according to the Brazilian Wind Energy Association – ABEEólica (1). Wind energy corresponds to more than 13% of Brazil's Energy Matrix according to data released by ABEEólica in March 2023, with a projection of having more than 44 GW of installed capacity by 2028. ABEEólica estimates a potential of more than 700 GW on shore considering the advancement of technology and the size of wind turbines, increasing productivity per machine and allowing the identification of previously unexplored potential.

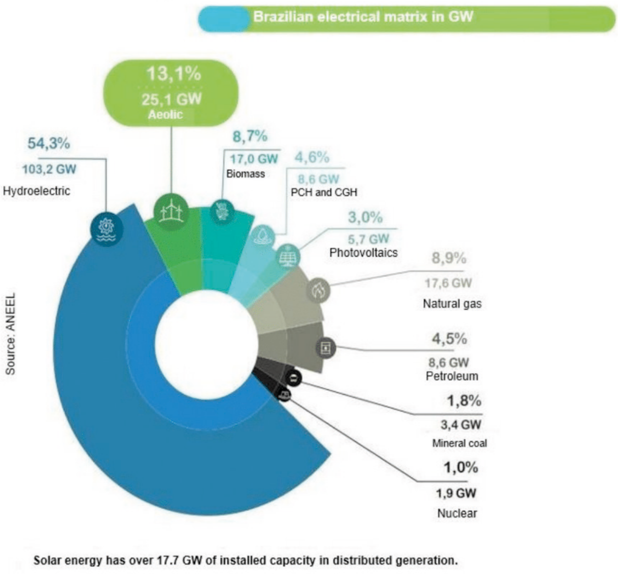

Figure 01: Brazilian Electrical Matrix

Source: Abeeólica, (2023).

According to Planelles and Sánchez (2018), the increasing search by companies for so-called Green Energy from renewable energy sources must increasingly drive the growth of Brazilian wind energy. The example is Europe, which by the year 2050 intends to radically change its energy matrix from fossil fuels to a matrix of sustainable origin, thereby reducing its CO_2 emissions to zero.

The Brazilian Wind Energy Association (ABEEólica) has data showing that for each new MW installed, around 15 jobs are created throughout the production chain.

Jobs generated by wind energy are divided into three categories:

1st Technological development and equipment manufacturing;

2° Installation and commissioning of plants, project management, transport and construction of plants;

3° Operation and maintenance and energy generation and distribution;

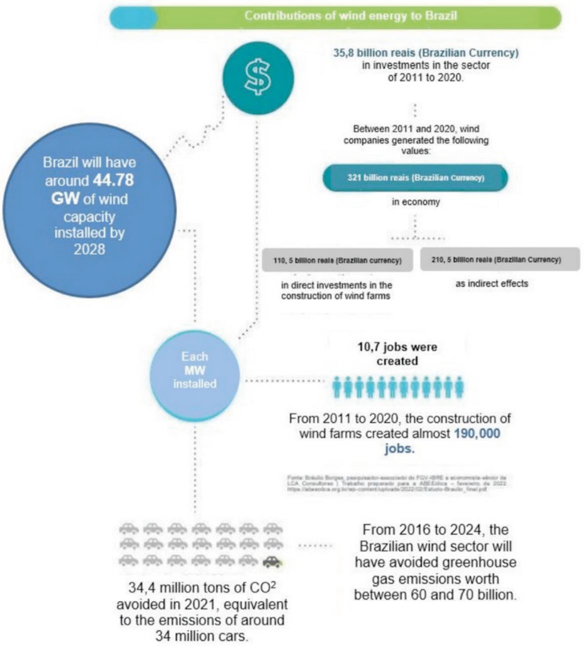

Figure 02: Contribution of Wind Energy to Brazil

Source: Abeeólica, (2023).

A study commissioned by Abeeólica shows that, between 2011 and 2020, the sector was responsible for creating 196 thousand jobs in Brazil.

The Brazilian Industrial Development Agency (ABDI) estimates that by 2026 the wind chain could generate approximately 200 thousand new direct and indirect jobs.

WIND FARM CONSTRUCTION STAGES

After the wind quality research stages, development of the wind project and its licensing with ANEEL and Environmental Agencies, the wind farm implementation stage begins, where several activities are developed, including:

1. Suppression of vegetation, opening access, construction of support areas, such as construction sites, concrete plants, material storage yards, among others;
2. Openings of tower squares, places where the towers will be installed, concreting of the tower bases;
3. Construction of transmission lines and substation;
4. Assembly of wind turbine structures;
5. Commissioning and operation.

The main occupations in the construction and assembly stage of wind farms are civil construction workers in general, machine and equipment operators, civil engineers, occupational safety personnel, electrical, project, mechanic, environmental area, project manager and works, among others.

In the construction/implementation of wind farms, the assembly of wind turbines is normally the responsibility of the equipment supplier, who hires companies with experience and specialized professionals to assemble this equipment due to the risks involved in this activity. The company that owns the park is responsible for the civil part and the construction of the wind turbine bases, where the tower will be bolted according to the specifications requested by the equipment manufacturer.

WIND TURBINES

Wind turbines are basically made up of:

1. A rotor or Hub is the element of the wind turbine that fixes the blades, made of steel or high-strength metal alloy. It is one of the heaviest components, however, its role is not just to fix it, as it also controls the rotation of the blades so that they can capture the wind at the so-called angle of attack.
2. The blades have the function of capturing the wind, they are made with fiberglass, a resistant and light material, but they can also be made with carbon fiber, somewhat more expensive, the most used equipment works with 03 blades;

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3. Tower starts on the base previously built in concrete on a foundation sized to support the weight of the equipment and the efforts suffered by the wind turbine. They can be made of steel (most common) or concrete, depending on the manufacturer. Towers are normally divided into 3 to 5 sections (parts) to facilitate transportation and assembly:

4. Nacelle is the part of the wind turbine that houses various equipment devices such as shaft, multiplier, generator, wind direction sensor and others. Its material and shape vary depending on the manufacturer.

MANAGEMENT OF RISK

The new projects being licensed by ANEEL are using wind turbines with a power exceeding 5 MW, which may exceed 6 MW depending on the manufacturer. This equipment has steel (most common) or concrete towers over 100 meters high, and blades over 75 meters long, which require specialized labor to assemble due to work at great heights.

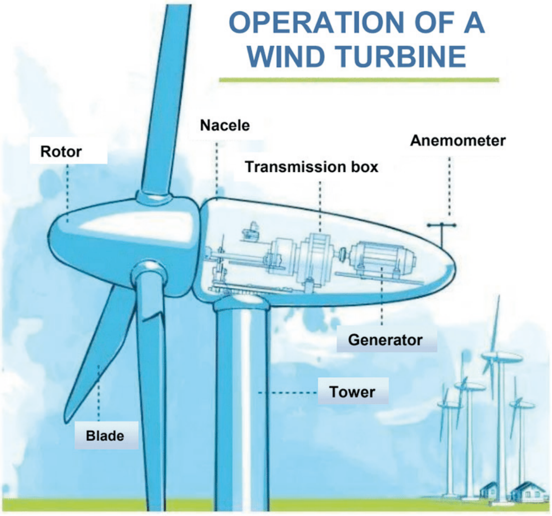

Figure 03: Wind Turbine Structure
Source: https://www.vivadecora.com.br/pro/energia-eolica/

As it is a relatively new energy matrix in the country, around 30 years after the installation of the first wind turbine in Fernando de Noronha in 1992, the risks of accidents to which workers are subject in this activity are still unknown to many. In Bahia, the first wind farm began operating in 2012 in the Municipality of Brotas de Macaúbas.

Risk analysis is a process in which the probability of certain negative events, unforeseen events and uncertainties arising or during a certain action is assessed. The objective of risk analysis is to verify what threats exist in a work environment, bringing safety to all workers involved in the activities carried out, thus reducing the occurrence of work accidents and occupational diseases.

This way, we can define risk analysis as a study that aims to identify the hazards present in a given location or activity, and determine ways to avoid, protect or minimize the hazards.

When risk analysis is correctly applied, it can improve safety and health in the workplace, as well as the company's performance in general.

RISK ANALYSIS

The purpose of this work is to analyze the risks of accidents associated with the assembly of wind turbines in wind farms, and based on this analysis, propose a Risk Analysis model for this activity as a tool to minimize the number of accidents.

The main steps associated with the Risk Analysis process are:

- Determine risk levels;
- Choose action priorities;
- Establish preventive and/or corrective measures;
- Check the functionality of existing measures;
- Detect workers' training needs;
- Allow worker participation

RISKS

This work will address the risks of accidents involved in the assembly of the tower sections on the previously concreted base, the coupling of the Nacelle to the tower, the assembly of the rotor in the nacelle and the connection of the blades to the rotor.

The main risks associated with the assembly of wind turbines are:

- Lifting loads;
- Risk of falling due to working at height;
- Extreme weather conditions, due to working at altitude, strong winds and lightning;
- Work in confined spaces;
- Working conditions that are often anti-ergonomic;
- Electrical risks;
- Risks of injuries due to the movement of loads of large parts, machines and equipment;
- Need for special attention to protecting rotating and moving parts of machines and equipment, which can cause lacerations, amputations or even lead to death of workers;

Figure 04: Assembly of the 1st Wind Farm in Bahia in Brotas de Macaúbas, March 31, 2011.

Source: Photo from the author's personal collection

PROBLEMATIC ISSUES

Due to the scarcity of information regarding work accidents arising from the construction stages of wind farms, it is difficult to carry out a quantitative analysis of the risks inherent to the process.

Today, social, environmental and health and safety aspects are taken into consideration in the process of purchasing these assets or in the energy commercialization process. Therefore, there is no interest from companies that manufacture wind turbines in providing information regarding accidents that have occurred.

Taking this scenario into account, we are left with carrying out a Prior Risk Analysis of the activity with the highest risk of accidents, which is the assembly of wind turbines.

REVIEW OF LITERATURE

The word risk is part of our daily lives and we use it in different ways and with different meanings. The risk of an accident, the risk of going wrong, the imminent risk, the high risk are some examples commonly found in our technical or lay literature, whose predominant meaning is to represent a certain chance of something happening.

It is a set of technical assessments that systematically seek to identify, qualify or quantify the potential risks associated with the activity.

The objective of applying risk analysis techniques is to determine the magnitude of potentially significant risks, evaluating the ability of chemical and physical processes, safety devices and procedures to prevent and control these risks, including proposing additional protective measures if necessary.

Risk analyzes form the main management element of the Risk Management Program, as they are what will indicate the risks that will actually be managed.

The purpose of risk analysis is to understand the nature of the risk and its characteristics, including the level of risk, where appropriate. Risk analysis involves detailed consideration of uncertainties, sources of risk, consequences, probability, events, scenarios, controls and their effectiveness. An event can have multiple causes and consequences and can affect multiple objectives. Risk analysis can be carried out with varying degrees of detail and complexity, depending on the purpose of the analysis, the availability and reliability of the information, and the available resources. Analysis techniques can be qualitative, quantitative or a combination of these, depending on the circumstances and intended use. The risk analysis must consider factors such as:

- Probability of events and consequences;
- Nature and magnitude of the consequences;
- Complexity and connectivity;
- Temporal factors and volatility;
- Effectiveness of existing controls;
- Sensitivity and confidence levels.

According to ABNT NBR ISO 31000:2018, risk analysis can be influenced by any divergence of opinions, biases, risk perceptions and judgments. Additional influences are the quality of the information used, the assumptions and exclusions made, any limitations of the techniques and how they are carried out. These influences must be considered, documented and communicated to decision makers. Highly uncertain events can be difficult to quantify. This can be a problem when analyzing events with severe consequences. In these cases, using a combination of techniques often provides greater insight. Risk analysis provides an input for risk assessment, for decisions about whether the risk needs to be addressed and how, and about the most appropriate strategy and methods for treating risks. The results provide insight into decisions, in which choices are being made and the options involve different types and levels of risk.

According to Marques (2020), there are some examples of Risk Analysis techniques, they are:

- Qualitative (Hazop, APP, Bow Tie);
- Semiquantitative (LOPA, SIL);
- Quantitative (AQR, Vulnerability Analysis).

According to Marcondes (2022), quantitative risk analysis is used to classify a risk using terms (words) that seek to measure the intensity of the consequences of a given risk with the probabilities of them occurring. Semi-qualitative analysis is one that seeks to assign numerical values to the terms selected in the qualitative analysis, without the need for the values to correspond exactly to the intensity of the consequences or their probabilities. The qualitative expression presupposes the idea of qualifying a risk in terms (words), while the quantitative expression seeks to qualify it in mathematical expression (numbers).

METHODOLOGY

PRELIMINARY HAZARD ANALYSIS; APP

This methodology can be used for systems at the beginning of development or in the

initial phase of the project, when only the basic system elements and materials are defined.

It can also be used as a general safety review of systems/installations already in operation.

Using the APP helps select areas of the facility where other, more detailed risk analysis or accounting techniques must be used later. The APP is a precursor to other analyses. (Aguiar, 2020)

The stages of the APP methodology are:

- Definition of analysis modules;
- Carrying out the APP itself (filling in the spreadsheet for each analysis module);
- Preparation of scenario statistics by frequency and severity categories,
- and the list of suggestions generated in the study;
- Analysis of results and preparation of the report.

The analysis itself takes place after completing the table below.

With the information collected it is possible to obtain a qualitative assessment of the process.

FREQUENCY

According to the APP methodology, accident scenarios must be classified into frequency categories, which provide a qualitative indication of the expected frequency of occurrence for each of the identified scenarios. Table 02 shows the frequency categories currently in use for carrying out APPs.

SEVERITY

Accident scenarios must also be classified into severity categories, which provide a qualitative indication of the expected severity of occurrence for each of the identified scenarios. Table 03 shows the severity categories currently in use for carrying out APP.

RISK

To establish the Risk level, a matrix is used, indicating the frequency and severity of undesirable events, as indicated in Figures 05 and 06, respectively.

Frequency

Severity	A	B	C	D	E
IV	2	3	4	5	5
III	1	2	3	4	5
II	1	1	2	3	4
I	1	1	1	2	3

Figure 05: Risk Classification Matrix - Frequency x Severity

Source: Marques, 2020.

Severity		Frequency		Risk	
I	Despicable	A	Extremely remote	1	Despicable
II	Marginal	B	Remote	2	Minor
III	Criticism	C	Improbable	3	Moderate
IV	Catastrophic	D	Probable	4	Serious
		E	Frequent	5	Critical

Figure 06: Legend of the Risk Classification Matrix - Frequency x Severity

Source: Marques, 2020.

DISCUSSION

Despite the complexity and the various steps in the wind turbine assembly process, it was found that the risk level was 3 (three), that is, moderate. This factor is mainly due to the type "C" frequency, that is, unlikely. However, this frequency determination was basically theoretical, since there is no database with information on work accidents in this segment.

Given the low dissemination of data regarding work accidents resulting from the assembly of wind turbines, the Preliminary Hazard Analysis ends up presenting superficial data based on the experience of the person responsible and bibliographical references.

<table>
<tr><td colspan="10">Preliminary Hazard Analysis</td></tr>
<tr><td colspan="4">Analyzed Area:</td><td>Activity:</td><td>APP number:</td><td colspan="2">Page:</td><td colspan="2" rowspan="3">Involved areas:</td></tr>
<tr><td colspan="4">Responsibility:</td><td>Date of elaboration:</td><td colspan="3">Reviewed in:</td></tr>
<tr><td colspan="8">Team:</td></tr>
<tr><td rowspan="2">Activity</td><td rowspan="2">Sub-activity</td><td rowspan="2">Danger</td><td rowspan="2">Risk</td><td rowspan="2">Causes</td><td colspan="3">Risk assessment</td><td rowspan="2">Recommen-dations</td><td rowspan="2">Person in charge</td></tr>
<tr><td>Frequency</td><td>Severity</td><td>Risk</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 01: APP Form

Category	Denominatio	Frequency Range (annual)	Description
A	Extremely remote	$f < 10^{-4}$	It is possible, but extremely improbable to occur during the life of the process/installation
B	Remote	$10^{-4} < f < 10^{-3}$	Not expected to occur during the life of the process/installation
C	Improbable	$10^{-3} < f < 10^{-2}$	A little probable to occur during the life of the process/installation
D	Probable	$10^{-2} < f < 10^{-1}$	Expected to occur 1 time during the life of the process/installation
E	Frequent	$f > 10^{-1}$	Expected to occur several times during the life of the process/installation

Table 02: Frequency Categories

Source: Marques, 2020.

Category	Denomination	Description/Characteristics
I	Despicable	➢ No damage or negligible damage to equipment, Property and/or the environment ➢ There are no injuries/deaths to employees, other people (non-employees) and/or people (industries or community); The most that can occur are cases of first aid or minor medical treatment.
II	Marginal	➢ Minor damage to equipment, property and/or the environment (material damage is controllable and/or has a low repair cost); ➢ Minor injuries to employees, service providers or community members.
III	Criticism	➢ Moderately serious injuries to employees, service providers or community members (remote probability of death) ➢ It requires immediate corrective actions to prevent it from developing into a catastrophe
IV	Catastrophic	➢ Irreparable damage to equipment, Property and/or the environment (slow or impossible repair) ➢ It causes death or serious injury to several people (employees, service providers or community members)

Table 03: Severity Categories

Source: Marques, 2020.

RESULTS

<table>
<tr><td colspan="10">Preliminary Hazard Analysis</td></tr>
<tr><td colspan="3">Area Analyzed: Construction</td><td></td><td>Activity: Wind turbine assembly</td><td>APP number: 01</td><td>Page: 01</td><td colspan="3" rowspan="3">Involved areas: Occupational Safety Engineering, Construction Engineering and Construction.</td></tr>
<tr><td colspan="3">Responsibility: Implementation/Work Safety</td><td></td><td>Date of Elaboration: May/2022</td><td colspan="2">Reviewed in:</td></tr>
<tr><td colspan="7">Team: Work Safety Coordinator and Engineer.</td></tr>
<tr><th rowspan="2">Activity</th><th rowspan="2">Sub-activity</th><th rowspan="2">Danger</th><th rowspan="2">Risk</th><th rowspan="2">Causes</th><th colspan="3">Risk assessment</th><th></th><th></th></tr>
<tr><th>Frequency</th><th>Severity</th><th>Risk</th><th>Recommendations</th><th>Person in charge</th></tr>
<tr><td>Tower Assembly</td><td>Crane positioning and steering</td><td>Hit people; Material damages</td><td>Tip over
Crushing/Press Equipment</td><td>Lack of operational discipline when assembling the crane; Equipment Failure;</td><td>C</td><td>III</td><td>3</td><td>Isolation and signage of the work area; Check soil compaction;
Do not place yourself in the path of the equipment;
Use of PPE;
Minister the daily security dialogue every day before starting activities; Implement the risk management program for the work;</td><td>Coordinator; Rigger; Assembly Supervisor; Mechanical Assembler; Engineer / Safety Technician;</td></tr>
<tr><td></td><td>Lifting the Sections and positioning them on the base and other Sections</td><td>Hit People; Material damage</td><td>Suspended load;
Falling Materials;
Crushing / Pressing;
Breakage of the load support;
Presence of wind.</td><td>Crane operation failure; Equipment Failure; Lack of cargo movement plan; Gusts of wind and lightning;</td><td>C</td><td>III</td><td>3</td><td>Do not walk under suspended loads; Stay out of the danger zone and machine accessories;
Isolation of the area;
Use of guide rope; Use of PPE;
Minister the daily security dialogue every day before starting activities;
Implement the risk management program for the project; Check weather data.</td><td>Coordinator; Rigger and Crane Operator; Assembly Supervisor; Occupational Safety Engineer/ Technician;</td></tr>
<tr><td></td><td>Fixing the Sections (screws, nuts and washers)</td><td>Hit people; Materials damage</td><td>Suspended load;
Fall of materials and equipment;
Crushing / Pressing;
Noise;
Electric shock;
Danger of falling from height;
Cut.</td><td>Failure in the operation of screw fixing equipment; Equipment Failure; Gusts of wind and lightning; Lack of training for assemblers;</td><td>D</td><td>II</td><td>3</td><td>Isolation and signage of the area;
Do not walk under suspended loads;
Do not place yourself in the path of the load;
Stay out of the danger zone and machine accessories; Inspect all electrical equipment;
Use of PPE;
Training in Working at Heights;
Minister daily security dialogue every day before starting activities; Implement the risk management program for the project; Check data meteorological.</td><td>Coordinator; Rigger and Crane Operator; Assembly Supervisor; Mechanical Assembler; Electrician; Occupational Safety Engineer/ Technician;</td></tr>
</table>

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Nacelle and Hub Assembly	Lifting the Nacelle to the upper flange of the last Section	Hit People; Materials damage	Suspended load; Falling Materials; Crushing / Pressing; Breakage of the load support; Presence of Wind.	Crane operation failure; Equipment Failure; Lack of cargo movement plan; Gusts of wind and lightning;	C	III	3	Do not walk under suspended loads; Stay out of the danger zone and machine accessories; Isolation of the area; Use of guide rope; Use of PPE; Minister the Daily Security Dialogue every day before starting activities; Implement the risk management program for the project; Check weather data.	Coordinator; Rigger and Crane Operator; Assembly Supervisor; Occupational Safety Engineer/ Technician;
	Fixing (screws, nuts and washers) of the Nacelle and Hub on the Section Flange	Hit People; Materials damage	Suspended load; Fall of materials and equipment; Crushing/ Pressing; Noise; Electric shock; Danger of falling from height; Cut.	Failure in the operation of screw fixing equipment; Equipment Failure; Gusts of wind and lightning; Lack of training for assemblers;	C	III	3	Isolation and signage of the area; Do not walk under suspended loads; Do not place yourself in the path of the load; Stay out of the danger zone and machine accessories; Inspect all electrical equipment; Use of PPE; Training in Working at Heights; Minister the daily security dialogue every day before starting activities; Implement the work's risk management program; Check weather data.	Coordinator; Rigger and Crane Operator; Assembly Supervisor; Mechanical Assembler; Electrician; Occupational Safety Engineer/ Technician;
Blade Assembly	Lifting the blades for fixing to the Hub	Hit People; Materials damage	Suspended load; Falling Materials; Crushing / Pressing; Breakage of the load support; Presence of Wind.	Crane operation failure; Equipment Failure; Lack of cargo movement plan; Gusts of wind and lightning;	C	III	3	Do not walk under suspended loads; Stay out of danger and machine accessories; Isolation of the area; Utilization of guide rope; Use of PPE; Minister the Daily Safety Dialogue, every day before starting activities; Implement the work's Risk Management program; Check weather data.	Coordinator; Rigger and Crane Operator; Assembly Supervisor; Occupational Safety Engineer/ Technician;
	Fastening (screws, nuts and washers) of the Blades to the Hub with a Hydraulic Torque Wrench	Hit People; Materials damage	Suspended load; Fall of materials and equipment; Crushing/ Pressing; Noise; Electric shock; Danger of falling from height; Cut.	Failure in the operation of screw fixing equipment; Equipment Failure; Gusts of wind and lightning; Lack of training for assemblers;	D	II	3	Isolation and signage of the area; Do not walk under suspended loads; Do not place yourself in the path of the load; Stay out of the danger zone and machine accessories; Inspect all equipment electrical; Use of personal protective equipment; Training in Working at Heights; Minister the Daily Security Dialogue, every day before starting activities; Implement the work's, risk management program; Check data meteorological.	Coordinator; Rigger and Crane Operator; Assembly Supervisor; Mechanical Assembler; Occupational Safety Engineer/ Technician;

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