Enhancing safety performance of Quay Crane Operators through predictive and visual analytics

WSH Symposium on Cranes 2021

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2020

PSA International

handled **86.6 million** TEU
(Twenty-foot Equivalent Units)
PSA Singapore: **36.6 million** TEUs

PSA Corporation
Corporatised
commercial entity

1997

PSA International
Global premier port
developer & operator

2003

World's largest automated container terminal

4 phases
from 2021 to 2040

1337
hectares of land

65 million
TEU capacity

~300
quay cranes

~800
automated yard cranes

~2000
automated guided vehicles

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QUAY CRANES

- Used for ***loading and discharging*** of containers from container ships.

- Quay Crane's booms has 70m outreach in length and has a lifting height of 52m which is equivalent to a 19-storey building!

- There are around ***200*** Quay cranes(QC) in ***PSA-Singapore***.

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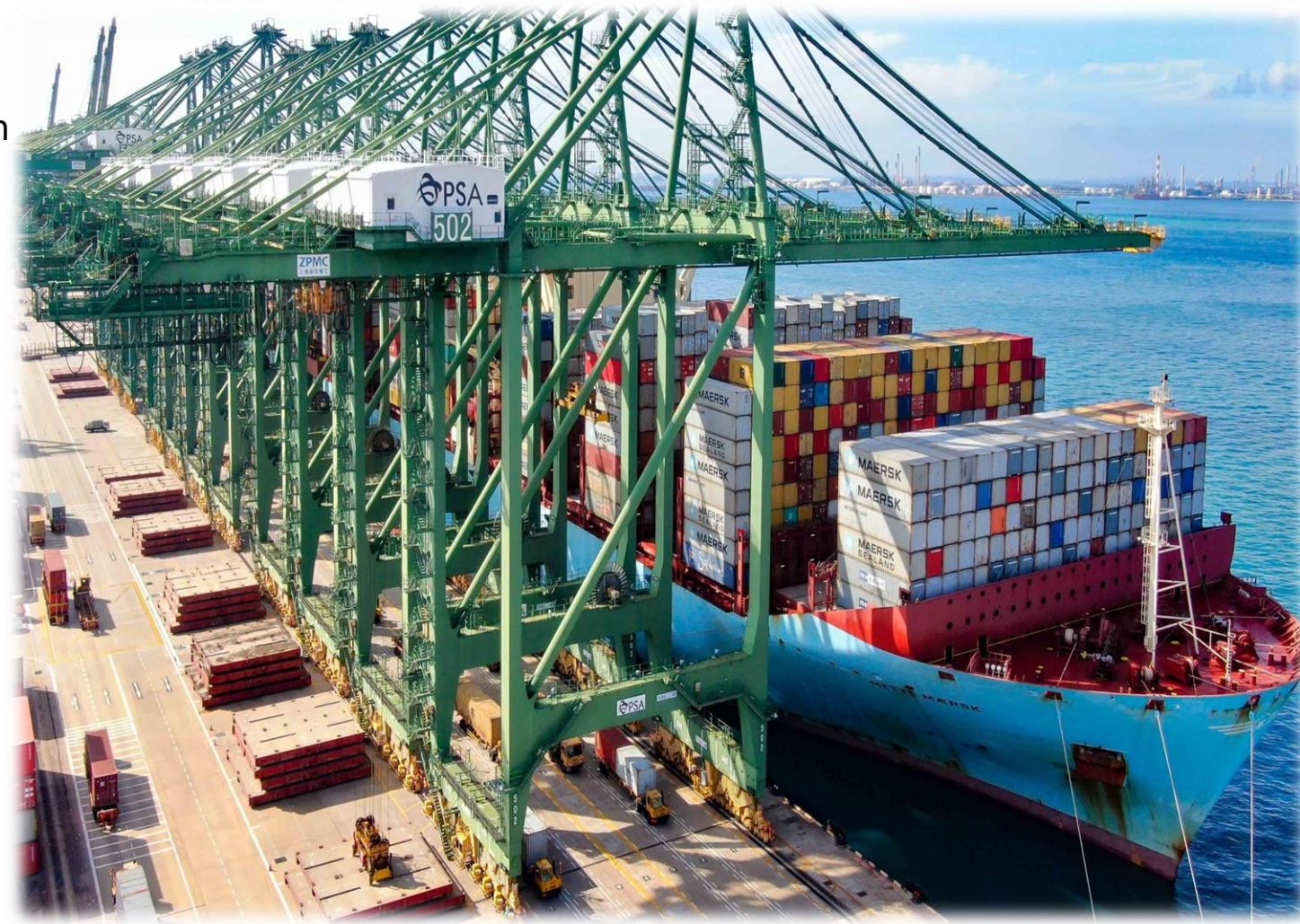
Consequences

❖ The consequences of QC incidents are severe in terms of **life, company's reputation** and **financial loss**.

Quay Cranes

❖ Huge amount of data is **collected** that tracks and capture the crane's "activities" which also depicts operating behaviour.

❖ However, these data were only used for **accident investigation** and for **maintenance** purpose.

Incidents

❖ Accidents from Quay Crane (QC) operations were mainly due to **human behaviour**.

❖ These accidents resulted in **damage** to vessels, containers and crane structure.

❖ Safety inspection, supervisions and trainings were **unable to totally prevent** these accident.

Behavior Analysis

❖ Manual assessment of operators is **time consuming** and **error prone**. Also, it is subjective and induces **bias** in decisions.

❖ Procedure to mitigating the **operating risk** exhibited by the operators.

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PROJECT TEAM

SAFETY & HEALTH DEPARTMENT

Envisages health and safety culture in PSA.
Investigates work place related incidents and conducts regular inspections.

ENGINEERING DEPARTMENT

Designed logic to capture data from Quay Crane sensors.

OPERATIONS

With Safety and Health Department conducts pre-emptive interventions for highlighted operators.

DATA SCIENCE & IT

Data science team implements techniques such as statistical modelling and machine learning.

IT Teams helps with data maintenance.

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OBJECTIVES

➢ This project aims to predict QC operator's risk scores based on historical data and analytics techniques such as ***statistical modelling*** and ***machine learning***.

➢ Provide a reliable tool for sending the ***high-risk operators*** to pre-emptive intervention to improve safe behaviour to ***prevent accidents*** and ***reduce costs, downtime*** and;

➢ The visual analytics portal will serve as a ***supporting tool*** during intervention sessions for the safety personnel to give a ***constructive feedback*** to the operators.

CRISP-DM FRAMEWORK*

6. Results are shared with the stakeholders; operators with high risk scores are recommended for intervention programs.

1. Understanding business objectives, requirements, stakeholders acceptance, and resources availability.

2. Data is gathered from different sources, validated and explored .

5. The models are evaluated to ensure learning is accurate.

3. Data Preparation involves combining different datasets, cleaning and re-arranging. It also involves steps like data aggregating, normalization, encoding and feature engineering.

4. Different predictive algorithms and machine learning techniques were explored.

1. Business Understanding

2. Data Understanding

3. Data Preparation

4. Modeling

5. Evaluation

6. Deployment

Data

Cross-Industry Standard Process for Data Mining

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DATA SOURCES

QC Edge Analytics data

Most of the QC in PSA Singapore are equipped with *sensors* that track and capture the crane's "activities". *Edge Analytics* was used to convert these activities into computer data and to identify *operating exceptions*. This was done by developing new logics inside Programmable logic controller (PLC).

Safety

Incident management system (IMS) and Safety enforcement system (SES)

Contains details of the *accident* that had occurred in PSA SG terminals. When the port users do not follow the safety rules and work procedures, they are given *demerit points* which are referred as Notice of Infringement of Safety Rules (NISR) points.

QC Operations data

Contains *operations* related data. Details like crane number, terminal, vessel operated on, boxes handled etc. are present.

HR Data

Contains details of *Demographics, Training, Job History, Competency* information of the operators.

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CHALLENGES & CONSIDERATION

Labelled data

- Unable to distinguish between the who are *"high-risk"* and *"low-risk"* operators.

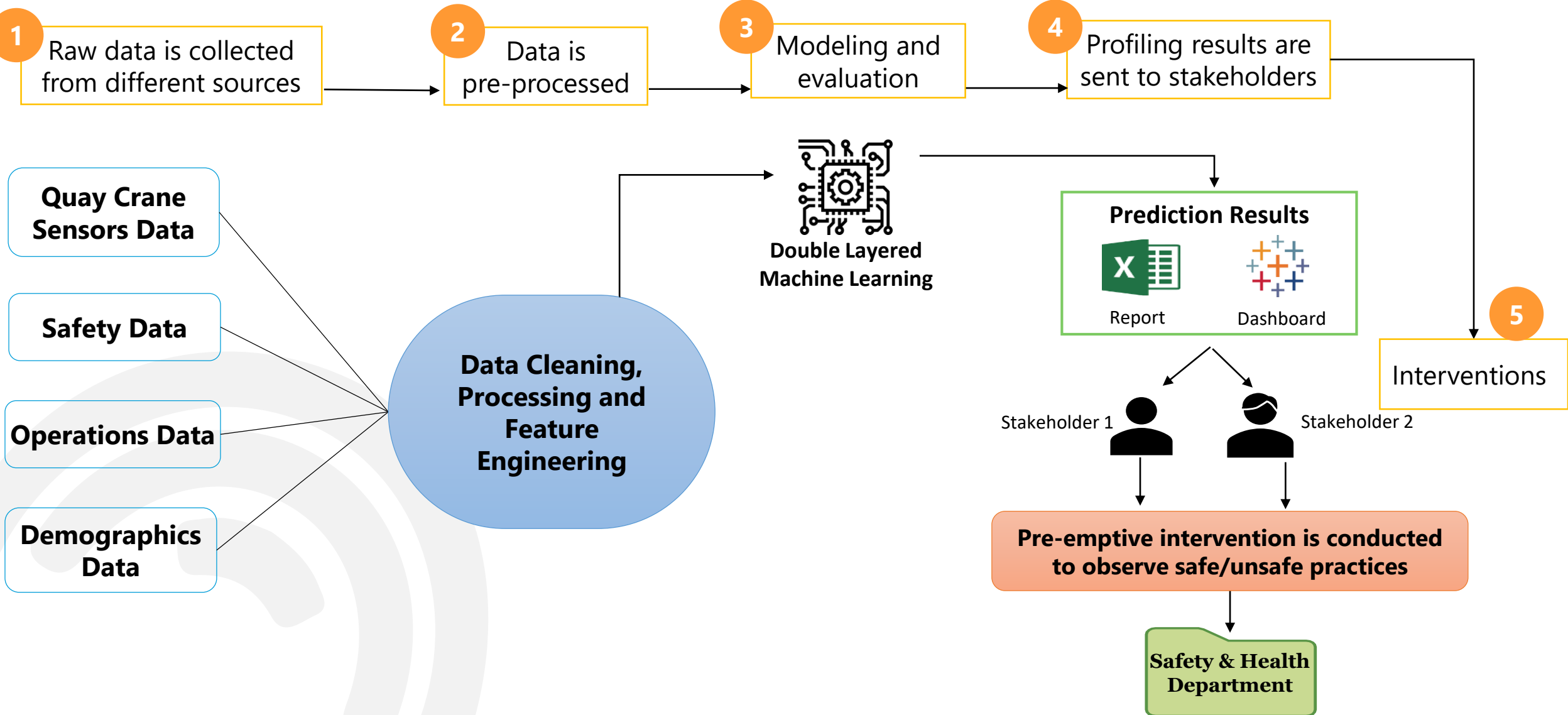**Machine learning performance**

- No gold standard/clear measurement to compare the *accuracy* of the models.

Identifying

- Factors/business knowledge to determine the *target variable*.

Algorithms/methods to use

- Determining the *machine learning methods* to implement.

Kneading

- *Connecting* the data from different sources to get a complete view.

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PROJECT ARCHITECTURE

1 Raw data is collected from different sources

2 Data is pre-processed

3 Modeling and evaluation

4 Profiling results are sent to stakeholders

5 Interventions

- Quay Crane Sensors Data
- Safety Data
- Operations Data
- Demographics Data

Data Cleaning, Processing and Feature Engineering

Double Layered Machine Learning

Prediction Results

Report   Dashboard

Stakeholder 1   Stakeholder 2

Pre-emptive intervention is conducted to observe safe/unsafe practices

Safety & Health Department

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MACHINE LEARNING TECHNIQUES

Layer-1

Unsupervised Learning methods

Purpose: Defining/creating labels.
Method: Learns from the existing historic data to create the labels for each operators.

Principal Component Analysis (PCA)

- Widely used statistical technique for dimension reduction.
- Emphasizes on variation and strong patterns in a dataset.
- Idea is to derive new variable from the original variables that preserve most of the information given by their variances.

K-Means Clustering analysis

- Partition data into groups/clusters based on similarities.
- Tries to make intra-cluster data points as similar as possible while also keeping the clusters as different (far) as possible.
- The less variation we have within clusters, the more homogeneous (similar) the data points are within the same cluster.

Output: Target variable - each operator is now labelled as either ***"high-risk"*** or ***"low-risk"***

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MACHINE LEARNING TECHNIQUES CONT.

Layer-2
Supervised Learning methods

Purpose: Dedicated predictive analytics layer; 8 Different machine learning models are implemented.
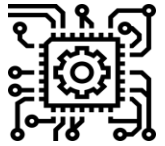
Ensemble method combines the decisions of all the methods, a operator is considered as a high risk if any two methods have identified him as a high risk.

Regressions
❖ Easy to interpret
- Logistic
- Lasso
- Ridge
- Elastic Net

Neural Network
❖ Inspired by the concept of human brain
❖ Scoring is quite accurate.
❖ Hard to interpret.

Support Vector Machine (SVM)
❖ Fits a hyperplane that best separates the data into different domains.
❖ Difficult to interpret.

Random Forest
❖ Powerful tree based algorithm.
❖ Increases accuracy.
❖ More Flexible than Regression techniques.

Gradient Boosting Machine (GBM)
❖ Tree based method
❖ Avoids overfitting.

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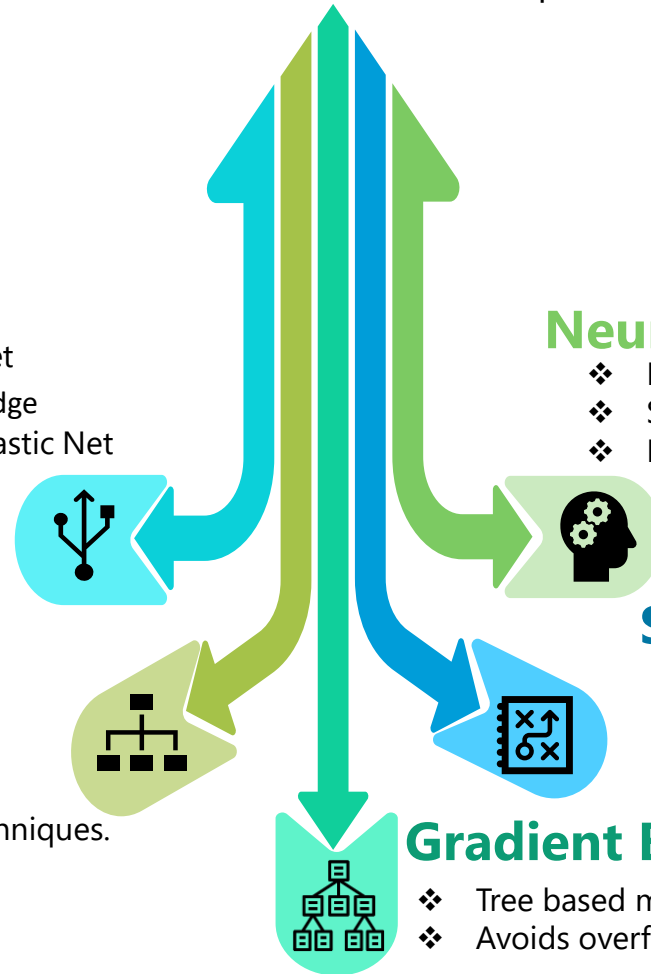
INTERVENTION PROGRAMS (IP)

- ➢ Prioritized high-risk operators **without incident in past 2 years**.

- ➢ **CCTV inspections** were conducted with objectives:
  - Identifying QCO unsafe behaviour/habits
  - Correct/guide QCO to adopt safe behaviour
  - Encourage safe behaviour/practices

- ➢ Operators were **coached** on their unsafe practices. The visual analytics portal will be used for constructive feedback.
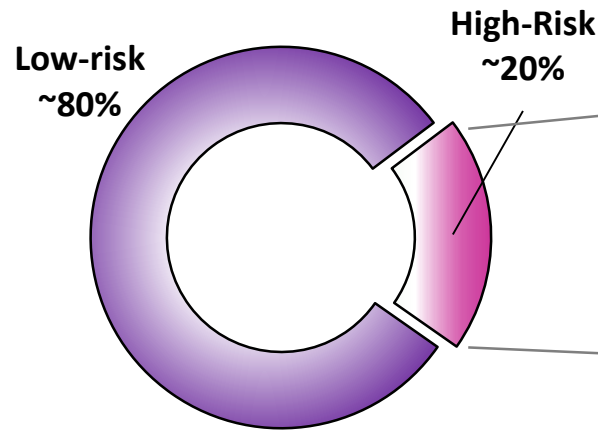
- ➢ Play back video reviewed showed that more than *60%* of high-risk operators did exhibit unsafe practices.
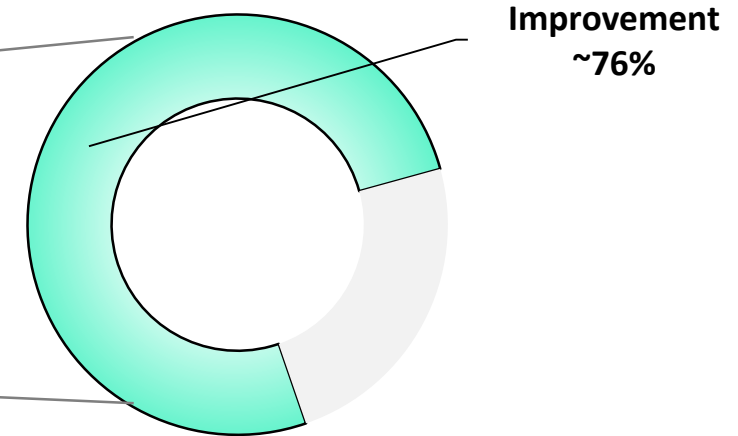
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RESULTS

Machine Learning

❖ On a monthly basis, approximately **20%** operators are classified as at a **high-risk**.

Low-risk ~80%

High-Risk ~20%

Accuracy of Ensemble methods was **~98%** .

Intervention programs

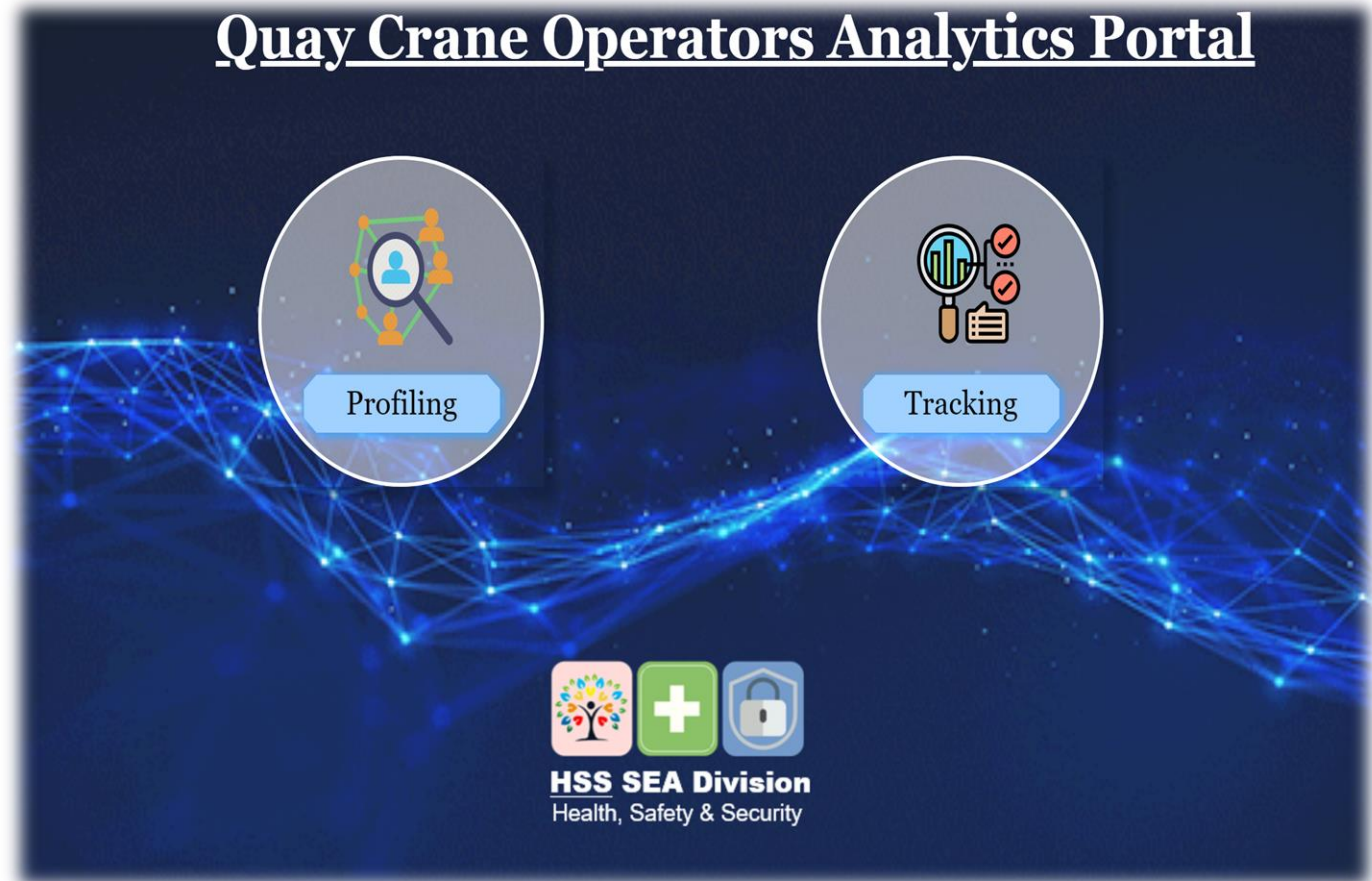❖ **76%** of operators who attended intervention programs showed improvement in the immediate month.

Improvement ~76%

It was also observed that, there was approximately **55%** reduction in observations/events.

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VISUAL ANALYTICS PORTAL

- ❖ Visual analytics portal for **Targeted interventions** and performance **tracking**.

- ❖ **Unified platform** containing operator's information, profiling results and operating behaviour.

- ❖ Portal serves as a supporting tool to the safety personnel to give a **constructive feedback** to the operators.

- ❖ Tracks the effectiveness of the programme and comparison of operator's performance before and after the interventions.

Quay Crane Operators Analytics Portal

Profiling

Tracking

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VISUAL ANALYTICS PORTAL

❖ Profiling results and operating behaviour.
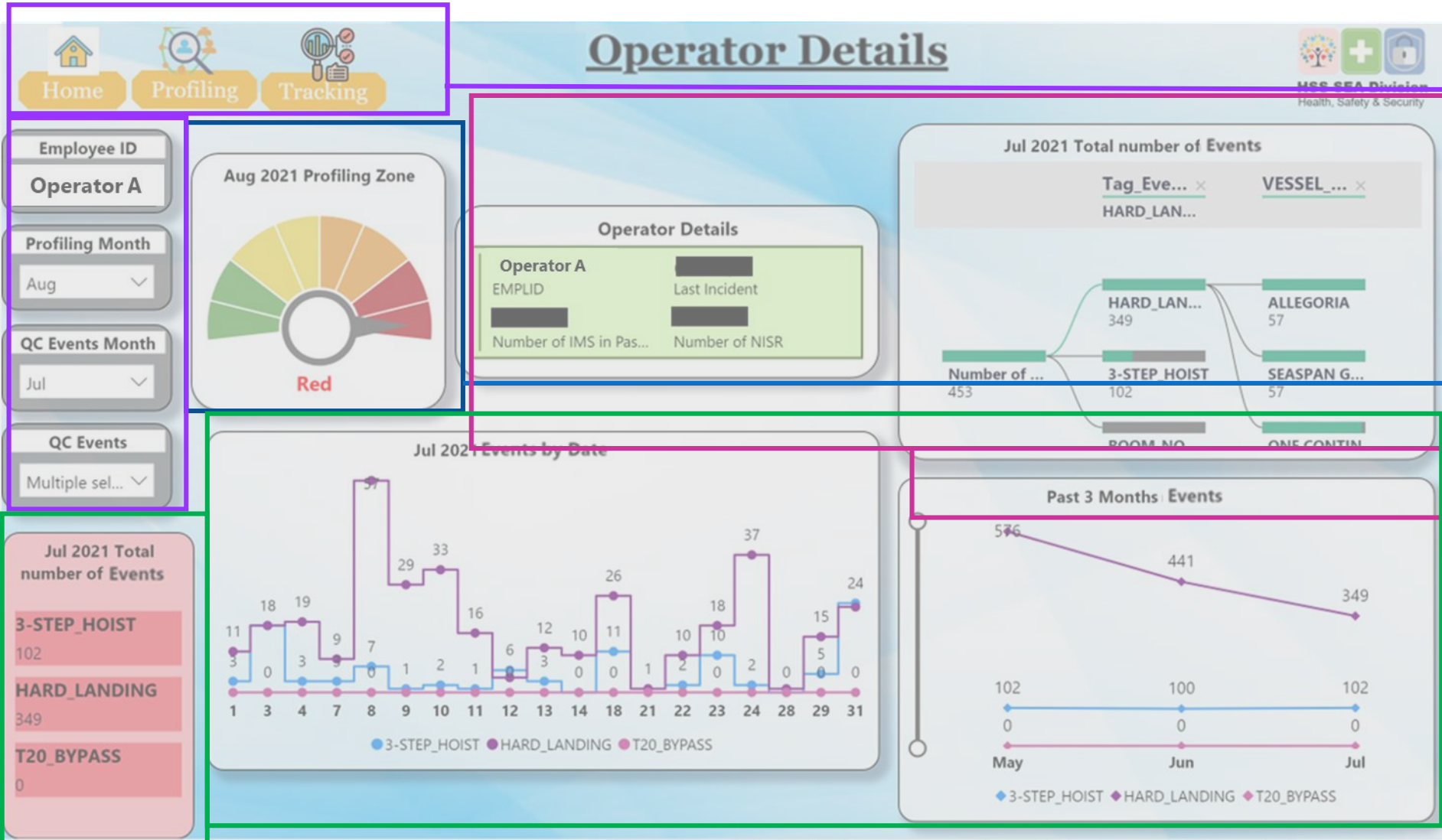
Navigation and Filters
Users can easily navigate to other pages.
Users can select and apply filters to refresh visualizations.
User can save as a ppt or pdf format.

Profiling Results
The results from machine learning based on historic data.

Operator Details
Operator's details like historic accidents, observations and vessel operation details.

Operating Exceptions
Operator's operating exceptions from QC sensors.
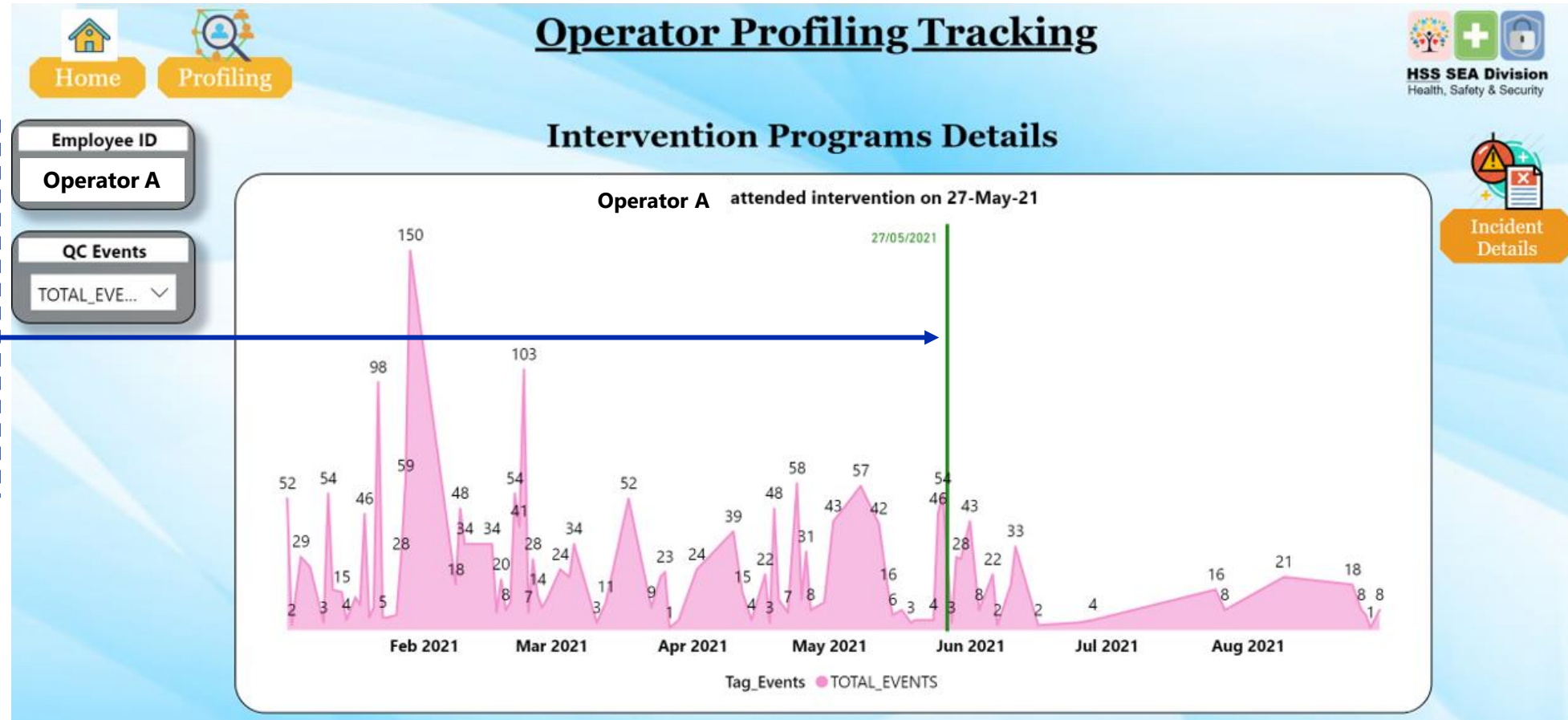
VISUAL ANALYTICS PORTAL

❖ Tracking the effectiveness of the programme and comparison of operator's performance before and after the interventions.

Example

Operator A attended the intervention program on 27-May.

His operating behaviour has improved consistently in the further months.

Overall reduction in the number of exceptions while operating.

CONCLUSION

Targeted interventions provides the operator to get a visual and better understanding of the **areas to focus** and improve on.

Data Analytics and Machine Learning enabled us to build an integrated platform for reliable **decision support** and **triage system**.

Project has benefited in enhancing operator's safety behaviour thus **preventing** work place accidents and injuries.

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