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INTEGRATED APPROACH FOR SAFE AND EFFICIENT PLANT LAYOUT DEVELOPMENT

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Abstract

Aluminium smelter layout development usually involves dealing with an integrated mix of operations and services (i.e. smelting, carbon anode formation, metal casting, material handling, etc.). The choice of a layout can significantly impact the success of the envisaged operation, in terms of safety, life-cycle cost and environmental impact.

This paper is a continuation of last year's publication, exploring the application of safety by design and lean manufacturing methods to the layout design of a fully integrated aluminium complex. An innovative approach, derived from lessons learnt assisting various plant layout development and resource analysis, is presented. This is an innovative approach for predicting traffic characteristics for an aluminium smelter configuration and measuring it in terms of safety, cost and environmental impact. This approach allows comparative analysis of competing layout designs and improvements to be implemented quickly to deliver a plant configuration that is Safe, Lean and Green.

Throughout this paper, the design of access roads, choice of transportation modes, and planning of resource are discussed.

Introduction

The Aluminium Center of Excellence (ACE) is the repository of Bechtel's institutional knowledge, technical capability, historical information and lessons learned on the design and construction of smelter projects. The mandate is to deliver value to projects by applying the above knowledge and skills focusing on sustainable design. The integrated approach presented below was developed by ACE and funded by a Bechtel internal technical research grant.

The choice of a layout can significantly impact an operation's long term success, both in terms of safety and its ability to compete successfully in the marketplace. In addition, investment costs associated with building a particular layout are substantial. Early development and finalization of the layout has a clear advantage from both a cost and schedule perspective to the project as compared to finalizing the layout later during project execution.

Layout development requires complete understanding of all operational aspects of a particular plant. The operation of an aluminium smelter relies on interactions between "customer" and "supplier" facilities to convey People, Products and Materials, with the road network having a direct impact on safety and efficiency of the operation. As a consequence, a quick and effective approach of assessing safety and efficiency of layouts early during the design phase is required.

Typically, layout development of "traffic intense" facilities such as aluminium smelters, involve a detailed understanding of traffic interactions and behavior. A known approach is to statically map the characteristics of the layout, identify roads, intersections and assign routes to traffic and calculate average inter-arrival times.

Further analysis using this evaluation method revealed that higher level safety and efficiency awareness was needed, and that it should be based on a better understanding of the dynamic characteristics of plant traffic flows. Discrete-event modeling (DEM) was chosen as a natural fit for the People-Product-Material (PPM) traffic flow problems. An example of DEM applied to traffic analysis is shown below in Figure 1 applied to a shuttle bus station during an envisaged shift change period.

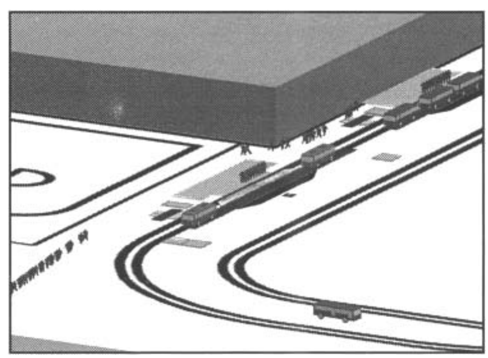


Figure 1 - Shuttle bus station at a Plant

Previous case studies demonstrated the complexity of different issues that arise through, layout development. Based on DEM, a systematic approach, here referred as the integrated approach, was created. The application of this approach automates data transfer and reduces cycle time for the assessment a layout safety, efficiency and CO_2 equivalent (CO_2e) emissions related to the traffic network.

The adoption of the integrated approach has proved to deliver value by quickly simulating and analyzing a particular plant layout and assessing the effectiveness of proposed improvements.

Layout Development

It is well-known that a "traffic intense" plant layout not only impacts the project capital cost but more importantly it impacts decades of plant operations. The development of a safe and efficient layout requires a collection of tools and expertise in order to design out the potential for accidents, waste and uncertainties related to conveyance between customers and suppliers.

Lean manufacturing and six sigma tools provide guidance to streamline layout development initiatives. Proper application of these tools during early project definition helps to "freeze" the layout early avoiding re-work, minimizing risk and providing certainty of outcome to the design team and future plant operators that their layouts are Safe, Lean and Green.

Safe - Safety by Design

Safety is an integral part of corporate social responsibility. There is a clear connection between operational safety and quality achieved (6). A safe plant configuration lays the early foundations for developing an organizational culture that values behavioral based safety.

Safety by Design applied to layout development has the objective of minimizing the potential for accidents. Safety-by-design reduces the likelihood of accidents over the life-cycle of a plant. As referenced above, Discrete Event Modeling (DEM) complements layout development and optimization studies. It provides a way of mimicking and monitoring the expected operation and collecting data for further analyses. A Failure Mode and Effect Analysis (FMEA) can then be applied to estimate the risk of accidents at any particular intersection in the road network.

Overall plant layout safety is directly influenced by a variety of operational factors, such as: intersection and vehicle type, schedule and transportation mode. Intersections are designed and scored using FMEA, by severity, occurrence and detection factors that are combined into a Risk Priority Number (RPN). RPN is the resulting safety measure for any particular point of a layout.

Lean – Lowest Life-Cycle Cost

Design of an efficient operation requires the application of lean principles and tools, in order to identify and eliminate waste and streamline the flow of people, product and materials. In theory, efficient operations have the capability of maximizing productivity with minimum waste, effort or expense. However variations generated by transient operational conditions directly impact and reduce efficiency.

DEM is used to predict the dynamic response of a particular operation including traffic and material conveyance and storage, to ensure that the proposed configuration can meet customer needs during normal, maximum and upset operating conditions. During overall layout development, DEM is used to mimic traffic flows and operations to validate the number of vehicles, load/unload stations, inspection lanes, parking lot requirements, inventory requirements, etcetera, to de-risk the overall plant layout design, offering a lower life-cycle cost.

Green - Environmental Impact

The environmental performance of a smelter layout is influenced by the movement of People, Products and Materials. The design of the road network, conveyance between customers and suppliers, and the segregation of traffic types impact the distance driven by vehicles. As a consequence, the emissions related to traffic are also impacted. During DEM simulation, confirmation of the number of vehicles required and the distance driven per vehicle is collected, not only to understand the operational cost related to traffic, but also to estimate CO2e emissions.

Integrated Approach

The quick and effective development of a Safe, Lean and Green layout required the integration of the various concepts, previously mentioned, into an automated platform.

The new platform automates data transfer and speeds the assessment of layouts. Figure 2 outlines the structure and the connections between the phases of layout analysis.

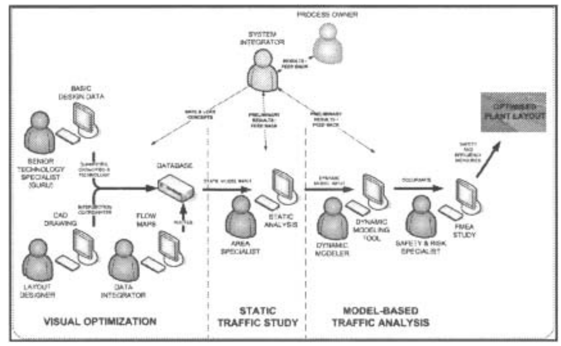


Figure 2 Integrated Approach

The integrated approach was assembled by coupling and partially integrating proven tools such as CAD drawings, Plant Basic Design Data (BDD) model, People, Product and Material (PPM) flow mapping, dynamic modeling (Flexsim® – Simulation Package), Failure Mode and Effect Analysis, and generalized Comparative Cost Function (CCF). The projected plant layout and plant operation parameters are automatically collected to and linked in a dedicated input Data Set. Then, this data set is used to specify, construct and run the plant dynamic model. The simulated plant operation is monitored, data from simulated scenarios collected and automatically exported to the same Data Set.

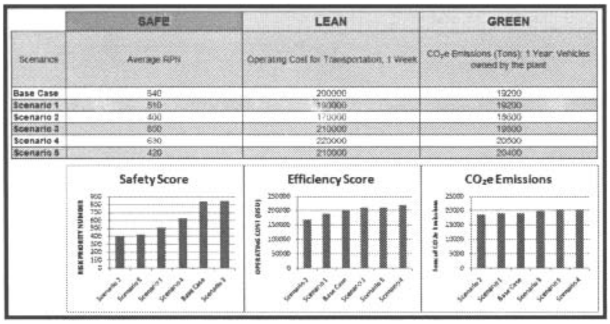
The platform provides quantitative analysis taking into account the dynamically changing conditions of the projected traffic (i.e. schedules, operational constraints, etc.). Emphasis is given to: movement of People, Products and Materials (i.e., distance traveled per vehicle/person, intersections crossings, unsafe conditions and possible bottlenecks on the road network).

FMEA & Comparative Cost Functions, linked to the Data Set, score the projected layout in terms of safety and efficiency. The main outputs of the platform are the factors representing risk of accidents in each specific intersection as well as an overall safety score for the layout, measures of efficiency (cost; utilization of vehicles & load / unload stations, etc.) and CO_2e emissions related to traffic.

Moreover, the Data Set provides complete post processing of the data simulated and collected. Some of the outputs include:

- Layout Safety Score: Average RPN from FMEA
- Layout Efficiency Score: Operating cost, related to traffic
- Layout Emissions Score: CO_2e Emissions related to traffic
- RPN of each intersection
- Number of vehicles required per flow type
- Distance driven per vehicle
- Number of trips executed per flow type
- Utilization of facilities (i.e. load / unload stations)
- Utilization of vehicles

Optimum benefit would result from implementation of this approach early during project development.



Scenarios	SAFE Average RPN	LEAN Operating Cost for Transportation, 1 Week	GREEN CO_2e Emissions (Tons): 1 Year: Vehicles owned by the plant
Base Case	540	200000	19200
Scenario 1	510	190000	19200
Scenario 2	400	170000	19500
Scenario 3	850	210000	19800
Scenario 4	630	220000	20500
Scenario 5	420	210000	20400

Figure 3 - Overall Scoring (Sample)

Figure 3 shows a sample of the overall score that is generated by the platform once a few layouts are tested. A scenario could represent any modification impacting the road network such as: plant arrangement, number of vehicles, schedule, route, number of stations, etc.

Case Study

The approach has been applied to an aluminium complex consisting of an alumina refinery, an aluminium smelter and an integrated rolling mill. The application focused on smelter traffic interacting with traffic from all facilities sharing the same external road network to cities and ports. The understanding of traffic patterns was crucial to validate the aluminium complex operation.

Due to the sensitivity of the information from the above referenced project, the results presented are based on hypothetical data and plant configuration for demonstration purposes. The hypothetical results presented below focus on the approach used and the results of the analyses.

The integrated approach was used to analyze the proposed layout. A summary of the key questions that the model was tasked to answers were:

- Identify potential for accidents related to traffic;
- Identify any bottlenecks impacting operational efficiency;
- Validate the number of load / unload stations, lanes at the security gate and weigh stations;
- Validate the number of vehicles required.

A one week simulated operation was initially targeted to cover the mandate. The study started by composing a list of flows expected during a typical week of operation. Then particular routes were defined and assigned to flows. The trajectories of people, products and materials (PPM) were automatically plotted, by the platform, on the CAD drawing,

The flow of PPM helps to align the project team (designers and future operators combined) on the expected vehicle movement. It raises attention to the mix of flows in any particular layout and eventually becomes the severity factor for the FMEA analysis. The flow of PPM identified potential areas of concern that would eventually be analyzed through the simulation. See Figure 4 on specifying routes (multy-colored lines) on the original CAD drawing.

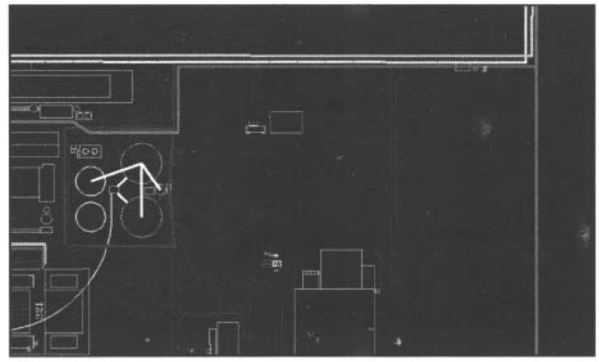


Figure 4 – Mapping of flow of PPM

Once the team agreed on the list of flows and routes, the delivery schedule on each flow was defined. As part of the scheduling activity, operations such as metal tapping and anode change were executed in accordance with the expected potroom operational schedule. Annual requirements for each material were taken directly from the linked Basic Design Data model. The communication between the platform and the DEM shell is automatically executed. The discrete event model is created on the input data with no interaction required from the user. Then, the simulation was performed and predicted output data recorded.

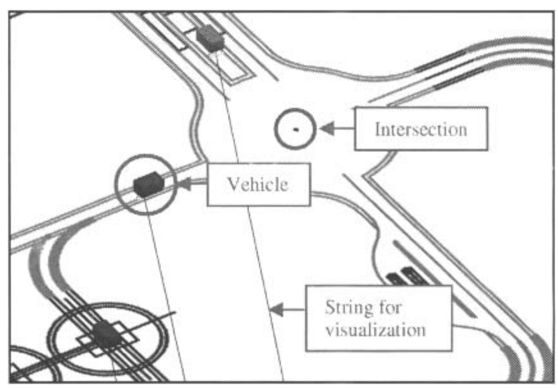


Figure 5 Example: DEM Model

A typical vehicle intersection is shown in Figure 5; visualization was kept to a minimum (e.g. colored boxes, are shown instead of nice 3D objects) to keep the focus on operational problems.

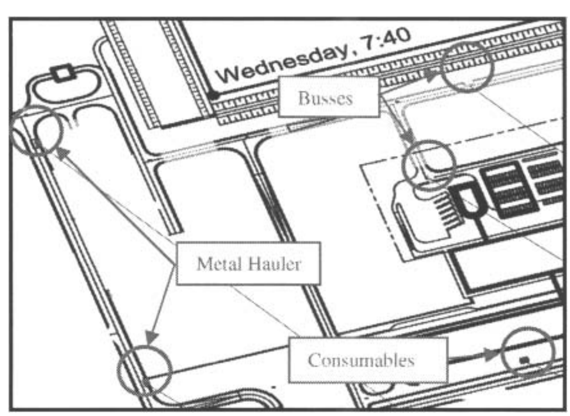


Figure 6 – Example: Smelter Model

Figure 6 shows a snapshot of the smelter where various flows are active. To bridge the gap in size-differences of vehicles and the whole complex, marker strings were used to visually locate the tiny cars when the view was zoomed out.

Once the results are generated and post-processing is executed, an analysis follows to answer the key questions and to identify safety and efficiency issues.

Safety Results

Once the FMEA analysis was performed, a Risk Priority Number was generated for each intersection; the highest score on each is presented in a Pareto-style chart. See Figure 7 for the RPN values and Figure 8 for the location of the corresponding intersections.

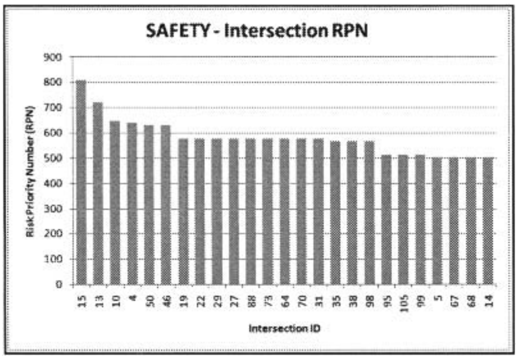


Figure 7 – RPN Score

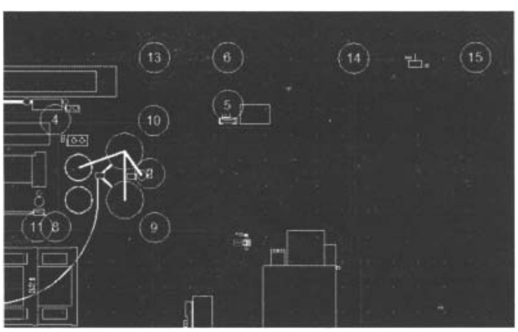


Figure 8 - Intersection IDs

The safety result is comparative and allows the team to focus on intersections with the highest risk for accidents. Considering the case study, intersections #15, #13 and #10 scored the highest RPN's. The following solutions were recommended:

- Intersections #15 and #13 required redesign and truck deliveries were not allowed during shift change.
- Deliveries to the carbon plant were re-routed to avoid interferences with alumina deliveries at intersection #10.

Efficiency Results

The analyses on utilization focused on the following aspects:

- Number of lanes at the gates;
- Number of lanes on major roads;
- Utilization of load / unload stations;
- Utilization of trucks weigh stations;
- Utilization of TAC / Skim stations at the casthouse;
- Operating cost related to traffic.

The model validated the design of all load/unload stations, weigh stations and security gates. Figures 9 & 10 provide a sample of the results generated by the model.

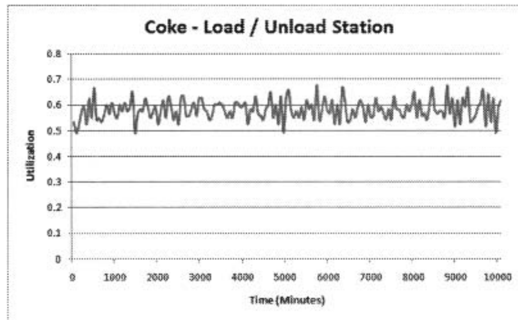


Figure 9 – Utilization Load / Unload Station

Figure 9 presents the utilization of the coke load/unload station during one (1) week simulation; predicted levels, including transient events, are within acceptable norms.

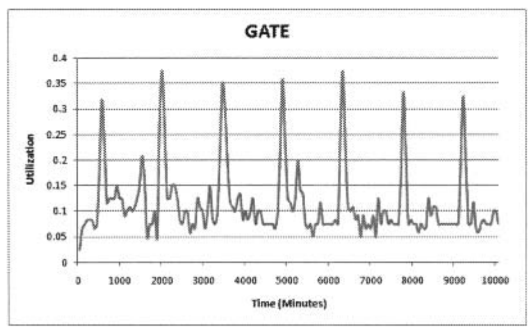


Figure 10 – Utilization Security Gate

Figure 10 presents the utilization of the security gate used by various delivery trucks during a one week simulation. The peaks represent the deliveries highly concentrated on day shift; the model validated the number of lanes used to inspect trucks.

As part of the validation process, a variety of scenarios were also run to understand the impact of an accident in the road from the port to the complex or the effect of a late ship arrival followed by a very early ship arrival.

Conclusions

The integrated approach has been conceptualized, developed, tested and then applied to a particular project, validating the proposed layout in terms of safety and efficiency. This innovative platform delivered value through the application of safety-by-design and waste elimination.

Early findings indicate that the integrated approach reduces the cycle time of aluminium smelter layout analyses by up to 50% compared to a sequential, non-integrated, approach.

Trademarks

AutoCAD is registered trademark of Autodesk group.

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