Simulation Improves Material Handling in General Assembly

Improvement of Material Flow, Work Apportionment, and Equipment Usage

Julio Pérez, Gabriel Carreño, Ozge Çivit
Simulation Analysis
PMC
Dearborn, Michigan, USA
{e-mail: jperez, gcarreno, ocivit}@pmcorp.com

Edward J. Williams
Business Analytics, College of Business
University of Michigan - Dearborn
Dearborn, Michigan, USA
e-mail: williame@umich.edu

***Abstract*—Discrete-event process simulation has long since achieved distinction as a powerful tool for the improvement of all aspects of manufacturing operations, including but not limited to equipment selection, maintenance policies, inventory management, buffer sizing and location, production scheduling, and work flow. The study documented here used simulation to analyze and improve the material handling operations responsible for delivering raw material to the line and taking finished product away for subsequent shipment. The improvements addressed important metrics such as reliability of supply, timeliness of supply, equipment utilization, worker utilization, and cost.**

Keywords- Material Handling; Material Flow; Assembly; Manufacturing; Discrete-Event Process Simulation.

I. INTRODUCTION

Historically, the first highly important commercial application of discrete-event simulation modelling was manufacturing operations [1]. Along with more recent and current simulation applications such as call centers [2], health care delivery [3], supply chains [4], retail stores [5], urban transport [6], and others, manufacturing remains a highly important application area.

In this paper, we document the successful use of simulation to analyze and improve material handling operations in the context of a large and complex manufacturing operation. This manufacturing operation undertakes the assembly of motor vehicles. The scope of the study included the assembly lines themselves, docks, material handling equipment (e.g., fork trucks and tuggers), the employees responsible for material-handling work, and the design of workflow. The client managers and engineers sought improvement of vital performance metrics such as timeliness and reliability of deliveries, worker and equipment utilization, inventory levels, and aggregate costs (labor, equipment, and operations). Simulation studies such as this one are often very useful for researchers and practicing industrial engineers seeking productivity improvements not only in manufacturing operations, but also in warehouses [7] and in shipping terminals such as those in railroad freight yards [8] and oceangoing ports.

The organization of this paper is as follows: Section II provides an overview of the manufacturing and material-handling operations. Next, in Section III, we provide a summary of operational data required to build, verify, and validate the model, with commentary on methods of collecting those data. The following Section IV describes the building, verification, and validation of the simulation model. Next, in Section V, we describe the execution of the model and summarize the conclusions drawn from that experimentation. We conclude, in Section VI, by describing our recommendations to the client company, along with indications for likely future work.

II. OVERVIEW OF OPERATIONS

The manufacturing plant in question fabricates automotive vehicle bodies; indeed, it is referred to colloquially as a "body shop." As such, it has many subassembly lines and therefore extensive material-handling requirements. This body shop has supply docks on both its east side (having four bay doors) and its west side (having two bay doors). These docks collectively contain three production hours' worth of inventory, comprising many (hundreds) of small lot parts, bulk parts, and unique part types. As the study began, the east side was served by six tuggers and four fork lift trucks; the west side, by five tuggers and three fork lift trucks. Dolly preparation occurs in front of the dock receiving doors, and empty dollies are subsequently returned to these dolly preparation areas.

At this plant, manufacturing operations were chronically plagued by tardy deliveries (idling expensive machines and highly paid production workers), frequent congestion of the material-handling equipment (the tuggers and fork lift trucks) in various aisles (leading to increased fuel costs and downtimes for battery recharging), and, derivatively, increased inventory levels and hence costs (consisting of both excessive accumulation of raw materials at the receiving docks and tardy delivery of finished goods to outgoing shipping docks, each of which worsened the client company's cash flow position). Motivated by these difficulties, the client company's engineers and managers requested an extensive consultation using the methods of industrial engineering. As is typically the case, the analytical methods of industrial engineering (e.g., process simulation, work flow analysis, ergonomics, value stream mapping, etc.) collaborated synergistically to provide suggestions for process and operational improvements.

Specifically, the objectives of this simulation project, defined collaboratively by plant managers, plant engineers, and the consultant's analysts, were to:

- Verify and update the existing material data for the current status of operations
- Update the "Plan for Every Part" (PFEP), the in-plant logistics database); this proprietary database comprises information about part storage locations, containers and racks used in storage, and in-plant replenishment systems
- Perform a material flow study to analyze the receiving of parts, staging of parts, delivery of parts (or containers there) to the assembly lines, and shipment of finished product
- Determine current-state material handling requirements
- Undertake a material flow analysis.

Having defined these objectives, the client company and the consultants then agreed on a division of responsibilities, most particularly including: providing complete documentation of plant operations; collection of data; analysis of data; model construction, verification, and validation; analysis of results, and presentation and documentation of results.

III. DATA COLLECTION AND ANALYSIS

Data collection began with confirmation of these basic assumptions, as provided by client engineers and managers:

- 1290 available minutes of work per calendar day
- Workers' walking speed 4.8 feet/second (English units used throughout study)
- 8.8 feet/second maximum fork truck speed and maximum tugger speed
- 2.28 feet/second/second fork truck and tugger acceleration (and matching deceleration)
- 626 unique part types in the PFEP
- 133 distinct delivery locations alongside the assembly lines
- 423 distinct locations for containers to be stored immediately after unloading from a truck

A PFEP, as mentioned in the previous section, was provided by the client company; each of these comprised a part description (sufficient to uniquely identify each part), storage location, location(s) of usage, daily volume required at these locations, container type, density, and physical dimensions. Using the numerous and powerful library of Microsoft Excel® functions – particularly those operating on text strings -- the consultant team sorted and filtered these data in various ways in search of errors in the client's originally supplied PFEP. Several such errors – primarily due to volatile data, which routinely become out-of-date – were called to the attention of client engineers. Therefore, the simulation project could and did begin with currently correct and audited data comprising details pertinent to all parts used in the manufacturing operations. An example subset of these data appears in the Appendix as Table 1.

Likewise, these initial observations of current plant operations determined the precise apportionment of material-handling tasks between tuggers and fork trucks, confirmed the carrying capacities of both, and mapped their routes through all parts of the operation. For the purpose of model run initialization, the assumption of three hours' initial inventory at the docks was made. For the tuggers, loading time of dollies was 29 seconds and unloading time was 47 seconds. For the fork trucks, both load and unload times were calculated based on the location and dimensions of the containers being loaded or unloaded. Consultant engineers travelled to the plant site for direct observation; their observation and data collection confirmed, with minor amendments agreed to by the client, for these and other detailed data items. In view of extensive worker involvement in the material-handling operations (as contrasted with extensively automated work tasks), great care was taken, largely by unobtrusive observation methods, to guard against the Hawthorne effect [9]. Given this detailed overview of operational procedures, it will be readily appreciated that (a) guarding against the Hawthorne effect was vitally important and (b) data collection (as opposed to model construction) was on the project critical path [10]. For the purposes of this study, no stochastic variation was incorporated in the values quoted above, in view of the "capacity planning" objective of the study.

IV. MODEL CONSTRUCTION, VERIFICATION, AND VALIDATION

After considerable discussion, the client managers and engineers, jointly with the consultants, decided on the use of Flow Planner®, which works within and compatibly with the well-known AutoCAD® tools, as an analytical software tool highly appropriate for this project. This software, like many of its worthy competitors [11], provides ease of use, high analytical power, the ability to analyse multiple alternatives, and extensive graphics and animation. The tool provides all of these capabilities in the context of manufacturing simulation. As such, it represents an advance over similar software tools often used for projects, such as this one, which aim to improve efficiency via manufacturing plant design [12]. A relatively recent application of Flow Planner® is documented in [13].

After visually analysing the material flow throughout the facility, the consultants worked with client engineers and plant operations supervisors to create flow diagrams. Material-handling methods (fork truck, tugger, or manual transport by an operator) varied with the part types, and each part flow was identified and checked based on both client-supplied data and the consultants' observations. Next, using information from the PFEP and the newly constructed flow diagrams, the consultants created a large Microsoft Excel® comma-separated-variable (".csv") file, as required by Flow Planner®. Much of the actual construction of this file involved repetitive and tedious tasks. Therefore, the consultants decided to, in large measure, automate it by investment of time in the creation of and debugging of a macro written in Visual Basic for Applications (VBA) [14]. Versus completely manual operations, the consultant team estimated that development of the macro returned a 5:1 benefit ratio of time required, and also greatly reduced the risk of "clerical" errors in organization of the data. A separate Microsoft

Excel® workbook, incorporating multiple worksheets, contained additional information of products, their method of transport, and their locations of storage and use.

Explicit verification and validation steps undertaken by the modeling engineers included the following [15]:

- Inserting one entity into the model and following it step-by-step (a "trace").
- Provisionally removing all randomness from the model and checking results against hand computations.
- Performing directional analysis – e.g., when the rate at which entities enter the model is increased, the lengths of queues must either remain the same or increase.
- Ensuring the client engineers and managers watched the animation and concurred in its representation of current operations.
- Building the model incrementally with the precautions above successfully performed upon the completion of each increment, before proceeding to model the next segment of the system.

After running Flow Planner®, the consultants collected the calculated parts-movement distances. Using these distances, loading and unloading times, and speed of transport method used, the consultants built a Microsoft Excel® file calculating expected time for all parts transport for all point pairs (A,B), considering "A" as the point of storage and "B" as a point of use. Similar calculations were performed for transport return trips "running empty." Then, with available work time per day being readily available, the utilizations of each class of transport equipment were calculated. Furthermore, these utilizations were readily subdivided into "definitely value-added" (transporting parts to where they were needed) and "inevitably necessary" (returning empty for another load). All these results were verified and validated against client data and experience.

V. RESULTS AND CONCLUSIONS

Many of the results of this study were most usefully visualized in the output graphics routinely provided by the Flow Planner® software. For example, Figure 1 in the Appendix depicts "straight-flow" aggregate data. In this figure, a particular line color represents an assignment of the vehicle to a plant zone (west, east, or LRS [a nickname for the stamping area, the origin of this nickname would reveal confidential information]). Straight flow paths are typically the best for viewing, understanding, and verifying where flows originate from and travel to, as they (mythically) go straight from the origin to the destination regardless of obstacles. By contrast, Figure 2 (Appendix), derived from the same input data as Figure 1, represents the part transport flows grouped by aisle. These flows are geometrically realistic, inasmuch as the vehicles do not "magically" penetrate physical obstacles. Different colors continue to represent vehicles assigned to different zones. This representation is superior for evaluating actual travel distances, travel paths, and aisle congestion, since they consider actual routes from the origin to the destination using user-defined aisles. Additional graphs (e.g., Figure 3, Appendix) and numerical output reports captured key performance metrics. For example, Figure 3 summarized tugger utilization by plant zone (west, east, or LRS). At this stage of the project, vehicle travel time performance metrics are not yet subdivided into travel time carrying parts versus "returning empty."

From the client's viewpoint, the three major revelations of this simulation study were:

- Due to the large numbers of parts (and their high variety) stored in the dock and the central market area (CMA), actually a centralized storage area, congestion in both areas is severe and obtrusively significant.
- The workload is well balanced on the dock areas (80-85%). However, the stamping fork trucks' traveling time was unduly high compared with the time that they spend loading and unloading, due to the distances between the stamping presses, CMA and the secondary storage areas (95%).
- With respect to the tuggers from both dock areas that served the lines, analysis (using the straight flow study) of the material flows from the respective dock area to the consumption point (Using LOCation, abbreviated "ULOC") identified the parts "guilty of" requiring the tuggers to travel long distances; these parts were stored in a conspicuously inappropriate area.

Accordingly, two recommendations were made to the client:

After identifying some of the parts that were making the tuggers travel long distances from the origin to the using locations (#1 above), the consultants recommended that the client transfer storage of eight specific parts from the west dock location to the east dock location, and one specific part from the east dock location to the west dock location. The client implemented this change, causing utilization of the vehicles assigned to the west zone to fall from 73.1% utilization to 66.4% utilization.

As a follow-up to the success of recommendation #1, the client was advised to reduce the total number of vehicles assigned to the east area from nine to seven, and in the west area from five to four. After this removal of three vehicles at first seemed excessive (reducing the total number of vehicles from fourteen to eleven), the vehicles were not over-utilized. After the client made this second change (hence saving significant labor and operations costs) vehicles assigned to the east area were utilized 87.5% and in the west area 83.1%, while still meeting delivery demands. Furthermore, for small lots, three vehicles were originally assigned to three continuous routes. After analysis of consumption patterns for these small lots within the ULOC, which was their typical destination for consumption, the consultant engineers created various scenarios involving only two routes, not three. Experimentation with the model, again using FlowPlanner®, revealed that the three routes could be profitably coalesced into two routes, using only two vehicles. The software readily recalculated the utilization of the two tuggers using these two new routes, based on the volume of parts being delivered to their respective ULOCs from their respective Dock

LOCations, (DLOC) and the pickup of empty containers then being returned to their Empty container LOCation (ELOC). Figure 4 in the Appendix shows this spatial analysis from the vantage point of the client. In this figure, the yellow circle delimits the workspace of the first tugger handling small lots. The two green circles delimit the delivery operations of the second tugger handling small lots; this tugger typically serves each of the two delimited areas alternately. The client also made this recommended change, and – as the model predicted – delivery demand for these small parts was still met, with new tugger utilizations as shown in Figure 5 (Appendix). As is to be expected, the first of these tuggers (serving the two areas delimited in green) has a higher percentage of load-&-unload time, a higher percentage of travel time, and hence a lower percentage of idle time, all relative to the second tugger serving only one area (delimited in yellow). This recommendation, the culmination of studying several proposed scenarios for using two instead of three tuggers, came gratifyingly close to equalizing the utilizations of the two remaining tuggers.

VI. PLANNED AND ANTICIPATED FUTURE ANALYSES

Aside from the quantitative financial benefits of this study, a significant qualitative benefit is the new understanding and appreciation, among the client engineers and managers, of the power of simulation. Since the enterprise is highly volatile, ongoing studies are very likely, and will be further refined. For example performance metrics on vehicles will be expanded to obtain travel distances and times "traveling empty" versus "traveling loaded," plus statistics on average, maximum, and minimum loads carried, both in aggregate and subdivided by part type. The model as currently implemented contains no provision for downtime of the material-handling equipment. Future work will include adding plausible downtimes to assist in the development of various contingency plans. Further, the graphical aids to client understanding (as exemplified by Figures 1, 2, and 4 in this paper) can be upgraded to two- or three-dimensional real-time animations.

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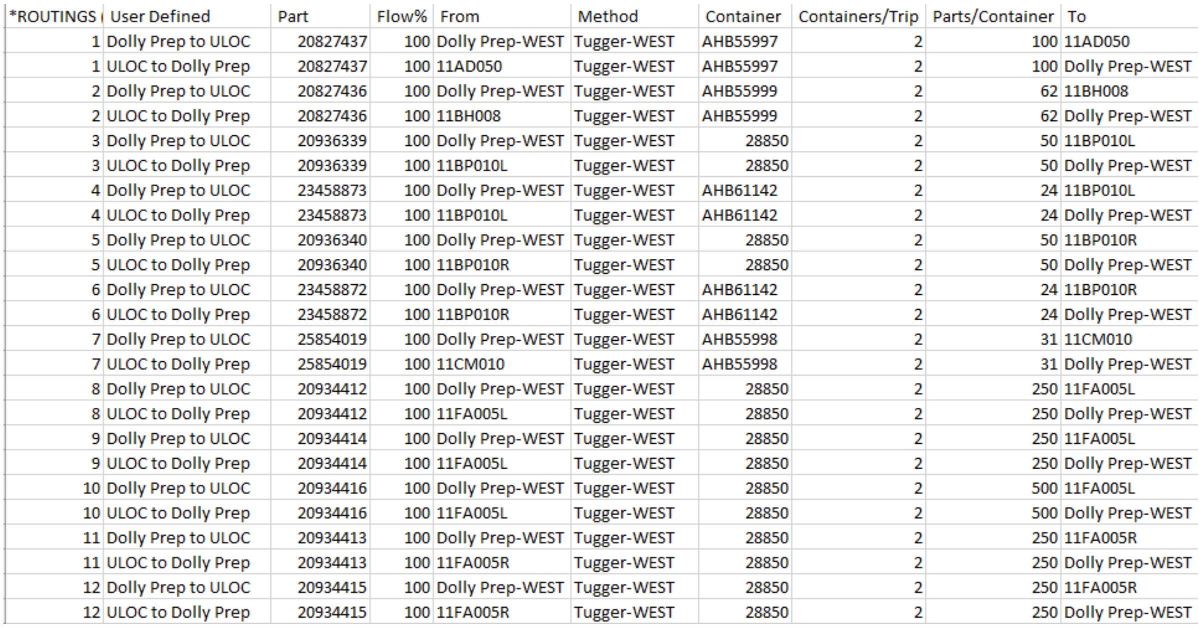
APPENDIX

TABLE I: SUBSET OF PARTS-ROUTING DATA AS INPUT INTO MODEL FROM MICROSOFT EXCEL®.



*ROUTINGS (	User Defined	Part	Flow%	From	Method	Container	Containers/Trip	Parts/Container	To
1	Dolly Prep to ULOC	20827437	100	Dolly Prep-WEST	Tugger-WEST	AHB55997	2	100	11AD050
1	ULOC to Dolly Prep	20827437	100	11AD050	Tugger-WEST	AHB55997	2	100	Dolly Prep-WEST
2	Dolly Prep to ULOC	20827436	100	Dolly Prep-WEST	Tugger-WEST	AHB55999	2	62	11BH008
2	ULOC to Dolly Prep	20827436	100	11BH008	Tugger-WEST	AHB55999	2	62	Dolly Prep-WEST
3	Dolly Prep to ULOC	20936339	100	Dolly Prep-WEST	Tugger-WEST	28850	2	50	11BP010L
3	ULOC to Dolly Prep	20936339	100	11BP010L	Tugger-WEST	28850	2	50	Dolly Prep-WEST
4	Dolly Prep to ULOC	23458873	100	Dolly Prep-WEST	Tugger-WEST	AHB61142	2	24	11BP010L
4	ULOC to Dolly Prep	23458873	100	11BP010L	Tugger-WEST	AHB61142	2	24	Dolly Prep-WEST
5	Dolly Prep to ULOC	20936340	100	Dolly Prep-WEST	Tugger-WEST	28850	2	50	11BP010R
5	ULOC to Dolly Prep	20936340	100	11BP010R	Tugger-WEST	28850	2	50	Dolly Prep-WEST
6	Dolly Prep to ULOC	23458872	100	Dolly Prep-WEST	Tugger-WEST	AHB61142	2	24	11BP010R
6	ULOC to Dolly Prep	23458872	100	11BP010R	Tugger-WEST	AHB61142	2	24	Dolly Prep-WEST
7	Dolly Prep to ULOC	25854019	100	Dolly Prep-WEST	Tugger-WEST	AHB55998	2	31	11CM010
7	ULOC to Dolly Prep	25854019	100	11CM010	Tugger-WEST	AHB55998	2	31	Dolly Prep-WEST
8	Dolly Prep to ULOC	20934412	100	Dolly Prep-WEST	Tugger-WEST	28850	2	250	11FA005L
8	ULOC to Dolly Prep	20934412	100	11FA005L	Tugger-WEST	28850	2	250	Dolly Prep-WEST
9	Dolly Prep to ULOC	20934414	100	Dolly Prep-WEST	Tugger-WEST	28850	2	250	11FA005L
9	ULOC to Dolly Prep	20934414	100	11FA005L	Tugger-WEST	28850	2	250	Dolly Prep-WEST
10	Dolly Prep to ULOC	20934416	100	Dolly Prep-WEST	Tugger-WEST	28850	2	500	11FA005L
10	ULOC to Dolly Prep	20934416	100	11FA005L	Tugger-WEST	28850	2	500	Dolly Prep-WEST
11	Dolly Prep to ULOC	20934413	100	Dolly Prep-WEST	Tugger-WEST	28850	2	250	11FA005R
11	ULOC to Dolly Prep	20934413	100	11FA005R	Tugger-WEST	28850	2	250	Dolly Prep-WEST
12	Dolly Prep to ULOC	20934415	100	Dolly Prep-WEST	Tugger-WEST	28850	2	250	11FA005R
12	ULOC to Dolly Prep	20934415	100	11FA005R	Tugger-WEST	28850	2	250	Dolly Prep-WEST

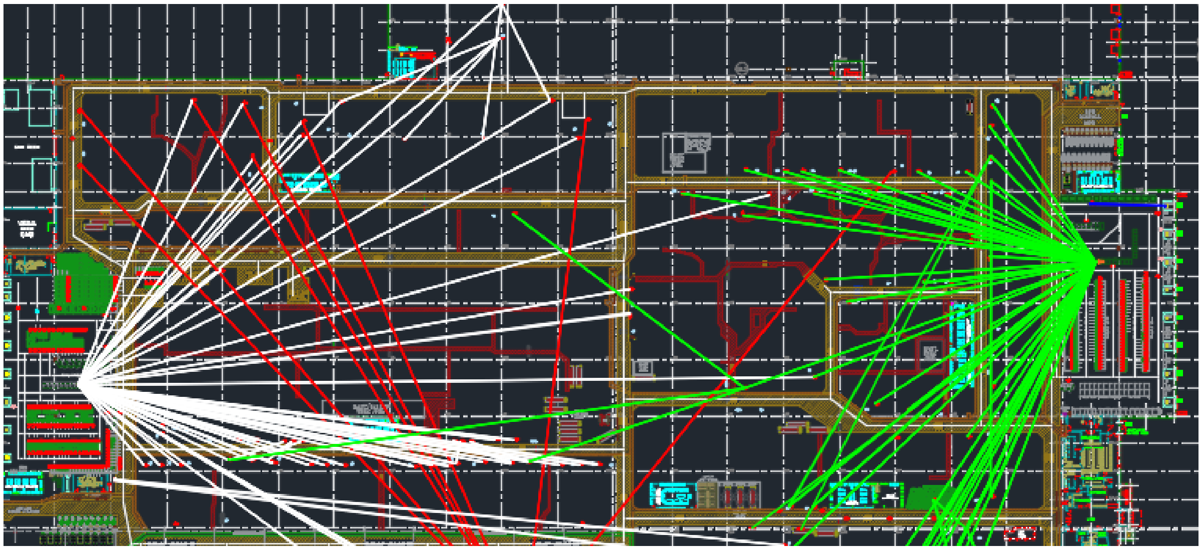


Figure 1. Straight Flow Point-to-Point Study.

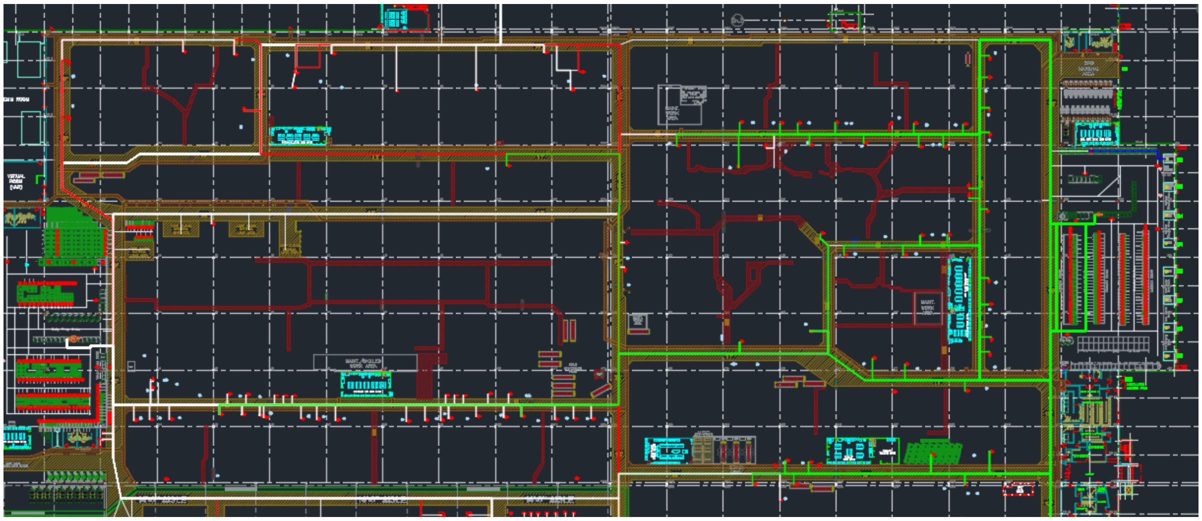


Figure 2. Vehicle Travel along Aisles.

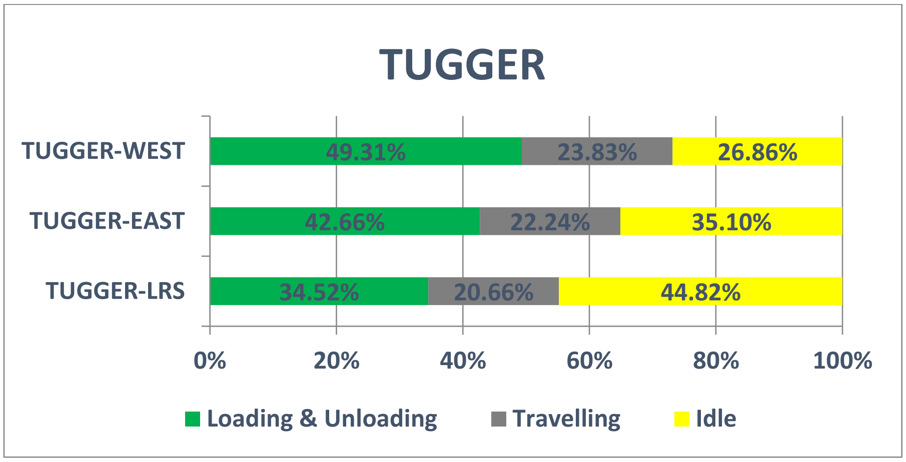


Figure 3. Tugger Utilization by Plant Zone.

Figure 4. Scope of Operations of the “Coalesced” Small-Lot Tuggers

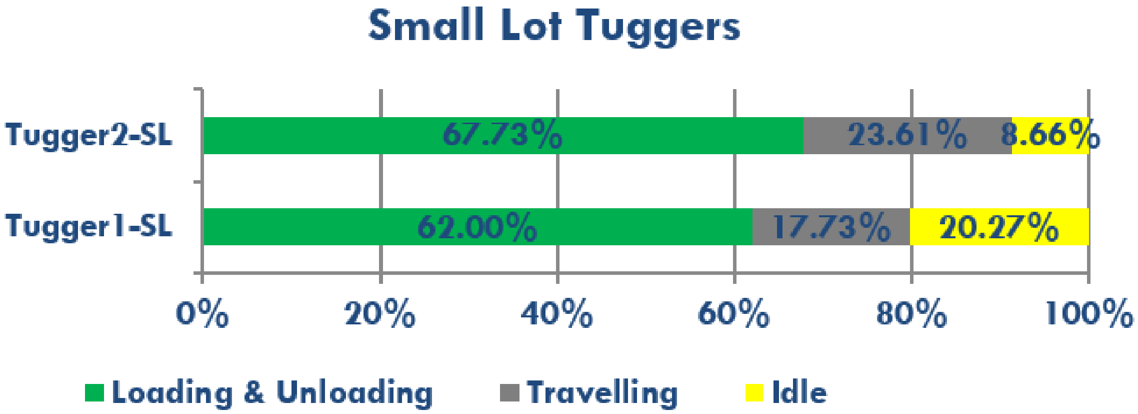


Figure 5. Small Tugger Utilization