Systematic Design of Tugger Delivery Routes

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Tugger versus Unit Load delivery

- Tuggers deliver to multiple locations on one trip, where Unit Load deliveries involve only one location per trip.
- Tugger deliveries are more complex since the transport distance may not be known (dynamic routes), and volumetric capacity limitations can greatly affect route trip frequency.

Tugger vs Unit Load Flows

Industry Problem

- Companies transitioning to tugger (tow train) delivery methods from unit-load (fork truck) methods.
  - Lean initiatives are identifying the waste associated with long route unit load deliveries (Making Materials Flow - Lean Enterprise Inst)
  - Smaller lot sizes, and part kitting are creating an increase in delivery frequency
- Practical analytical techniques are unavailable and Lean textbooks are promoting field based trial and error.

Goal of Methodology

- Use data that is readily available to the field engineer.
  - AutoCAD layout drawings.
  - Excel spreadsheets of daily part consumption or part request history.
- No Model to program
  - Desire is for a deterministic technique that can be performed in a few hours with minimal expertise.
- Systematic technique
  - In the absence of a global optimization technique, develop a minimal approach to reaching a quality outcome.

Simulation as a Technique

- Layout is CAD based and distances can be extracted automatically, otherwise, considerable effort is involved in computing distances and creating/importing layouts.
- Dynamic route design is often not allowed.
- Models can be time consuming to create and validate.
- Not nearly as easy to create new routes and evaluate alternatives to layout, staging and delivery locations.

Tugger Design Objectives

- Minimize the quantity of Route drivers needed to deliver materials within a specified maximum replenishment time.

- Subject to
  - Route Delivery Time <= Replenishment Time
    - Delivery Time=Transport + N_p(pickup)+N_d(dropoff)
    - Where N_p, N_d is Qty of pickups and dropoffs Respectively
  - Route Delivery Time <=Average Delivery Time
  - Tugger Volume Capacity >= Total Volume of containers to be delivered / number of Route Trips

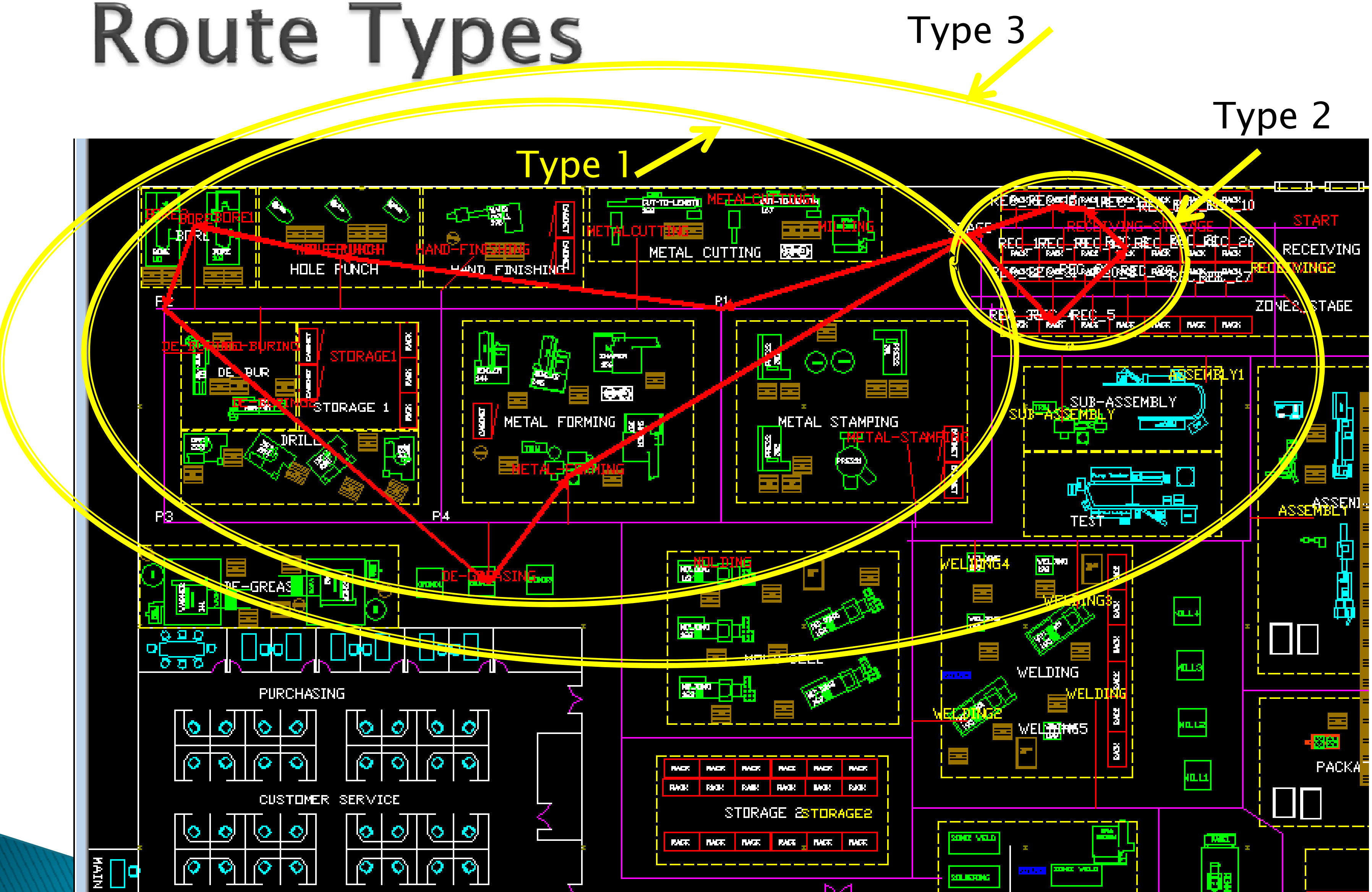
Tugger Design Parameters

- 3 Types of Routes (same operator)
  1. Staging to Line
  2. Storage to Staging
  3. Figure 8 – (Storage to Stage to Line). Used if delivery driver also fills tugger carts

- Analysis performed for a day at a time, different historical or random days are evaluated.

- Container Volume specified as
  - Quantity of containers (fixed slots)
  - Summation of stacked container volumes minus a cubic efficiency factor

Route Types


Type 3
Type 2
Type 1
HOLE PUNCH
HAND FINISHING
METAL CUTTING
RECEIVING
START
ZONE STAGE
DE-BUR
STORAGE 1
DRILL
METAL FORMING
METAL STAMPING
SUB-ASSEMBLY
TEST
DE-GREASING
PURCHASING
CUSTOMER SERVICE
WELDING
STORAGE 2
PACKA
MAIN

Tugger Design Parameters

- Transport Time includes distance of actual path through facility, respecting lack of tugger ability to turn around within aisle. Path distance could be fixed or dynamic.
- Transport Sequence (travelling salesman problem), tugger will visit locations in shortest path.
- Load Time to pickup empty containers or kanban cards (stopoff, plus load times per activity)
- Unload Time to dropoff full containers (stopoff plus unload times per container)
- Time Between Staging areas, for tugger routes that serve multiple staging areas.

Delivery Input Format

ID	Part	Container	Cont. Qty	From	Stage	To	ETD	Dir
1	111456	BOX35	1	REC_2	STAGE	HOLEPUNCH	7.1	1
2	111847	BOX36	1	REC_3	STAGE	DE-BURING	UFM(7/10/2/.5)	1
3	111332	CRATE2	1	REC_4	STAGE	BORE	7.1	-1
4	111445	CRATE2	1	REC_5	STAGE	DE-BURING1	TRG(7/10/8/1/1)	-1
5	235448	FLAT	2	REC_14	STAGE	DE-GREASING	7.1	1
6	235449	FLAT	1	REC_15	STAGE	METAL-FORMING	7.1	1
7	235450	FLAT	1	REC_16	STAGE	METAL-STAMPING	7.7	1
8	111456	BOX35	1	REC_17	STAGE	HOLEPUNCH	8.2	1

Daily Consumption Input

- Historical Deliveries can be used directly, by using the actual delivery request time for a container.

- Random Deliveries can be derived from Daily consumption using Uniform or Triangular.
  - Containers/Day= (Parts/Day) / (Parts/Container)
  - The Containers/Day determines the probability of a container being scheduled in the day.
  - A second probability is used (uniform or triangular) which determines when a container is scheduled.

Daily Consumption Input

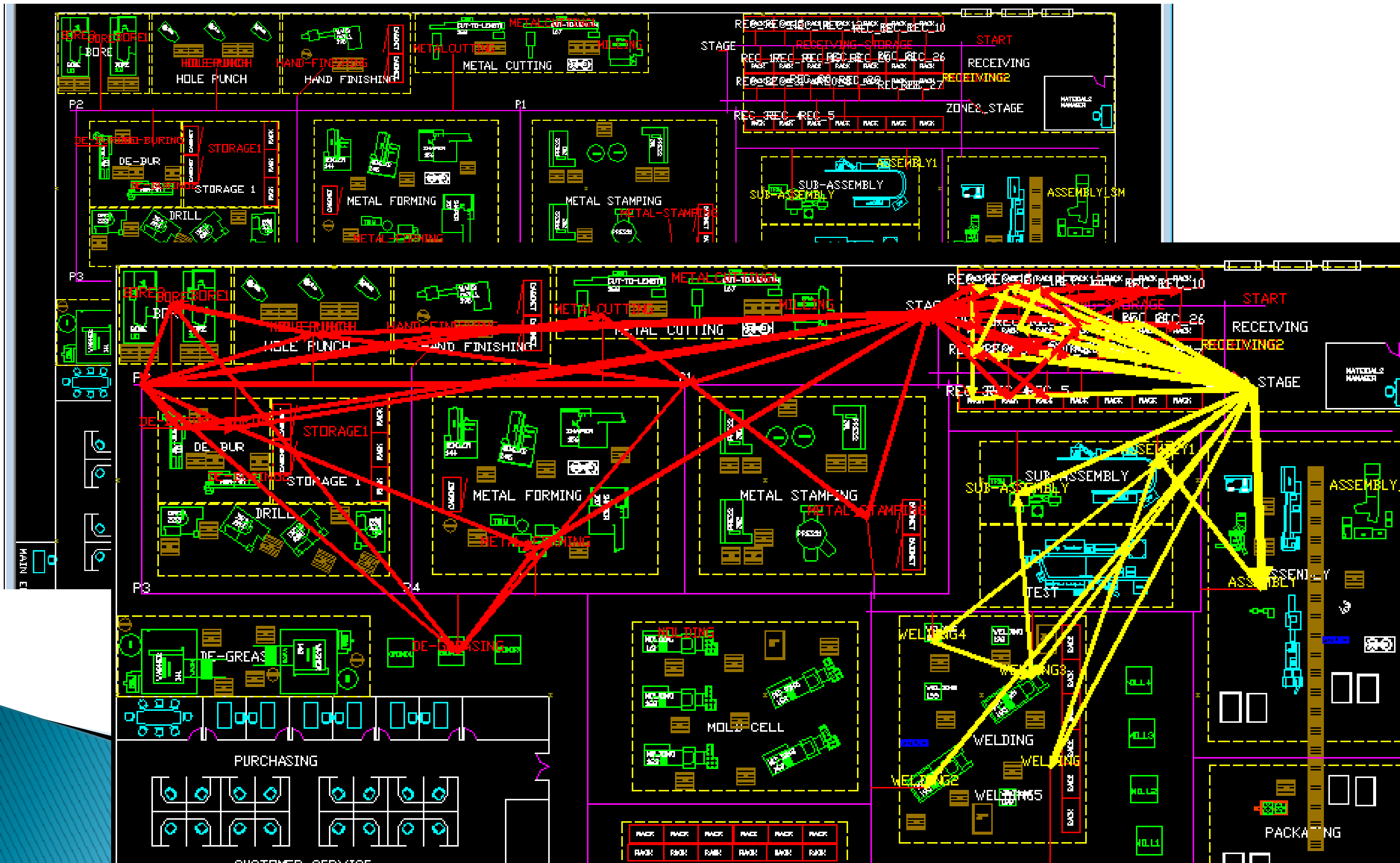
- UFM(8/17/2/0.5) means that 0, 1 or 2 containers of a particular part will be delivered between 8am and 5pm. Each container has a 50% chance of being delivered.
- TRG (8/12/9/1/0.15) means that 0 or 1 container of a particular part will be delivered between 8am and noon, with a mean at 9am. The container has a 15% chance of being delivered.
- Delivery probabilities typically reflect fractional containers per day, or optional part take-rates.

Delivery Route Input

Route	Interval (mins)	Include	Path	Volume	Eff%	Stage
ZONE1	7/15/10/10	YES	*T/P1/P2	300	100	
ZONE2	7/15/10/10	YES		300	100	ZONE2_STAGE

- A Route is defined as a set of locations served by a tugger.
- Routes have fixed time intervals for dispatch, plus a time to perform the delivery. This allows a route to have multiple drivers with staggered dispatch times.
- Routes have volume constraints, optional fixed passthru points and optional fixed staging areas.

Delivery Route Input



Analytical Methodology

1. Group container deliveries
   - First by route driver, and then by time slot (delivery window). Optionally move containers to the next window if volume capacity is exceeded.
2. Create a distance matrix
   - First between locations along an aisle, then between locations at aisle ends to other locations (not in aisle middles). Include passthru nodes for fixed routes.
   - Distances are computed using aisle network and application of shortest path algorithm.
3. Apply travelling salesman approach
   - Select the order to visit the locations, starting at staging
   - Branch and bound works due to limited locations per route

Automatically Created Route

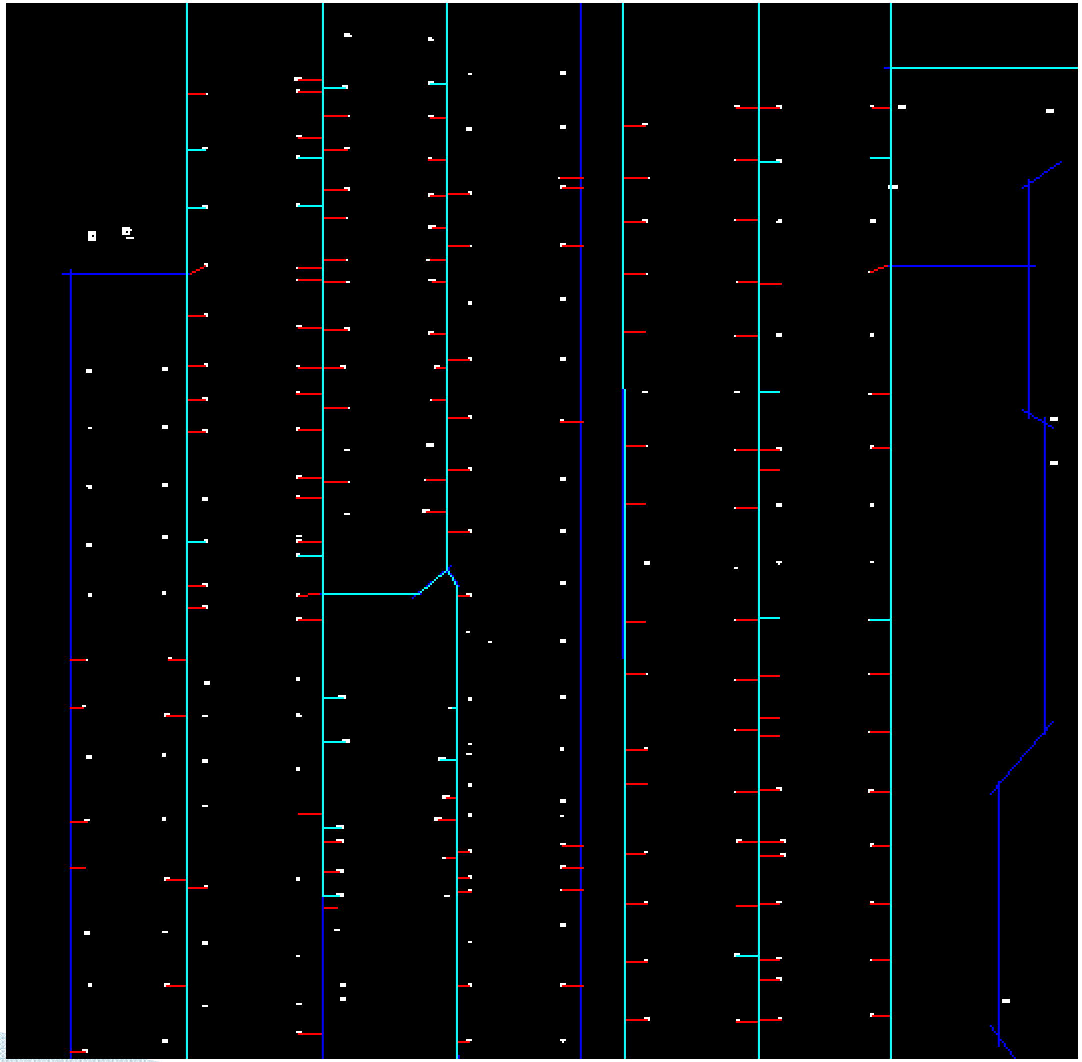
Part	%	From	Method	(C)ontainer	C/Trip	Parts/C	To Loc
111332	100	STAGE	ZONE1	CRATE2	1	-2	REC_4
111456	100	REC_4	ZONE1	BOX35	1	-1	REC_2
235448	100	REC_2	ZONE1	FLAT	2	-1	REC_14
235449	100	REC_14	ZONE1	FLAT	1	-1	REC_15
RETURN	100	REC_15	ZONE1	!NA	1	-1	STAGE
TRAVEL	100	STAGE	ZONE1	!NA	1	-1	P1
111456	100	P1	ZONE1	BOX35	1	-2	HOLEPUNCH
111332	100	HOLEPUNCH	ZONE1	CRATE2	1	-1	BORE
TRAVEL	100	BORE	ZONE1	!NA	1	-1	P2
235448	100	P2	ZONE1	FLAT	2	-2	DE-GREASING
235449	100	DE-GREASING	ZONE1	FLAT	1	-2	METAL-FORMING
RETURN	100	METAL-FORMING	ZONE1	!NA	1	-1	STAGE

- Example above shows a circle of work generated for a route at a time slot (i.e. 9:30am). This work starts at staging, picks up parts in storage, then goes through staging to deliver the parts to the assembly line, and then returns to staging

Automatically Created Route

Assembly Plant Aisle Structure

- Long aisles are typical in vehicle assembly plants.
- This simplifies TSP when using Branch and Bound techniques

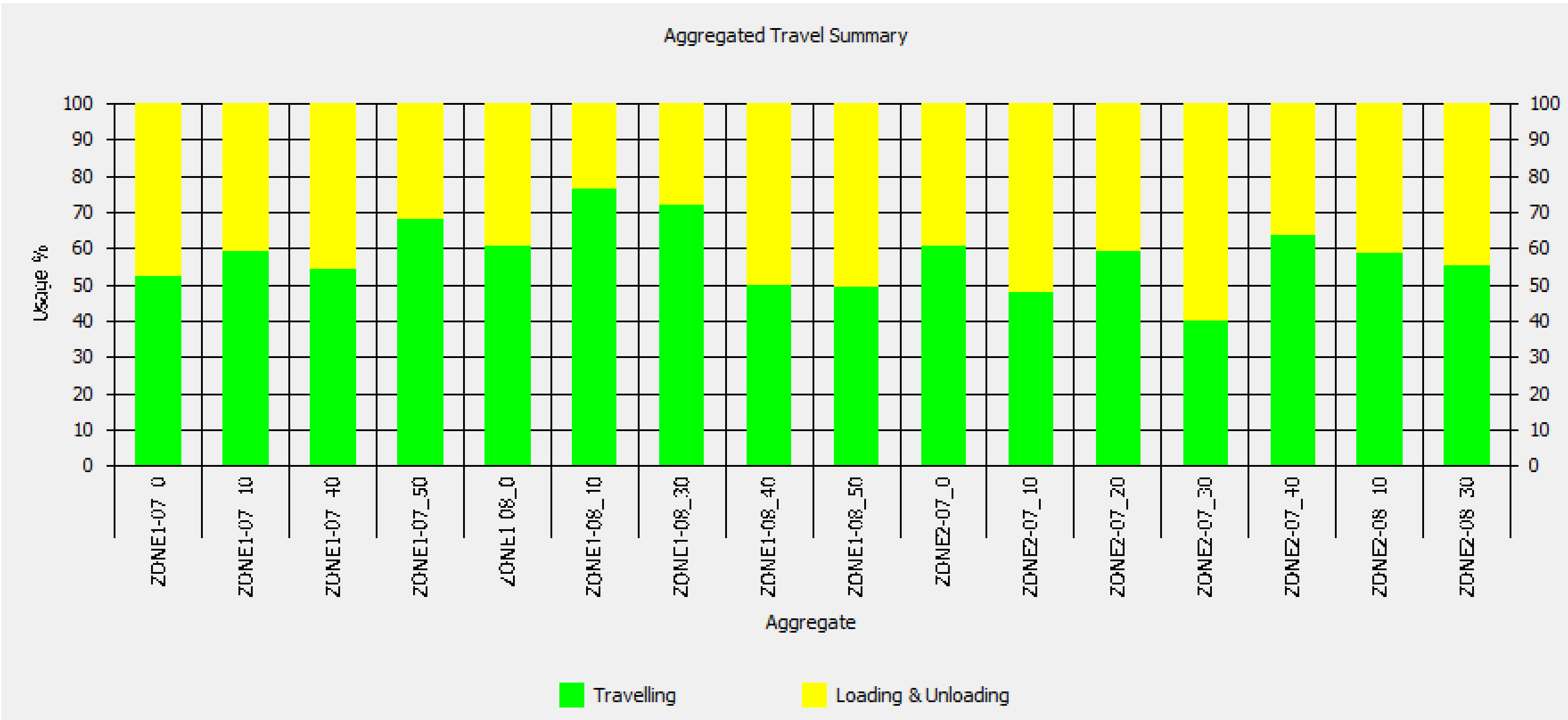


Analytical Methodology

5. Create a circle of work route that starts and ends at a staging area. Three types of routes are possible.

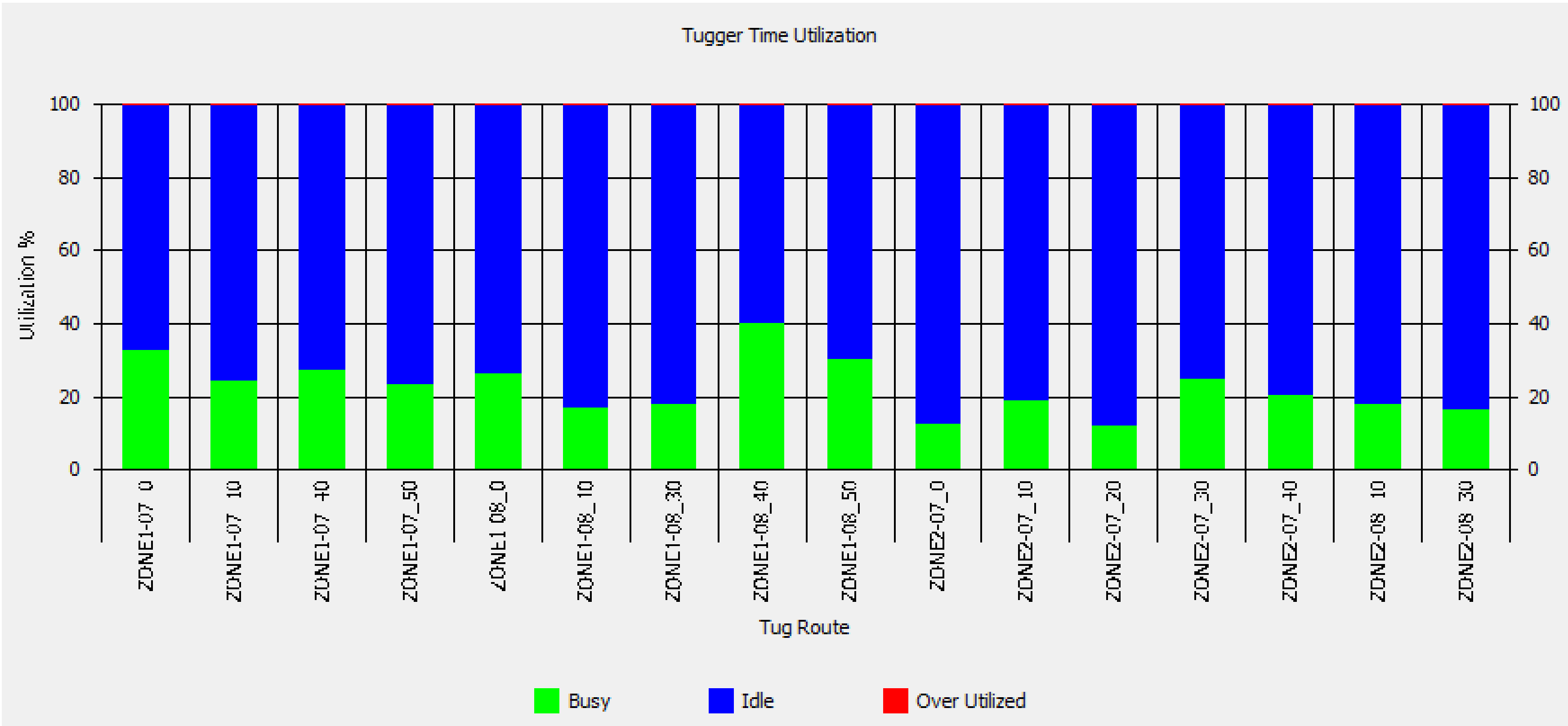
6. Compute travel time and container volume of route, for each delivery throughout day.
   - Implement shortest path algorithm to navigate between locations (stopoff, passthru)
   - Travel Time = Distance in AutoCAD / Tugger Speed
     - Plus stopoff times

Route Trip Effectiveness



Showing Relative Time Spent on Load & Travel

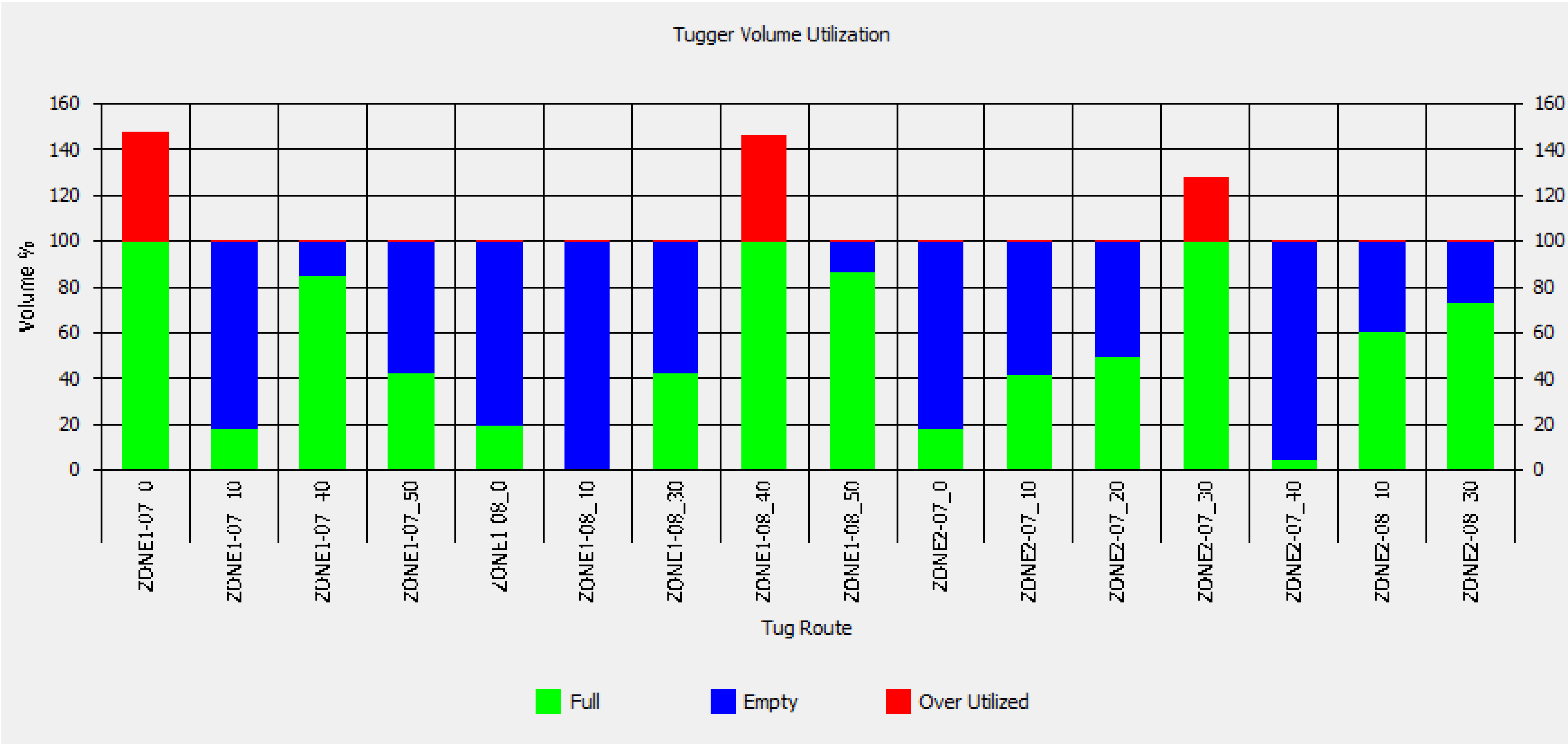
Route Trip Time vs Available



Time Utilization of Route Deliveries

Time for trip / Allowed time

Volume Per Trip



Could be Qty or Volume of containers

Route Summary Report

AGGREGATE	FROM	TO	FREQUENCY	TOTAL DISTANCE FEET	TRIP DISTANCE FEET	EFF. TRIP DISTANCE FEET	TRAVEL TIME SECONDS	L/UL TIME SECONDS	TOTAL TIME SECONDS	TRIP TRAVEL TIME SECONDS	COST $	VOLUME %
ZONE1-07_0	STAGE	REC_4	1.00	27.25	27.27	27.25	5.45	30.00	35.45	5.45	.20	9.00
	REC_4	REC_2	1.00	23.58	23.57	23.58	4.71	.00	4.71	4.71	.03	.67
	REC_2	REC_14	1.00	13.08	13.11	13.08	2.62	.00	2.62	2.62	.01	42.67
	REC_14	REC_15	1.00	7.25	7.22	7.25	1.44	.00	1.44	1.44	.01	21.33
	REC_15	STAGE	1.00	19.67	19.69	19.67	3.94	.00	3.94	3.94	.02	.00
	STAGE	P1	1.00	58.58	58.58	58.58	11.72	.00	11.72	11.72	.07	.00
	P1	HOLEPUNCH	1.00	87.08	87.12	87.08	17.42	24.00	41.42	17.42	.23	.67
	HOLEPUNCH	BORE	1.00	33.33	33.34	33.33	6.67	.00	6.67	6.67	.04	9.00
	BORE	P2	1.00	20.08	20.04	20.08	4.01	.00	4.01	4.01	.02	.00
	P2	DE-GREASING	1.00	96.08	96.04	96.08	19.21	10.00	29.21	19.21	.16	42.67
	DE-GREASING	METAL-FORMING	1.00	30.08	30.08	30.08	6.02	30.00	36.02	6.02	.20	21.33
	METAL-FORMING	STAGE	1.00	106.08	106.09	106.08	21.22	.00	21.22	21.22	.12	.00
SUB TOTAL			12.00	522.14			104.43	94.00	198.43		1.11	147.34
ZONE1-07_10	STAGE	REC_5	1.00	34.17	34.13	34.17	6.83	30.00	36.83	6.83	.20	9.00
	REC_5	STAGE	1.00	34.17	34.13	34.17	6.83	.00	6.83	6.83	.04	.00
	STAGE	P1	1.00	58.58	58.58	58.58	11.72	.00	11.72	11.72	.07	.00
	P1	P2	1.00	126.00	126.00	126.00	25.20	.00	25.20	25.20	.14	.00
	P2	DE-BURING1	1.00	13.42	13.42	13.42	2.68	30.00	32.68	2.68	.18	9.00
	DE-BURING1	STAGE	1.00	175.50	175.52	175.50	35.10	.00	35.10	35.10	.20	.00
SUB TOTAL			6.00	441.84			88.36	60.00	148.36		.83	18.00

Systematic Methodology

- Parameters for experimentation
  - Route Volume
  - Route Time
  - Number of Routes
  - Locations visited per Route (and implied layout dist)

- Assuming
  - Layout is fixed and delivery locations known
  - Container delivery quantities to locations is fixed (within variability)
  - Tugger speed, unload/load times are fixed.

Systematic Methodology

1. Initial Route Definition
    1. Evaluate low density, high volume containers (i.e. seats, engines, IP, etc.). Establish dedicated routes per staging for those items and determine available route capacity.
    2. All remaining containers: Establish 1 route per staging area, set delivery time = replenishment time

2. Address the Volume constraint.
    1. Increase time between deliveries (up to Replenishment Time limit) in order to maximize cube of tugger.
    2. Or Decrease time between deliveries to increase the number of route deliveries until tugger volume < 100%

Systematic Methodology

3. If tugger volume is 100% and tugger route time utilization is > 100% then:
   1. If opportunities exist to cluster delivery locations to reduce tugger travel distance, then **break route area into multiple routes** (zones). Design zones to reduce overall tugger travel distance, possibly evaluate new staging areas.
   2. Else, **add parallel route drivers** along the same route and stagger their departure times.

Systematic Methodology

- Additional Issues
  - Address partially utilized (time) routes. It may be necessary to service multiple staging areas with one driver. This is evaluated manually, after a first pass of the method.

  - Address time constrained routes, where tugger volume capacity is not the limiting constraint. In this case, is time limit based on travel or load/unload. If so, then a layout or load/unload process improvement is recommended.

Conclusion

- Implementation of Tugger delivery systems is on the rise.
- Lean (quick, low cost and effective) analytical techniques are needed in the field today.
- The proposed technique:
  - Uses readily available layout and container delivery data in an existing format.
  - Provides a simple iterative approach to achieving near optimal results in under a day.

Thank You

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