Systematic Design of Tugger Delivery Routes

Dave Sly, PhD, MBA, PE
Iowa State University
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
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.
Minimize the quantity of Route drivers needed to deliver materials within a specified maximum replenishment time.

Subject to

- Route Delivery Time $\leq$ 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 $\leq$ Average Delivery Time
- Tugger Volume Capacity $\geq$ 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
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

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<th>ID</th>
<th>Part</th>
<th>Container</th>
<th>Cont. Qty</th>
<th>From</th>
<th>Stage</th>
<th>To</th>
<th>ETD</th>
<th>Dir</th>
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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.
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.
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.
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

<table>
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<th>Part</th>
<th>%</th>
<th>From</th>
<th>Method</th>
<th>C/Container</th>
<th>C/Trip</th>
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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

Aggregated Travel Summary

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

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<th>FROM</th>
<th>TO</th>
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<th>TRIP DISTANCE FEET</th>
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|             | RBC_6 | STAGE | 1.00 | 34.17 | 34.13 | 34.17 | 6.83 | 0.00 | 6.83 | 6.83 | .04 | .00 |
|             | STAGE | P1 | 1.00 | 50.56 | 50.56 | 50.56 | 11.72 | 0.00 | 11.72 | 11.72 | .07 | .00 |
|             | P1 | P2 | 1.00 | 128.00 | 128.00 | 128.00 | 26.20 | 0.00 | 26.20 | 26.20 | .14 | .00 |
|             | P2 | DE-BURNING | 1.00 | 13.42 | 13.42 | 13.42 | 2.68 | 30.00 | 32.68 | 2.68 | .18 | 9.00 |
|             | DE-BURNING | STAGE | 1.00 | 176.50 | 176.52 | 176.50 | 26.10 | 0.00 | 26.10 | 26.10 | .20 | .00 |
| SUB TOTAL |       |   | 6.00 | 441.94 | 98.26 | 60.00 | 148.26 | .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%
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.
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

davesly@iastate.edu

515-450-2335