Instance Generation Process and Cost/Emissions Tables

Content

1 Test Data Generation

We assume C groups (for example companies) indexed using set $\mathcal{C}$ and N warehouses indexed using set $\mathcal{N}$. Assume $C \leq N$. Each warehouses is assigned to a group using the following algorithm:

1. Associate to each $c \in \mathcal{C}$ a unique random warehouse $n \in \mathcal{N}$ preferably from a new location.
2. Remove associated warehouses from $\mathcal{N}$.
3. Remove $\lfloor C/3 \rfloor$ groups from $\mathcal{C}$
4. If $\mathcal{N} \neq \emptyset$, go to step 1.

Half of the products (non-perishable and perishable) are evenly associated to the groups. The other half of products are randomly assigned to a group, where the assignment probability is directly proportional to the group size. Furthermore, each product is requested in between 25% and 100% of all demand regions (but at least one) where the group has no associated warehouses. A product is twice as likely to be demanded in a middle-sized demand region and four times as likely to be demanded in a large-sized demand region compared to a small-sized region. The product dimension is drawn from a heavy-tailed Lévy-distribution with location $\mu = 0$ and scale $c = 0.2$ to emphasize smaller products but not exclude larger ones (see Figure 1). The dimension[1] is rounded

[1] 2.16 m^3 roughly correspond to the maximal dimensions of a fully loaded Euro-pallet.

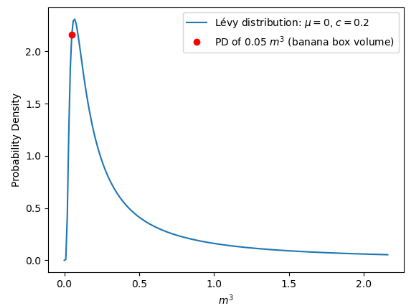

Figure 1: (Unscaled) Probability density function of commodity volumes.

up to the next 0.01 m^3 (interpretable as a minimum modular-container size) and redrawn if exceeding 2.16 m^3. Product weight is calculated by assuming a density uniformly drawn between 50 $\frac{kg}{m^3}$ and 1200 $\frac{kg}{m^3}$[2].

The average requested product-weight in a demand region is drawn uniformly between the weight of exactly one product k_W and 20.000 kg. Additionally, the drawn demand is lowered by 10% for small regions and increased by 10% for large regions. The average requested number of products $\hat{r}$ is then calculated by dividing the requested product-weight by k_W and rounding to the next integer. A product is requested daily, every two days or weekly. The actual product demand for each request is drawn from a normal distribution with mean $\hat{r}$ and a standard deviation of $0.1 \cdot \hat{r}$.

Each product is in stock in one or multiple warehouses. A product demand is satisfied by the closest warehouse of the associated company. If the product is perishable, its lifetime is set uniformly between the minimum travel time of a truck to the most distant associated demand node t_{min} and $t_{min} + 4$.

Warehouse-stock is generated in the time-period such that a truck can fulfill the requested demand on time. This means, if the demand is at time t, the stock is generated for time period $t - t_{min}$. To determine the generated stock size for a commodity, its average request size for a particular demand region $\hat{r}$ is summed up over all demand regions it has to service yielding $\hat{r}_{sum}$ and adding 20% interpretable as safety stock[3].

The maximal capacity of a warehouse is set in such a way that the maximal generated stock for the warehouse is assumed to occupy between 50% and 80% of its capacity (again drawn uniformly). If a warehouse carries no stock, its capacity is set to half of the average capacity found in its region size.

We generate loosely and tightly capacitated version of each instance. In a loosely capacitated version, only warehouses are capacitated in the way ex-

[2]Minimum weight-density corresponds to the density of styrofoam.

[3]Assuming a fixed lead time of one day, this correspond to a cycle service level of roughly 0.98 Chopra (2019). In the rare case of demand exceeding the available stock, the stock is increased to the requested demand to ensure feasibility.

plained above. In the tightly capacitated instance, each transshipment point has an incoming and outgoing handling capacity of 30% of the average demand in the associated region and a total handling capacity of 60%[4]. If the associated region has no demand, handling capacity is calculated based on the closest region having non-zero demand.

2 Cost and Emissions Tables

	Lorry		Rail		Ship		Storage	
$C(f,y)$	c_y	c_f	c_y	c_f	c_y	c_f	c_y	c_f
Dry	0.8	0.005	0.5	0	0.3	0	0	0.16
Fresh	0.838	0.005	0.553	0	0.436	0	0	0.32
Handling	0	1/0.5	0	3	0	3	-	-

Table 1: Fixed costs per km. Variable prices for transportation modes (dry, fresh) in tonne.km and for storage per m^3. Handling costs per ton. Lorry handling refers to warehouse/cross-dock.

	Lorry		Rail		Ship		Storage	
$\Delta(f,y)$	Δ_y	δ_f	Δ_y	δ_f	Δ_y	δ_f	Δ_y	δ_f
Dry	933	69	92	23	116	29	0	16
Fresh	1011	69	201	23	396	29	0	37
Handling	0	510/255	12578 (6289)	0	13968 (6984)	3492 (1746)	-	-

Table 2: Emissions in g CO_2e (equivalent). Transportation per tonne.km. Storage per Volume. Handling per container or tonne. Lorry handling refers to warehouse/cross-dock. Rail and ship terminals require two handling operations, one from the truck or incoming train/ship to a stack and from the stack to an outbound train/ship. The cost of one handling operation is in parenthesis.

	Lorry		Rail		Ship		Storage	
$\Delta(f,y)$	Δ_y	δ_f	Δ_y	δ_f	Δ_y	δ_f	Δ_y	δ_f
Dry	0.0933	0.0069	0.0092	0.0023	0.0116	0.0029	0	0.0016
Fresh	0.1011	0.0069	0.0201	0.0023	0.0396	0.0029	0	0.0037
Handling	0	0.0204	0.6289	0	0	0.1746	-	-

Table 3: Emission costs based on g CO_2e (equivalent) values outlined in table 2 and climate change costs per tonne of CO_2e of 100€. Transportation per tonne.km. Storage per Volume. Handling per container or tonne.

[4]Percentage is based on the maximum number of containers based on demand weight or demand volume.

2.1 Notes

- All values are well-to-wheel.
- Transport units / containers on transport modes are always 40-feet ISO-Container[5]
- We have collected references (some are scientific papers, some are web-pages) for all cost and emission values not obtained from our industry partners. We plan to write a section on them here. For now, if you want a reference on any of these values, please do not hesitate to contact us!

2.2 Climate change costs per tonne of CO_2 equivalent

Following the 2019 Handbook on the External Costs of Transportation (Delft, 2019) we price emissions at 100€/tCO_2e. The costs are derived using an avoidance cost approach (McKinnon et al., 2015) based on target emission values in accordance with the Paris Agreement. The price results as central value for the short-and-medium-run costs with short-and-medium defined as a time-horizon up to 2030. Central long run avoidance costs (up to 2060) are 269€/tCO_2e.

References

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McKinnon, A., Brown, M., Piecyk, M., and Whiteing, A. (2015). *Green Logistics : improving the environmental sustainability of logistics.* Kogan Page Limited, 3th edition.

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[5] Volume: 67,5m^3, 4t weight when empty, net load 26,48t $\rightarrow$ in total 30.48t