BACKGROUND

The procurement team at Caterpillar Asia Distribution Center, Singapore wants to use the power of analytics and optimization to split their daily shipment of spare parts among three freight forwarders (FFs). Caterpillar reserves shipment spots and appoints FFs on daily basis, instead of contracts for distribution.

ALLOCATION

Using the results of the multi-objective optimization problem, the results of freight forwarders allocation for the 10 countries are given below in Table 1:

Table 1: Freight Allocation

Freight Forwarder	Allocated Countries
Freight Forwarder 1 (FF1)	Brunei, Indonesia, Philippines and Singapore
Freight Forwarder 2 (FF2)	Myanmar, Vietnam
Freight Forwarder 3 (FF3)	Cambodia, Laos, Malaysia, Thailand

STRATEGY

As mentioned in the case study article, Caterpillar's allocation strategy is based on the optimization of the following three objectives: (1) Minimize the Cost from the quotes, (2) Maximize the On-time Performance (OTP) of the FFs for each route, (3) Minimize the number of Transit Days for making deliveries. Using OTP and Transit Days, we compute expected number of days it takes a freight forwarder to complete the delivery in a country.

$$Expected\ Number\ of\ Days = \frac{Transit\ Days}{On\text{-}time\ Performance}$$

Expected Number of Days accounts for the impact of delayed deliveries for every delivery and for an FF. This helps in reducing the number of objectives to make the optimization problem simpler. We now only have two objectives for the optimization problem: (1) Minimize Total Daily Cost, and (2) Minimize Total Expected Days. As this is a multi-objective optimization problem, CEPLEX was used for the analysis. The following constraints were considered in CEPLEX:

1. Only one FF should be appointed for one country. This condition has been assigned based on business understanding that only one freight forwarder carries the freight to a country.
2. Per case study article, it is assumed that a freight forwarder should not be allocated freight for more than 60% of the total cost in a day. This is because Caterpillar does not want to rely too much on one freight forwarder.
3. FF1 does not deliver in Cambodia and Laos, and FF2 does not deliver in Cambodia.

Different combinations of Cost and Expected Days for Delivery are plotted below in Figure 1. From the chart, it can be observed that as the Number of Expected Days for Delivery increases, Total Cost decreases. However, to find the optimal price point, one may look at the marginal savings as shown in Table 2. Results of Total Cost and Total Expected Days are also shown below in Table 2. Marginal savings here are defined as the savings associated with per unit change in Number of Expected Days. For example, marginal savings for Allocation 2 is calculated using

$$Marginal\ Savings = \frac{Total\ Expected\ Cost\ for\ Allocation\ 2 - Total\ Expected\ Cost\ for\ Allocation\ 1}{Expected\ Days\ for\ Allocation\ 2 - \ Expected\ Days\ for\ Allocation\ 1}$$

Figure 1: Variation of Cost with Total Expected Days

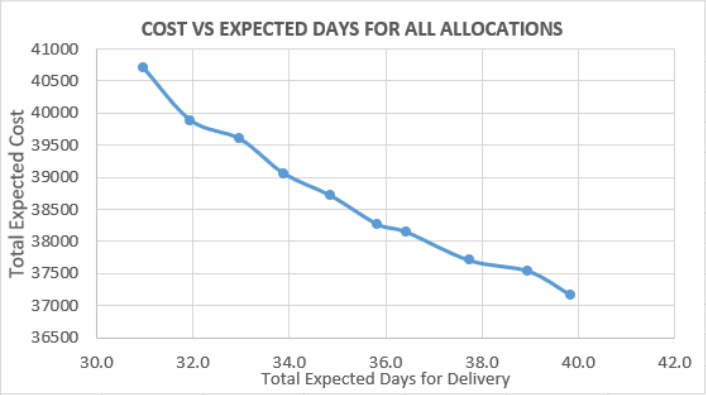

Table 2: Analysis results for different allocations

	Total Expected Days	Total Expected Cost	Marginal Savings ($)
Allocation 1	31.0	40703	-
Allocation 2	32.0	39886	832
Allocation 3	33.0	39594	284
Allocation 4	33.9	39062	593
Allocation 5	34.9	38714	356
Allocation 6	35.8	38271	459
Allocation 7	36.4	38146	205
Allocation 8	37.7	37706	337
Allocation 9	39.0	37536	139
Allocation 10	39.8	37166	424
Marginal Savings = Change in Savings per unit change in Expected Days			

According to the results shown in Table 2, if we choose Allocation 2 and Allocation 5, marginal savings would be very high. In both cases, all the allocations are the same except for Thailand. Per the results for Allocation 2, FF2 should be allocated freight delivery for Thailand. It has 91% on-time performance and 2 Transit days for a cost for $5999, whereas, per results of Allocation 4, the freight for Thailand should be assigned to FF3 which has 4 transit days but highest on-time performance for 97% and the lowest price of $5175 amongst all three FFs for Thailand.

Table 3: Allocation results for Allocation 2 and Allocation 4

Allocation 2	FF1	FF2	FF3
Brunei	1	0	0
Cambodia	0	0	1
Indonesia	1	0	0
Laos	0	0	1
Malaysia	0	0	1
Myanmar	0	1	0
Philippines	1	0	0
Singapore	1	0	0
Thailand	0	1	0
Vietnam	0	1	0

Allocation 4	FF1	FF2	FF3
Brunei	1	0	0
Cambodia	0	0	1
Indonesia	1	0	0
Laos	0	0	1
Malaysia	0	0	1
Myanmar	0	1	0
Philippines	1	0	0
Singapore	1	0	0
Thailand	0	0	1
Vietnam	0	1	0
1 indicates FF has been allocated the freight 0 indicates FF has not be allocated the freight			

Therefore, for example, if the delivery of freight for Thailand is very time-sensitive then we should choose Allocation 2 given in Table 3 (left), otherwise, the optimal solution would be to go with Allocation 4 given in Table 3 (right) as it has reasonable overall Cost and Expected Days for Delivery. It also aligns with Caterpillar's reputation of working with the higher On-time Performance in the industry.

OTHER FACTORS

Delayed Deliveries: Delayed deliveries not only hamper reputation but also cost money, and sometimes the company bears this loss instead of the freight forwarder depending upon the Service Level Agreement (SLA) between the parties. In the case of Caterpillar, we are not provided with any information regarding Caterpillar's agreement with the FFs for daily contracts. Both SLA and the loss due to delayed/misplaced deliveries should have been considered in this analysis.

Daily Availability of FFs: Caterpillar reserves shipment spots and appoints FFs on a daily basis for the 10 countries. If there have been days in the past when no spots were found with any of these three freight forwarders, then such information would have been useful for the present analysis. A metrics percentage of availability of the FFs per year should have been considered as an input.

Price Fluctuations: It is also not clear from the case study article if the costs are for ad-hoc or steady demand. Prices are usually based on demand and availability. So, some information about price fluctuations should have been considered in the optimization problem. Percentage or range of price fluctuations over a period of time would have been a good metric to include in our analysis.

Delivery Frequency: One very important factor that would have impacted the analysis is the frequency of delivery. It is also not clear if all these FFs take the freights every day, and does Caterpillar need to ship spare parts every day? Information regarding FFs schedule would have added a new dimension to our analysis as we could account for if certain FFs do not ship on certain days.

Risks with Daily Reservations: Risks are involved in reserving the spots on a daily basis than with contracts. Caterpillar procurement team is probably saving money by this dynamic freight allocation. However, no information is available that allows us to quantify these risks and add to our analysis.

Carbon Footprint: With Industry 5.0, major companies now consider it their responsibility to lower their carbon footprints and protect the environment. If some data on carbon footprints of FFs were available, minimization of total carbon footprints could also be considered as an objective function.

INDUSTRY 4.0 and 5.0

Industry 4.0: Per Ref 1, "Industry 4.0 is the idea of smart factories where machines are augmented with web connectivity and connected to a system that can visualize the entire production chain and make decisions on its own." Industry 4.0 is also referred to as the Fourth Industrial Revolution, Industrial Internet of Things, and Smart Factory (Ref 1; Sniderman, 2019). Salient characteristics of Industry 4.0 include information transparency, decentralized decision-making, Interoperability (machines, devices, and humans connect and communicate with one another), etc. Some challenges associated with industry 4.0 are as follows: maintaining the integrity of production process with less human oversight, possible loss of human jobs due to automation, increased data security issues, and expensive outages caused by technical problems (Forbes, 2018).

Industry 5.0: Like Industry 4.0, Industry 5.0 can be interpreted as the Fifth Industrial Revolution. As stated in Ref 5, "the greatest advances predicted of Industry 5.0 involve the interaction of human intelligence and cognitive computing." Industry 5.0 basically is an improved and more efficient version of Industry 4.0. With Industry 5.0, it is expected that companies will develop more environment-friendly processes that use renewable energy and recycle waste. Also, with the advancement in artificial intelligence and with robots behaving more like human beings, the interaction between humans and machines will become more productive in the future.

SELECTION OF SINGAPORE AS ADC

Strengths

- Global Connectivity: Excellent connectivity with export and import activities, flight or sea connectivity to more than 123 countries, state-of-the-art, world class seaports and airports, presence of major air express courier companies, etc. Singapore is also expanding and coming up with newer ports in Pasir Panjang area and optimizing its older ports in Jurong.
- High Degree of Logistic Professionalism: All major logistics companies have a base in Singapore, several stakeholders such as SPRING Singapore, A*STAR, Singapore Workforce Development Agency and universities are together setting up advanced institutions (Ref 7).
- Comprehensive Logistics Value-added Services: Services in sectors such as legal, finance, insurance, and logistics skill development and vocational training.
- Forefront of Technology Advancements: One of the most automated countries in the world, wants to become the first Smart Nation in the world (Ref 9), has infrastructure to quickly adopt industry 5.0 in logistics industry.
- Geographic Position: Located at one of the busiest shipping routes, has easy access to all South Asian countries.

- Financial Stability: Singapore has lower inflation rate and very stable economy. As a major logistics hub and ranked first in Asia by the World Bank (Ref 6).
- Easy Access to Talent: With world-class education system and schools, Singapore produces top notch talent to fulfill the demand of logistics industry.

Weaknesses

- Rising Costs: Fast development of Singapore has also brought rising costs, Caterpillar, Inc. should be prepared for any challenges this may bring up.
- Government Regulations: Government regulations (e.g. rising pay levels, liability laws) may strike companies hard.
- Adjacent New Ports: Shipping lines, notably Evergreen and Maersk SeaLand are now shifting their base to the adjacent new port of Tanjung Pelepas in Malaysia. Caterpillar, Inc. should be watchful of such developments.
- Environmental Regulations and Taxes: Events like Paris agreement (2016) and government-imposed environment regulations may put burden on companies.
- Shortage of skilled workforce: Shortage of work force skilled in advanced technologies (Artificial Intelligence and Machine Learning) may hamper Singapore to adopt Industry 5.0. This may be a threat to logistics industry and affect steady growth of profits for Caterpillar.

CONCLUSION

Using the Cost, Transit Days and OTP data provided in the case study article, multi-objective optimization analysis was performed. A chart showing the relationship between the minimum Cost and the Expected Delivery Days is developed. Considering different price points and the constraints, most optimum freight allocation was identified as the one with average Cost of $3906.2 per country with Expected Delivery Days of 3.39 days per country. Other factors such as price fluctuations and delivery frequency of FFs which may impact the optimization analysis but not included here are briefly discussed. Reserving the spots on a daily basis rather than having a contract is risky, but it helps Caterpillar reduce its carbon footprint by sharing logistic resources with others.

Based on the discussion regarding the strengths and weaknesses of Singapore as ADC, I believe having Singapore as ADC is a good decision. Singapore is aware of issues such as rising costs, limited resources and need for technology advancements, and hence it is already taking steps to adopt industry 5.0. Only when the countries nearby Singapore reach a similar level of technological excellence, have strong logistics industry, and have similar awareness for the environmental issues, it would be wise to consider those locations for a new ADC.

REFERENCES

1. Singfat Chu, Ramya Subramanian of Caterpillar Inc.: Aftermarket Parts Freight Optimization case study.
2. Ref 1: https://en.wikipedia.org/wiki/Industry_4.0
3. Sniderman, Brenna; Mahto, Monika; Cotteleer, Mark J. "Industry 4.0 and manufacturing ecosystems Exploring the world of connected enterprises" (PDF). Deloitte. Retrieved 25 June 2019.
4. Ref 3: https://www.forbes.com/sites/bernardmarr/2016/06/20/what-everyone-must-know-about-industry-4-0/#609a3920795f
5. Ref 4: https://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act
6. Ref 5: https://blog.gesrepair.com/2017/11/16/industry-4-and-5/
7. Ref 6: https://spring.enterprisesg.gov.sg/Developing-Industries/LOG/Pages/logistics.aspx
8. Ref 7: https://www.edb.gov.sg/en/news-and-events/insights/manufacturing/automation-in-manufacturing-help-workers-ride-the-change.html
9. Ref 8: https://www.researchandmarkets.com/research/7gkfq8/singapore_freight?w=4
10. Ref 9: https://www.edb.gov.sg/en/news-and-events/insights/innovation/singapore-builds--smart--into-logistics.html