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Design of Inputs for a Refrigerators Manufacturing Company Case Study

C. Arampantzi, I. Minis

University of the Aegean
Dep. of Financial & Management Engineering
Design Operation & Production Systems Lab
(DeOPSys Lab)

Forward

To investigate the effectiveness of the proposed mathematical model for the problem of the strategic supply chain network design from the perspective of the manufacturer, a case study was studied concerning a world-class commercial refrigerator manufacturer. All the necessary data were sourced by the publicly available information that is the Annual Reports and the Financial Statements. For confidentiality reasons, we do not present the company's further details.

In this report, we describe the above actual data and the necessary assumptions that we take into our consideration for this case study. We have structures these in main categories of assumptions: (a) Customers and demand, (b) Suppliers, (c) Manufacturing, (d) Distribution Centers, and (e) Transportation assumptions.

Inputs for a Refrigerators Manufacturing Company Case Study

Customers and demand

Following the "Pareto distribution" we assumed that 64% of the total demand comes from 4% of the total number of customers (Krogerus and Tschäppeler, 2012; Taylor, 2012). Thus, based on the actual geographical allocation of the company's 346 customers, we assumed that only 4% of them are major customers (14 customers), as presented in Table 1. Furthermore, using the level of total sales, we may determine the number of refrigerators sold in these major customers (64% of total sales volume amounts to 264,104 items). Note that the allocation of customers per wide geographical area is known from company information. This allocation was used to distribute the demand related to major customers, thus estimating the demand per customer (all models) for the first period of the planning horizon.

To do so, we have selected countries at random in each geographical area. Among these countries we have distributed the aforementioned demand in proportion to their GDP (World Bank, 2013). The location of each customer is presented in Table 2. In case multiple customers are located in the same country, the estimated volume for this particular country is distributed equally among the number of related customers. The total demand per customer is distributed among the four product families using a uniform distribution (Table 1).

Table 1 Geographical allocation of customers and their demand for one time period

Location	Number of customers	
	Actual number of customers	**4% of actual number of customers**
East Europe	163	7
West Europe	59	2
Asia	100	4
USA	24	1
Total number of customers	**346**	**14**
Total demand for one time period (items)	**384,538**	**264,104** *(64% of the total demand)*

Table 2 presents the detailed demand distribution of each customer. In order to estimate the demand for the remaining four years of the planning horizon, we have assumed that the company increases sales by 1.4% in Europe, 2.9% in USA and by 5.5% in Asia annually (Global Economic Outlook, 2015).

Table 2 Customers demand for 1st time period per product family (items)

Location	Product family	Customer id per geographical area 1	2	3	4	5	6	7
East Europe *(1=Athens, 2=Moscow, 3= Bucharest, 4=Milan, 5=Sofia, 6=Prague, 7=Zagreb)*	1	2,401	20,785	1,880	21,307	540	2,070	574
	2	1,000	8,660	783	8,878	225	862	239
	3	1,201	10,392	940	10,654	270	1,035	287
	4	750	6,495	587	6,659	169	647	179
West Europe *(1=Munich, 2=Rotterdam)*	1	15,104	3,565					
	2	6,293	1,485					
	3	7,552	1,782					
	4	4,720	1,114					
Asia *(1=Hong Kong, 2=Beijing 3=Hyderabad, 4=Istanbul)*	1	13,552	13,552	5,505	2,412			
	2	5,647	5,647	2,294	1,005			
	3	6,776	6,776	2,753	1,206			
	4	4,235	4,235	1,720	754			
USA *(1= Silver Spring-Maryland)*	1	7,156						
	2	2,982						
	3	3,578						
	4	2,236						
Total demand	**all**			**264,104**				

Procurement assumptions

According to the company's classification, raw materials are classified into six main families: (a) metals, (b) glass, (c) plastics, (d) refrigerants, (e) insulation, and (f) paint. The current supply chain network comprises 850 suppliers. Following the "Pareto distribution" we have assumed that 4% of them are strategic suppliers (35 suppliers). The number of suppliers for each continent (i.e. Europe, Asia and USA) and each raw material family is generated from a uniform distribution in the interval [1,4] ensuring that the total number of suppliers equals to 35 (Table 3).

Table 3 Allocation of 4% of suppliers per raw material family

Location	Number of suppliers per raw material's family: Metals	Glass	Plastics	Insulation	Paint	Refrigerants
Europe	3 (Brașov, Moscow, Distomo)	1 (Mainz)	4 (Târgu Mureș, Thiva, Dolný Ohaj, Moscow)	1 (Halle)	1 (Milan)	2 (Düsseldorf, Athens)
Asia	4 (Istanbul, Mumbai, Qingyuan, Dongguan)	4 (Chon Buri, Pune, Xingtai, Beijing)	1 (Istanbul)	1 (Istanbul)	1 (Tianjin)	3 (Tianjin, Cumhuriyet, Maharashtra)
USA	3 (Pompton Lakes-New Jersey, Bensalem-Pennsylvania, Hickory-Maryland)	1 (Morganton-North Carolina)	2 (Morganton-North Carolina, Edgewood-Illinois)	1 (Fort Belvoir-Virginia)	1 (Indian Head-Maryland)	1 (Fort Belvoir-Virginia)
Total number of suppliers			**35**			

To estimate the BoM of each product family, we considered: (a) the actual quantity purchased from each raw material family (expressed in kg). This is known from available company information. We used these quantities to determine the weight ratios of each material. (b) The actual weight corresponding to each product family. We used the ratios of (a) and the weight of (b) to estimate the weight of each raw material family in the BoM of each product family, as presented in Table 4.

Table 4 BoM per product family

Raw material family	Percentage distribution of raw material weight in BoM	Weight of raw material (kg) in BoM per product family			
		Product family 1	Product family 2	Product family 3	Product family 4
Metals	61.9	26.00	100.28	68.71	120.71
Glass	21.5	9.03	34.83	23.87	41.93
Plastics	7.0	2.94	11.34	7.77	13.65
Insulation	0.5	0.21	0.81	0.56	0.98
Paint	8.2	3.44	13.28	9.10	15.99
Refrigerants	0.9	0.38	1.46	1.00	1.76
Total	**100**	**42**	**162**	**111**	**195**

Regarding the procurement unit cost (in €/kg) per raw material family, this is estimated based on: (a) the actual product cost of each product family (in €), (b) assuming that the total cost of materials per product equals to almost 70% of the respective product cost, and (c) the actual BoM of each product family (in kg as presented in Table 4).

Specifically, in order to estimate the cost of raw materials (per raw material family) of each product family (see Table 5) we followed the following simple steps:

- We assumed the procurement unit cost per raw material family (inspired by public available databases i.e. IndexMundi, 2016; InfoMine, 2016).
- We multiplied the assumed procurement cost of each raw material family by the required weight in the BoM of each product family.
- We estimated the total procurement cost of each product family.
- If this total procurement cost was equal to almost 70% of the corresponding product cost, we stopped and used the related values. Otherwise, we repeated the estimation process by appropriately adjusting the assumed unit costs of raw materials.

Note that for suppliers in Asia, we have assumed 15% lower unit procurement costs.

Table 5 Procurement cost per raw material's family (€ per kg)

Location	Procurement cost per raw material's family ***(€ per kg)***					
	Metals	Glass	Plastics	Insulation	Paint	Refrigerants
Europe/USA	2.5	1.5	3.5	3	3.5	190
Asia	2.13	1.28	2.98	2.55	2.98	161.50

Plant establishment/expansion assumptions

The company currently operates eight plants that are located in: (a) Romania, (b) Russia, c) Greece, (d) Turkey, (e) India, (f) China, (g) Indonesia, and (j) USA. Inspired by Braglia *et al*. (2006) we have assumed that there are five production departments at each plant: metal department, glass department, plastics department, assembly department, and paint department

To determine the capacity of each department in each plant, we considered the known numbers of labor staff per plant (see Table 6). We scaled the latter to 64% of labor force. Subsequently, based on an assumed reasonable distribution of employees among the five departments (see Table 6) we evaluated the number of employees per department per plant. Finally we have estimated the capacity of each department using (1) below. The related estimates are presented in Table 6.

Department capacity per period (year) *(h)* = 1,760 *(h per employee-period)* · Number of employees per department (1)

Table 6 Number of employees and capacity of plant's departments related to each existing plant

Location	**Number of employees**		**Capacity of plant's departments (*h/year*)**				
	Actual total number of employees	**64% of actual employees**	**Metal (20%)**	**Glass (10%)**	**Plastic (15%)**	**Assembly (50%)**	**Paint (5%)**
Romania	770	493	174,240	86,240	130,240	434,720	44,000
Russia	840	538	190,080	95,040	142,560	473,440	47,520
Greece	349	224	79,200	38,720	59,840	197,120	19,360
Turkey	590	378	133,760	66,880	100,320	332,640	33,440
India	143	92	31,680	15,840	24,640	80,960	8,800
China	300	192	66,880	33,440	51,040	168,960	17,600
Indonesia	335	215	75,680	38,720	56,320	190,080	19,360
USA	125	80	28,160	14,080	21,120	70,400	7,040

To evaluate the approximate depreciation cost per period, we took under consideration: (a) the cost of assets, and (b) the actual depreciation cost per asset class of the company. Specifically, we evaluated the approximate depreciation cost per period applying the following formula (2):

Appr. depreciation cost per period *(€)* = Cost of assets *(€)*/ Beneficial life of fixed assets per asset class (2)

As a result, the total company depreciation cost per period equals to 27,713,442 €, as presented in Table 7.

Table 7 Estimated depreciation per period

Asset class	Actual beneficial life of fixed assets per asset class (*years*)	Actual cost of assets (€)	Approximated depreciation per period (€)
Land	40	9,668,000	241,700
Building & technical works	40	90,095,000	2,252,375
Machinery technical installation	15	327,723,000	21,848,200
Motor vehicles	6	6,005,000	1,000,833
Furniture & fixtures	6	14,222,000	2,370,333
Total		**447,713,000**	**27,713,442**

Applying the following formula (3), we estimated that the depreciation cost of each department equals to 4.6 euro per working hour.

Depreciation cost *(€/h)* = Approximated depreciation cost per year *(€)*/Capacity of all plants per year *(h)* (3)

Manufacturing assumptions

Inspired by Braglia *et al*. (2006), we have assumed that setup times per department (for all product families) are equal to: (a) 0.5, (b) 1, (c) 0.5, (d) 2 and (e) 0.5 hours per product batch, respectively. Moreover, we have assumed that the total production time per unit of each product family equals to: (a) 8, (b) 9, (c) 10, and (d) 11 in hours per refrigerator. The distribution of this total production time among the plant's departments follows the aforementioned distribution of employees in each plant's department. The results of this process are given in Table 8. Moreover, we have assumed that 100 setup operations are required during one time period (year).

Table 8 Production time per product family and plant department

Plant's Department	Production time (*h*)			
	Product family 1	Product family 2	Product family 3	Product family 4
Metal department	1.6	1.8	2	2.2
Glass department	0.8	0.9	1	1.1
Plastic department	1.2	1.35	1.5	1.65
Assembly department	4	4.5	5	5.5
Paint department	0.4	0.45	0.5	0.55
Total	**8**	**9**	**10**	**11**

We have assumed that the idle cost per hour is equal to the labor cost per hour. The actual value of the labor cost at each plant depends on its geographical location and has been adopted from Institut der Deutschen Wirtschaft (2010), and from Global-production Inc (2014). The setup and the production costs are calculated according to (4) and (5).

Setup cost*(€/unit)* = Setup time *(h/unit)* · Labor cost *(€/h)* (4)

Production cost *(€/unit)* = Production time *(h/unit)* · Labor cost *(€/h)* (5)

The resulting cost estimates are provided in Table 9.

Table 9 Idle, setup and production cost per plant

Location	Labor idle cost (€/h)	Setup cost (€ per batch)	Production cost (€ per unit)			
			Product family 1	Product family 2	Product family 3	Product family 4
Romania	3.39	15.3	27.1	30.5	33.9	37.3
Russia	3.61	16.2	28.9	32.5	36.1	39.7
Greece	16.44	74.0	131.5	148.0	164.4	180.8
Turkey	4.33	19.5	34.6	39.0	43.3	47.6
India	1.1	5.0	8.8	9.9	11.0	12.1
China	2.25	10.1	18.0	20.3	22.5	24.8
Indonesia	3.8	17.1	30.4	34.2	38.0	41.8
USA	22.95	103.3	183.6	206.6	229.5	252.5

Workforce management assumptions

Concerning workforce mobility issues, we have assumed that the severance compensation per employee equals to a half period's (year in this case) salary, and the hiring cost equals to three months' salary. It is worth mentioning that the salary per employee per year depends on the aforementioned labor cost of each plant (Table 9).

Warehousing and DC assumptions

We considered that the maximum useful storage capacity of the existing DC in the Czech Republic (Chomutov) equals to 6,000 m^2. In addition to the existing DC, we have assumed that there are three potential subcontracted DCs with unlimited capacity in: (a) Netherland-Amsterdam, (b) China-Hong Kong, (c) East Coast of USA-Pennsylvania. Furthermore, we have assumed that the minimum stock level of each product family equals to 15% of its annual demand. Note that each product family occupies different space in the DC according to the company's brochures, and thus each product family is related to different warehousing cost.

To evaluate the depreciation cost per unit of storage (expressed in units of area i.e. m^2) and time period, we have assumed that: (a) the construction cost of a warehouse in Chech Republic equals 960 €/m^2 (Ivanhoé Cambridge, 2014), and (b) the building depreciation rate per year reported in the company's financial statements (2.5%). The resulting depreciation cost equals 24 €/m^2/year.

The idle cost of the existing DC is estimated by assuming that: (a) 70 employees are required in a warehouse of an area of 10,000 m^2 (Schiller, 2008) and (b) the labor cost in a warehouse in Chech Republic equals 15,594 €/year (Grünig and Morschett, 2012). Multiplying the required number of employees per m^{2}per year by the labor cost per employee per year, the resulting idle labor cost equals 109 €/m^2/year. We also assumed the value of the idle infrastructure cost per unit of storage (expressed in units of area i.e. m^2) and time period. Finally, we estimated the severance and hiring cost as described previously.

Finally, we assumed that the insourcing warehousing cost equals to 24 €/m^2/year (excluding rent cost). This value may be much higher in certain environments. Secondly, we assumed that the outsourcing warehousing cost per year is 30% higher than the total insourcing warehousing cost (including rent cost). The resulting outsourcing inventory cost equals 62.4 €/m^2/year.

Transportation assumptions

We have assumed that there are four possible types of transport:

- Full Truck Load (FTL),
- Full Truck Load and Less than Train Load (FTL and LTL′),
- Full Truck Load and Full Container Load during sea transport (FTL and FCL),
- Full Truck Load, Less than Train Load and Full Container Load during sea transport (FTL, LTL′ and FCL).

These transport types are related to different transportation costs and lower bounds in terms of quantities transported (Table 10). As lower bound we defined the minimum load that can be transported (carried out) by each type of transport per each time period with a specific transportation cost.

The transportation capacity is typically limited by mass, volume, and area. We estimated and expressed the lower bounds: (a) in area units (i.e. m^2) for product families (see below), and (b) in mass units (i.e. kg) for raw material families.

To estimate the values of these lower bounds, firstly we assumed the following parameters related to a TEU: (a) the area of a common TEU equals about 15 m^2, (b) a truck may transfer one TEU, and (c) one train may transfer 75 TEUs (inpired by Kruk and Donner, 2009). Secondly, we assumed that: (a) an FTL shipment is defined to be the load that fills up an entire truck that is used once per month (i.e.1 TEU · 15 m^2/TEU/month · 12 months/year = 180 m^2/year), (b) an FTL′ shipment is defined to be the load that fills up an entire train used once per month (i.e. 75 TEU · 15 m^2/TEU/month · 12 months/year = 13,500 m^2/year, and (c) a FCL shipment means that the load will fill up an entire ship container per month (i.e.1 TEU · 15 m^2/TEU · month · 12 months/year = 180 m^2/year). Based on the aforementioned assumptions, the lower bounds for each type of transport are presented in Table 10.

The transportation cost of each type of transport (see Table 10) has been inspired by "Statistical coverage and economic analysis of the logistics sector in the EU-SEALS" project, European Commission, DG Energy and Transport (Meyer-Rühle *et al*., 2008). In order to convert the aforementioned unit of transport cost from € per TEU-km to € per product-km, we considered the maximum number of products that can be carried in one m^2 for each product family is: (a) 3, (b) 1, (c) 2 and (d) 1 products/m^2, respectively. Also, the maximum quantity of each raw material that can be carried in one m^2 equals to 600kg.

Table 10 Transportation cost and lower load bound per type of transport

Type of transportation	Transportation cost of products (*€ per TEU-km*)	Transportation Cost of raw materials (*€ per kg-km*)	Lower bound of products (m^2)	Lower bound of raw materials (*kg*)
FTL truck	0.80	0.000089	180	9,000
			(one TEU per month→one truck)	
FTL truck and FTL′ rail	0.70	0.000078	13,500	675,000
			(75 TEUs per month→one train)	
FTL truck and FCL sea	0.20	0.000022	180	9,000
			(one TEU per month→one truck)	
FTL truck, FTL′ rail and FCL sea	0.18	0.000020	13,500	675,000
			(75 TEUs per month→one train)	

Conclusion

In this work, we have described all the actual parameter values and necessary assumptions in order to investigate the strategic design supply chain network of a world-class commercial refrigerator manufacturer applying the proposed mathematical model.

Taking into account the real data and the aforementioned assumptions, the structure of multiechelon supply chain network under study is illustrated in the following Figure 1 and consists of 35 suppliers, 8 existing plants, 1 existing DC and 3 possible outsourcing DCs, 14 final customers and 4 possible types of transportation.

Figure 1 Structure of the supply chain network under study of a word-class commercial refrigerator manufacturer

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