Supply Chain Analytics (42380)
Project: Flexibility and resilience in network design

Group size	4–6
Hand-in date	Wednesday 30 March
Hand-in format	Detailed report in PDF addressing all questions thoroughly, plus the corresponding Julia files

Assessment of this assignment will be based on **individualization**. Read more about this here on DTU Inside (scroll down to *Group projects*): `https://www.inside.dtu.dk/en/undervisning/regler/regler-for-eksamen/eksamensformer`

In particular, DTU requires the following for individualization:

> *For group projects/group assignments, where individualization is required, students' individual contributions must be clearly distinguishable in regards to the chapters and sections in the assignment.*
>
> *If the project states that the assignment overall has been prepared jointly, this will not fulfill the requirement for individualization.*

Your individual grade will thus be based on the sections of the report that you were responsible for. Therefore, **please clearly state** on the front page of the report with section(s) each student was responsible for.

The assignment continues on the next page.

Read the following case study, which appears in Chopra & Meindl, *SCM Strategy, Planning and Operation*, Chapter 5, and the answer the questions that follow (ignore the "Study questions" below).

CASE STUDY

Managing Growth at SportStuff.com

In December 2008, Sanjay Gupta and his management team were busy evaluating the performance at SportStuff.com over the previous year. Demand had grown by 80 percent. This growth, however, was a mixed blessing. The venture capitalists supporting the company were very pleased with the growth in sales and the resulting increase in revenue. Sanjay and his team, however, could clearly see that costs would grow faster than revenues if demand continued to grow and the supply chain network was not redesigned. They decided to analyze the performance of the current network to see how it could be redesigned to best cope with the rapid growth anticipated over the next three years.

SportStuff.com

Sanjay Gupta founded SportStuff.com in 2004 with a mission of supplying parents with more affordable sports equipment for their children. Parents complained about having to discard expensive skates, skis, jackets, and shoes because children outgrew them rapidly. Sanjay's initial plan was for the company to purchase used equipment and jackets from families and surplus equipment from manufacturers and retailers and sell these over the Internet. The idea was well received in the marketplace, demand grew rapidly, and, by the end of 2004, the company had sales of $0.8 million. By this time, a variety of new and used products were being sold, and the company received significant venture capital support.

In June 2004, Sanjay leased part of a warehouse in the outskirts of St. Louis to manage the large amount of product being sold. Suppliers sent their product to the warehouse. Customer orders were packed and shipped by UPS from there. As demand grew, SportStuff.com leased more space within the warehouse. By 2007, SportStuff.com leased the entire warehouse and orders were being shipped to customers all over the United States. Management divided the United States into six customer zones for planning purposes. Demand from each customer zone in 2007 was as shown in Table 5-15. Sanjay estimated that the next three years would see a growth rate of about 80 percent per year, after which demand would level off.

The Network Options

Sanjay and his management team could see that they needed more warehouse space to cope with the anticipated growth. One option was to lease more warehouse space in St. Louis itself. Other options included leasing warehouses all over the country. Leasing a warehouse involved fixed costs based on the size of the warehouse and variable costs that depended on the quantity shipped through the warehouse. Four potential locations for warehouses were identified in Denver, Seattle, Atlanta, and Philadelphia. Leased warehouses could be either small (about 100,000 sq. ft.) or large (200,000 sq. ft.). Small warehouses could handle a flow of up to 2 million units per year, whereas large warehouses could handle a flow of up to 4 million units per year. The current warehouse in St. Louis was small. The fixed and variable costs of small and large warehouses in different locations are shown in Table 5-16.

Sanjay estimated that the inventory holding costs at a warehouse (excluding warehouse expense) was about $600\sqrt{F}$, where F is the number of units flowing through the warehouse per year. This relationship is based on the theoretical observation that the inventory held at a facility (not across the network) is proportional to the square root of the throughput through the facility. As a result, aggregating throughput through a few facilities reduces the inventory held as compared with disaggregating throughput through many facilities. Thus, a warehouse handling 1 million units per year incurred an inventory holding cost of $600,000 in the course of the year. If your version of Excel has problems solving the

TABLE 5-15 Regional Demand at SportStuff.com for 2007

Zone	Demand in 2007	Zone	Demand in 2007
Northwest	320,000	Lower Midwest	220,000
Southwest	200,000	Northeast	350,000
Upper Midwest	160,000	Southeast	175,000

TABLE 5-16 Fixed and Variable Costs of Potential Warehouses

Location	Small Warehouse Fixed Cost ($/year)	Small Warehouse Variable Cost ($/Unit Flow)	Large Warehouse Fixed Cost ($/year)	Large Warehouse Variable Cost ($/Unit Flow)
Seattle	300,000	0.20	500,000	0.20
Denver	250,000	0.20	420,000	0.20
St. Louis	220,000	0.20	375,000	0.20
Atlanta	220,000	0.20	375,000	0.20
Philadelphia	240,000	0.20	400,000	0.20

nonlinear objective function, use the following inventory costs:

Range of F	Inventory Cost
0–2 million	$250,000Y + 0.310F$
2–4 million	$530,000Y + 0.170F$
4–6 million	$678,000Y + 0.133F$
More than 6 million	$798,000Y + 0.113F$

If you can handle only a single linear inventory cost, you should use $\$475{,}000Y + 0.165F$. For each facility, $Y = 1$ if the facility is used, 0 otherwise.

SportStuff.com charged a flat fee of $3 per shipment sent to a customer. An average customer order contained four units. SportStuff.com, in turn, contracted with UPS to handle all its outbound shipments. UPS charges were based on both the origin and the destination of the shipment and are shown in Table 5-17. Management estimated that inbound transportation costs for shipments from suppliers were likely to remain unchanged, no matter what warehouse configuration was selected.

Study Questions

1. What is the cost SportStuff.com incurs if all warehouses leased are in St. Louis?
2. What supply chain network configuration do you recommend for SportStuff.com? Why?
3. How would your recommendation change if transportation costs were twice those shown in Table 5-17?

TABLE 5-17 UPS Charges per Shipment (Four Units)

	Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast
Seattle	$2.00	$2.50	$3.50	$4.00	$5.00	$5.50
Denver	$2.50	$2.50	$2.50	$3.00	$4.00	$4.50
St. Louis	$3.50	$3.50	$2.50	$2.50	$3.00	$3.50
Atlanta	$4.00	$4.00	$3.00	$2.50	$3.00	$2.50
Philadelphia	$4.50	$5.00	$3.00	$3.50	$2.50	$4.00

Additional assumptions

- Use the formula $\$475{,}000Y + 0.165F$ (as mentioned in the text) to calculate inventory cost.
- Assume that the lease for any warehouse is fixed for 3 years. So if you lease a warehouse in 2008, for instance, you also have to lease it in 2009 and 2010 and pay the corresponding fixed and variable costs.

Part 1: Network Design Model

1. Write down a mathematical optimization model for solving the network design problem described in the case study for the period 2007–2011. Clearly state what are the decision variables, constraints and objective function.
2. Implement and solve the model in, for example, Julia (you may also use other optimization software)
3. Report on the solution to the model. Which DCs are leased? Which regions are served by which DCs? What is the total cost? Etc.

Part 2: Flexibility

Consider the following two types of increased flexibility in the lease agreements:

- The lease is fixed for one year only, instead of two.
- It is not necessary to lease the entire warehouse, but only part of it as needed.

1. Adapt the mathematical model from Part 1 as needed to include the above flexibility. State how the decision variables, constraints and objective function change, where relevant.
2. Implement and solve the model in, for example, Julia (you may also use other optimization software)
3. Report on the solution to the model. In particular, what is the difference with the solution found in Part 1? What is the explanation for this difference?

Part 3: Resilience

Return to the model from Part 1 before flexibility was added. In this part you will investigate the resilience of the network design against significant deviations from what is expected. In particular, you should investigate situations where (a) demand is much larger than initially forecasted and where (b) warehouse capacity is much less than initially agree upon.

A scenario-based approach should be followed as studied in class, using either stochastic or robust optimization. For this you need to develop your own scenarios based on assumptions on what can change in terms of demand and capacity.

1. Adapt the mathematical model from Part 1 as needed into either a stochastic or robust optimization model based on your scenarios. State how the decision variables, constraints and objective function change, where relevant. In particular, make a distinction between first-stage and second-stage decisions.
2. Implement and solve the model in, for example, Julia (you may also use other optimization software)
3. Report on the solution to the model. In particular, what is the difference with the solution found in Part 1? What is the explanation for this difference?

Part 4: Flexibility + Resilience

As the title suggests, combine the modelling aspects of Parts 2 & 3 in order to take into account both the two types of flexibility proposed in Part 2 and the scenarios developed in Part 3.

1. Write down the new mathematical model, as before stating how the decision variables, constraints and objective function change. Again, make a distinction between first-stage and second-stage decisions.
2. Implement and solve the model in, for example, Julia (you may also use other optimization software)
3. Report on the solution to the model. What is the difference with the solution found in Parts 2 & 3? What is the explanation for this difference?