Supply Chain Analysis HW #1

1. Summarize, in your own words, what mathematical modeling and what operations research is. Connect them to the supply chain. How are they useful?

Mathematical modeling. The *Introduction to Management Science* textbook by Hillier and Hillier defines a mathematical model as “an approximate representation of, for example, a business problem that is expressed in terms of mathematical symbols and expressions”. To expand on that, it is the use of mathematical formulas to make sense of data derived from sampling and other measurements from real world systems or simulations.

Operations research, aka Management Science, is the scientific study of operations. Data is collected and analyzed to create mathematical models to understand past trends, simulate alternative scenarios and/or forecast future outcomes with the goals of informing and improving the effectiveness of decision makers.

These concepts apply to supply chain in a variety of ways. Supply chain is the management of the production and flow of goods from the point of origin to the end consumer (and beyond when reverse logistics and the circular economy are taken into account). SCM uses data analytics in mathematical modeling and other operations research tools to identify means to optimize supply chain and logistical processes and improve operations.

2. Read Selected Reference A8 that describes an OR study done for the Rijkswaterstaat of the Netherlands. (Focus especially on pp. 3–20 and 30–32.)

    a. Summarize the background that led to undertaking this study.

The OR study, called the PAWN (Policy Analysis for the Water-Management of the Netherlands) Project, done for the Rijkswaterstaat was undertaken as a means to improve the Dutch government’s water management in the wake of a major drought. The situation was exacerbated by the unique geography of the Netherlands’ complex network of dikes, canals, water storage reservoirs and salt-water coastlines (Goeller 4).

The Rijkswaterstaat needed to manage and balance water use across a variety of industries, such as agriculture, drinking water, manufacturing and mining companies. Considerations were also given for managing water levels in shipping lanes (if the water got too low due to allocations elsewhere, certain channels became unnavigable), water salinity, industrial discharges and dead organic matter which can contribute to toxic algae blooms.

b. Summarize the purpose of each of the five mathematical models described on pp. 10–18.

Water Distribution Model – this model concerns the water system infrastructure consisting of rivers, canals, lakes and reservoirs, and the mechanisms involved for storing and transporting water throughout the Netherlands. With national and regional components broken up between 77 districts, this network model includes 92 nodes, which are connections between waterways, or places where water is stored, and 154 links, or individual waterway sections (Goeller 10).

The Water Distribution Model accounts for water entering and exiting the network, including through rainfall, drainage into rivers and streams, and consumption through one of the water-use categories such as for agricultural use across the various districts. This data is then used to inform water-use policy to better balance water demands across the different sectors, and which water resources are better allocated to those uses.

Information is aggregated from 10-day periods, with a system of linear equations used to represent the water balance at each node. The equation use variables to represent flows in the links, coefficients to represent water management facilities, and constants to represent water demands such as extraction, discharges and maintaining the water level. When certain constraints are violated as indicated by data gathered and used in these equations, water management rules are invoked to make adjustments until those constraints are again met (11-12).

Finally, this model also calculates the impacts of pollutants and heat on the water supply, financial impacts on the agricultural and shipping sectors as compared to idealized situations and conditions, and the investment and operating costs of maintaining policy through use of this system.

Industry Response Simulation Model – this model takes into account price and regulation strategies to allocate and conserve groundwater for industrial use. The model considers taxes and quotas on groundwater extraction per district. These policies prompt firms to adjust their production processes to use less water, with any associated price increases passed on to the consumer, meaning that there is also a larger economic impact to consider if this tool is used too heavily.

Electric Power Reallocation and Cost Model – this model uses linear programming optimization to calculate a power generation schedule for the conditions of relaxed thermal standards and strict thermal standards. The constraints used in this model are:

- Power production per unit cannot exceed maximum capacity
- Power demand in each region must be met
- Amount of power transmitted across regions must not exceed grid capacity
- Each network node's thermal standards must also be met (Goeller 16)

The thermal results of this model are fed back into the Water Distribution Model.

The Nutrient Model – pollution, fertilizer in groundwater runoff and water stagnation all contribute to algae blooms, a major water quality issue in the Netherlands. This model works in conjunction with the Algae Bloom Model (below) to help address this issue. The Nutrient Model feeds data into the Algae Bloom Model with estimates of nutrient concentrations available in the water such as phosphates, nitrogen and silicon, all of which are known to contribute to algal growth.

The Nutrient Model is based on the laws of chemical thermodynamics for a body of water in a certain state of equilibrium. With the goal of minimizing the Gibbs free energy subject to mass balance equations as determined by the chemical species present in the water (Goeller 17).

The Algae Bloom Model – In conjunction with the Nutrient Model, the Algae Bloom Model monitors algae blooms and how they are effected by control tactics. It calculates maximum algal bloom given environmental conditions (weather, nutrient availability) using linear programming. Light availability is calculated based on light intensity at the water's surface, absorption per meter of water depth, and overall depth of the water. The model also accounts for the size of the bloom, the algae species present, and factors that limit bloom growth (Goeller 17-18).

c. Summarize the “impact measures” (measures of performance) for comparing policies that are described on pp. 6–7 of this article.

The impact measures for comparing policies were used by PAWN to assess the consequences of policy actions as determined or advocated by various interest groups. This was important for this kind of study because the stakeholders includes a broad cross-section of Dutch society and industry. By choosing such a comprehensive selection of impact measures, PAWN was able to allow the different groups to assess how the policy would affect their interests and objectives.

The impacts presented included investment and operating costs of adopting the policies prescribed; environmental impacts such as water quality, flood risks at certain fresh water storage basins and ecological effects; and the financial impacts (in terms of cost and profit, revenue and expenditure for each user group).

All of this is aggregated to national level impacts such as net monetary impact on the Netherlands' GDP and factors such as the trade balance, employment, and health of industries affected. The model attempts to track the distribution of water resources both in regard to direct use and economic benefit or impact across user groups such as consumers, producers and the government. This is done in the spirit of both equity and efficiency.

d. List the various tangible and intangible benefits that resulted from the study.

The benefits are outlined in **The Impact of PAWN** section of the paper:

Tangible Benefits:

1. Based on the study, it was determined that investment in the Brielse Meer pipeline would be more advantageous than the Waddinxveen-Voorburg Canal. Infrastructure spending was shifted as a result, saving an estimated $38 million of investment and providing a “$15 million per year average net benefit in reduced salinity damage to agriculture” (Goeller 30).

2. Another infrastructure project, an additional Oostvaarders Dike, was rejected because the costs were greater than the benefits. $95 million (or 0.2% of Dutch GDP) of investment cost was saved as a result.

3. A new policy for flushing the Markermeer reservoir was devised and implemented, which at the time was expected to yield between $1.2 - $5.4 million per year.

4. A stricter thermal standard was adopted, limiting allowable temperature increase due to industrial activity to within 3º Celsius. This was shown to be practical and not very costly, but also enough to minimize ecological effects of heat discharge.

Intangible Benefits:

1. The Dutch government has changed its approach to managing eutrophication, which is their most serious water quality challenge. The previous policy of controlling phosphate levels would be ineffective by itself. Complementary measures were added to the policy. In addition, the original model that PAWN produced is under constant review and updating to actively improve such policies.

2. The Nota Waterhuishouding (the national water policy document drafted by the Rijkswaterstaat using the PAWN study and framework) formally recommended that PAWN tactics identified as being promising be seriously considered for water management plans in development. This was expected to produce profits of $58 - $128 million per year.

3. Because of limitations in groundwater extraction, priority was given to industry and drinking water companies. This would reduce groundwater sprinkling until more practical methods of groundwater replenishment can be devised.

4. The comprehensive methodologies that PAWN developed have been adopted for use by the Rijkswaterstaat, the Delft Hydraulics Laboratory and other organizations for major water-use studies.

5. PAWN has provided a thoroughly written and documented case study for use in educating policy makers and analysts about complex natural resource and environmental questions. With data modifications, the models are also transferable to other countries.

6. The approach that PAWN used, and tools it developed such as the scorecard, are useful for a wide variety of additional applications. The paper offers the examples of the Rand Corporation's application of these tools in a study of Middle East military strategy, and Delft Hydraulics' use of the approach in master planning for Taiwanese waterways, and shore protection in parts of Italy and the Netherlands.

3. Read pp. 603–617 of Selected Reference 3

    a. What does the author say about whether a model can be completely validated?

On pages 609-610, the author describes validation as testing "the agreement between the behavior of the model and the real world system being modeled". While validation is a top concern for decision aiding models, any model that has unknown factors (such as future predictions) cannot be entirely validated. In fact, the paper quotes a 1980 paper by Quade as saying "'A particularly dangerous myth is the belief that a policy model can be fully validated-that is, proved correct. Such models can, at best, be invalidated.'"

This is actually in line with the scientific method: you test the model by changing one variable at a time to try to invalidate the model. If none of the invalidation attempts succeed, at least under certain conditions, then you can have a high degree of confidence in the model as well as a thorough understanding of the strengths, weaknesses and limitations of the model.

    b. Summarize the distinctions made between model validity, data validity, logical/mathematical validity, predictive validity, operational validity, and dynamic validity.

Model validity – "validation of a model attempts to establish how closely the model mirrors the perceived reality for the model user/developer team (Gass 611)." As mentioned above, a model cannot be entirely validated, but the more evidence it has in its favor, the higher the level of confidence in that model. The paper goes on to list these concepts as especially applicable to validating new (untested) models:

1. Face validity or expert opinion. Does the model seem credible to an experienced decision maker?

2. Variable-parameter validity or sensitivity analysis. How does the model stand up to changing data? How does it compare to the real world.

3. Hypothesis validity. Do subsystem models interact the way that their real-world counterparts would?

Data validity – models of real world systems can be tested using actual data. Raw and unstructured data are taken from measurements of real systems. The raw data is valid if it withstands tests of accuracy, impartiality, and representativeness. Structured data is valid if each step of the manipulation of that data is properly reviewed and documented.

Logical/Mathematical validity – this component of model validity is an evaluation of the model's ability to produce solutions using a numerical or even computerized process. Model verification of this type includes these aspects:

1. determining the correctness and accuracy of the calculations.

2. Analyzing the logic flow and intermediate results for correctness.

3. Ensuring that all variables and relationships have been taken into account.

Predictive validity – this is monitoring for erroneous outcomes of the model when compared to real world data. This means looking for the magnitude of error (accuracy/precision), the reasons for the error (often due to flaws in the calculations or processes in the intermediate steps), and if the erroneous results can be corrected. This will inform areas of concern in using the model.

Operational validity – this is based on evaluation of the importance of the errors detected during assessments of technical validity. Because there is always some level of error in a model, a decision needs to be made based on an analysis of the information produced from the model and its representation of the real system it is emulating. Operational validity must also be assessed by whether the results are acceptable in the context being considered, and with use of a cost-benefit analysis if adopted.

Dynamic validity – this part of the validation framework considers if the model can be maintained during its life cycle, and if it can remain relevant as a model of real systems during that period. While a model of gravity may be able to stand the test of time, a model of automobile manufacturing will be liable to change frequently over time as technology enables new forms of automation and changes in vehicle design. As a result, the model must be kept up with regular updating and review, as well as with further consideration for when it may become obsolete.

c. Describe the role of sensitivity analysis in testing the operational validity of a model.

Sensitivity analysis is the practice of systematically altering the values of the model parameters over some range of interest (for example, if there is concern that some assumed conditions may change, such as market values or policy changes). This is done by varying one parameter at a time to extreme values to see what outcomes will result.

This is important in testing the operational validity of a model because it is important to know the kinds of changes the altered parameters could effect, and the magnitudes involved. This can aid in improving the model outcomes and if the model is implemented, help decision makers to know the limitations of the model.

d. What does the author say about whether there is a validation methodology that is appropriate for all models?

The author states plainly that “there is no validation methodology appropriate for all models” (Gass 615). This is because we can never assume that absolutely all model alternatives have been considered, only those alternatives that anyone on the team was able to think of during the study. Further, there is no real data about the alternatives that were not considered.

e. Cite the page in the article that lists basic validation steps.

In spite of what is said in the previous answer, the Gass lists in this article some basic validation steps on page 616 as provided by Emshoff and Sisson:

1. The analyst assures himself that the model performs the way he intends it to; using test data, and if available, real historical data.

2. Reasonableness is checked by:
   a) showing that key subsystem models predict their part of the world well (using historical data);

   b) showing that… the parameters have reasonable values;

   c) having people who are knowledgeable about the situation (preferably including the decision maker) review the model in detail and agree to its structure and parameters.

3. The decision maker has an opportunity to explore the use of the model to become familiar with its predictions and to examine the interactions it implies. At this point, the analysts and decision maker may be able to agree as to what is a close enough fit between model output and actual data.

4. The model is used for decision-aiding. Careful records are kept of its predictions and of actual results. This may involve a time span of years, meaning it is important for the evaluation procedure to be set up carefully with the time spans in mind.