MCM: The Mathematical Contest in Modeling
ICM: The Interdisciplinary Contest in Modeling

2015 MCM Problems

PROBLEM A: Eradicating Ebola

The world medical association has announced that their new medication could stop Ebola and cure patients whose disease is not advanced. Build a realistic, sensible, and useful model that considers not only the spread of the disease, the quantity of the medicine needed, possible feasible delivery systems (sending the medicine to where it is needed), (geographical) locations of delivery, speed of manufacturing of the vaccine or drug, but also any other critical factors your team considers necessary as part of the model to optimize the eradication of **Ebola**, or at least its current strain. In addition to your modeling approach for the contest, prepare a 1-2 page non-technical letter for the world medical association to use in their announcement.

PROBLEM B: Searching for a lost plane

Recall the lost Malaysian flight MH370. Build a generic mathematical model that could assist "searchers" in planning a useful search for a lost plane feared to have crashed in open water such as the Atlantic, Pacific, Indian, Southern, or Arctic Ocean while flying from Point A to Point B. Assume that there are no signals from the downed plane. Your model should recognize that there are many different types of planes for which we might be searching and that there are many different types of search planes, often using different electronics or sensors. Additionally, prepare a 1-2 page non-technical paper for the airlines to use in their press conferences concerning their plan for future searches.

2015 ICM
Problem C

Managing Human Capital in Organizations

Building an organization filled with good, talented, well-trained people is one of the keys to success. But to do this, an organization needs to do more than recruit and hire the best candidates – they also need to retain good people, keep them properly trained and placed in proper positions, and eventually target new hires to replace those leaving the organization. Individuals play unique roles within their organizations, both formally and informally. Thus, the departure of individuals from an organization leaves important informational and functional components missing that need to be replaced. This is true for sports teams, commercial companies, schools and universities, governments, and almost any formal group or organization of people.

Human resource (HR) specialists help senior leadership manage personnel by improving retention and motivation, coordinating training, and building good teams. In particular, leaders seek to create an effective organizational structure, where people are assigned to positions appropriate to their talents and experience, and where efficient communication systems are in place to facilitate development of innovative ideas and quality products (commodities or services). These talent management and team building aspects of HR management are remaking many modern organizations.

Managing the fluid network of human capital within an organization requires understanding personnel loyalties to the company and to subgroups; building trust in the workplace; and managing the formation, dissolution and retention of formal and informal ties between people. When people leaving for other jobs or retiring are replaced, the resulting turbulence is collectively termed organizational “churn”. Your team has been asked by your HR manager to develop a framework and model for understanding churn within the Information Cooperative Manufacturing (ICM) organization of 370 people. ICM is in a highly competitive market place, leading to challenging issues related to effectively managing its human capital.

The HR manager wants to map the human capital in the organization by building a network model. Here are some issues your company faces:

1. ICM aims to identify the risk of churn in its early stages, as it is cheaper to gain the loyalty of an employee early in their carreer rather than have to improve the culture once it has soured. It is more productive to have a motivated workforce from the start rather than having to provide incentives to prevent people from leaving.

2. A worker is more likely to churn if he or she was connected to other former employees who have churned. Thus churn seems to diffuse from employee to employee, so identifying those that are likely to churn is valuable information to prevent further churning.

3. One HR issue is matching employees to the right position such that their knowledge and abilities can be maximized. Currently each employee gets an annual evaluation based on performance as judged by the supervisor. These ratings are currently not used by the HR office.

4. ICM recognizes that middle managers (Junior Managers, Experienced Supervisors, Inexperienced Supervisors) often feel stuck in their jobs with little opportunity to advance, causing them to leave the company when they find a comparable or better job. These mid-level positions are critical ones that unfortunately suffer high turn-over (twice the average rate of the rest of the company) and seem to need filling all the time.

5. Recruiting good people is difficult, time consuming and expensive. ICM usually has only 85% of its 370 positions filled at any time and, because of administrative delays and office capacity and internal promotions, the HR office is actively hiring about 8-10% of the ICM positions (about 2/3 of the current vacancies).

6. In order to move up into the higher management-level positions, people are currently required to have several years of experience in the company at specific levels and types of positions. This can pose major obstacles for the HR department.

7. The churn rate has been increasing steadily, especially for middle managers. The ICM HR manager sees this as the biggest challenge the company faces. The CEO panicked when hearing that the current churn rate is 18% per year.

8. Because ICM is always worried about being short-handed, marginal and poor employees are allowed to stay on in an attempt to lower the churn and, therefore, very few employees are relieved or fired. This results in lower quality employees who often stay with the company for a full career. This quality issue is causing concern with the management, but no one seems to have a solution.

9. Your organization is proud of its modest CEO-to-worker salary ratio (i.e., the CEO salary is approximately 10 times the median of the salaries of all the employees in the organization as compared to hundreds of times the median as found in many companies).

The ICM HR manager has recently put together a comprehensive organizational graph (Figure 1) and detailed statistics describing the basic structure, staffing, recruiting costs, training costs, and salaries of the company employees (Table 1). The company has never conducted any analyses, modeling or simulation of the HR functions of the company. Therefore, she feels that now is the time to automate and analyze the HR elements of ICM using network science.

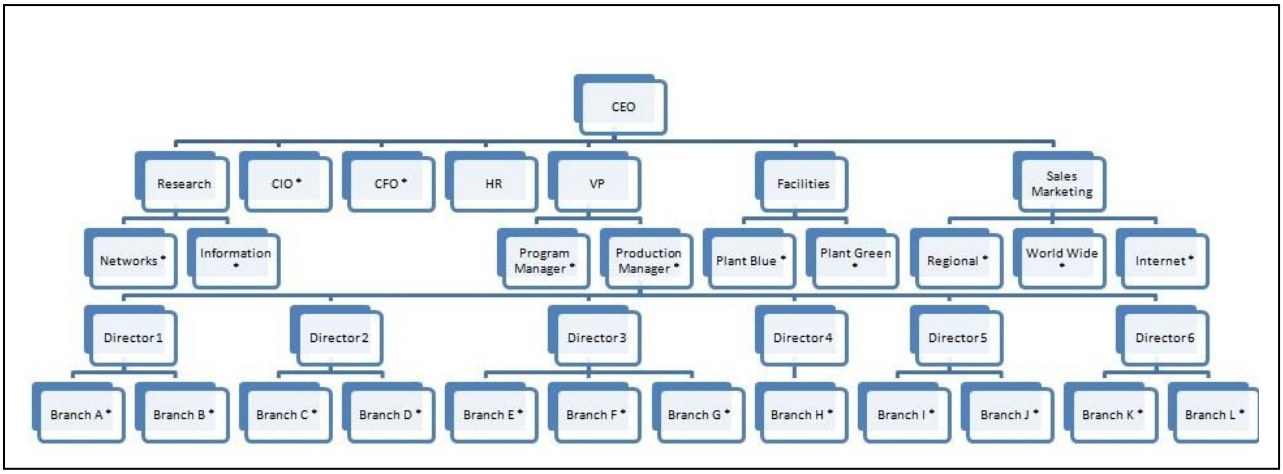

Figure 1: The rigid structure and supervisory nature of ICM comes from the requirement that each branch or staff office with an * consists of two divisions of 7 people. Otherwise, each entry in this chart without an * consists of 4 staff people. Therefore, the 370 total employees are organized in 46 divisions of 7 people and 12 offices of 4 people.

Level of Position	Median time to recruit (months)	Median cost of recruitment ($)	Number of Employees at this level	Average annual salary rate for this level ($)	Average annual training cost ($)
Senior manager/Executive	7	1.2 σ	10	8 σ	0.5 σ
Junior manager/Executive	6	0.7 σ	20	4 σ	0.6 σ
Experienced supervisor (Branch)	5	0.6 σ	25	2 σ	0.2 σ
Inexperienced supervisor (Division)	4	0.6 σ	25	1.5 σ	0.3 σ
Experienced employee	3	0.3 σ	110	σ	0.1 σ
Inexperienced employee	1	0.1 σ	150	0.9 σ	0.3 σ
Administrative clerk	2	0.3 σ	30	0.9 σ	0.05 σ

Table 1: The HR manager has provided you with this critical HR data on number and level of employees, average salary, the average costs and time of external recruitment for various levels of personnel, and annual training costs. The median income of the company is defined as σ. The value of σ for ICM does rise slowly with the inflation rate so all the decision makers in ICM are comfortable with reports and decisions based on the changing and relative value of σ, instead of exact monetary values.

Tasks:

The ICM HR department work-tasks and research questions from your HR manager include the following:

1) Build a Human Capital network model of ICM organization's personnel situation using the data provided. You may have to make bold assumptions to build the model — be sure to describe the model and your assumptions.

2) Use your model to identify dynamic processes within the Human Capital network. Describe and incorporate dynamic processes involved in (1) organizational churn (e.g., influence, dissatisfaction) and (2) direct and indirect effects on the organization's productivity. You may have to make some bold assumptions to explain these processes. Describe your model and all your assumptions.

3) Use your model to analyze your organization's budget requirements for talent management in terms of σ for both recruiting and training over the next 2 years.

4) Can ICM sustain its 80% full status for positions if the annual churn rate for all positions goes to 25%? How about 35%? What are the costs of these higher turnover rates? What are the indirect effects of these high churn rates?

5) The ICM HR supervisor wants to use your model to simulate the impact of 30% churn in both junior managers and experienced supervisors with 1) no external recruiting and 2) promoting only qualified employees for the next two years. Other churn values should remain at 18% in your model. Explain to her the impact of that situation on the HR health of the organization.

6) Your supervisor calls this kind of talent management — team science. She has provided you with these references to start your work:

   - E. Salas, N.J. Cooke, and M.A. Rosen. (2008). On Teams, Teamwork, and Team Performance: Discoveries and Developments. *Human Factors: The Journal of the Human Factors and Ergonomics Society* June 2008 vol. 50 no. 3 540-547.

   - D. Stokols, K.L. Hall, B.K. Taylor, R.P. Moser (2008). The Science of Team Science: Overview of the Field and Introduction to the Supplement, *Am J Prev Med* 2008;35(2S): S77-S89.

Ultimately, she wants to connect your Human Capital network to other organizational network layers such as information flow, trust, influence, and friendship that the other offices of ICM are considering building. The HR manager's vision is that the HR office should take the lead in this effort to connect the network models of the organization and wants your team to consider how that could happen. For that consideration she provides the reference

- Mikko Kivelä, Alexandre Arenas, Marc Barthelemy, James P. Gleeson, Yamir Moreno, Mason A. Porter. (2013). Multilayer Networks, *J. Complex Netw*orks, 2(3): 203-271 (2014); *arXiv preprint arXiv:1309.7233*, 2013.

Summarize the potential use of team science and multi-layered networks in fulfilling the vision of your HR manager.

7) Write a 20-page report on your organizational model and its function and the issues that the supervisor wants you to consider. The one-page executive summary of the report does not count; therefore, you can submit a total of 21 pages, maximum.

2015 ICM
Problem D

Is it sustainable?

Problem background

One of the largest challenges of our time is how to manage increasing population and consumption with the earth's finite resources. How can we do this while at the same time increasing equity and eradicating poverty? Since the beginning of the modern environmental movement in the 1960's, balancing human needs with the earth's health has been a topic of considerable debate. Are economic development and ecosystem health at odds? In order to reconcile this difficult balance, the concept of sustainable development was introduced in the 1980's.

Sustainable development is defined by the 1987 Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Since its conception, sustainable development has become a goal for international aid agencies, planners, governments, and non-profit organizations. Despite this, striving towards a sustainable future has never been more imperative. The United Nations (UN) predicts the world's population will level at 9 billion people by 2050. This, coupled with increased consumption, places a significant strain on the earth's finite resources. Understanding that the earth is a system that connects both time and space is critical to sustainable development. Development must focus on needs (e.g., reducing the vulnerability of the world's poor) and limitations (e.g., the environment's ability to detoxify wastes). In 2012, the UN conference on sustainable development recognized that: "that poverty eradication, changing unsustainable and promoting sustainable patterns of consumption and production and protecting and managing the natural resource base of economic and social development are the overarching objectives of and essential requirements for sustainable development." Decreasing personal poverty and vulnerability, encouraging economic development, and maintaining ecosystem health are the pillars of sustainable development.

Problem statement

The International Conglomerate of Money (ICM) has hired you to help them use their extensive financial resources and influence to create a more sustainable world. They are particularly interested in developing countries, where they believe they can see the greatest results of their investments.

Task 1: Develop a model for the sustainability of a country. This model should provide a measure to distinguish more sustainable countries and policies from less sustainable ones. It can also serve to inform the ICM on those countries that need the most support and intervention. Some factors may include human health, food security, access to clean water, local environmental quality, energy

access, livelihoods, community vulnerability, and equitable sustainable development. Your model should clearly define when and how a county is sustainable or unsustainable.

Task 2: Select a country from the United Nations list of the 48 Least Developed Countries (LDC) list (http://unctad.org/en/pages/aldc/Least%20Developed%20Countries/UN-list-of-Least-Developed-Countries.aspx). Using your model and research from Task 1, create a 20 year sustainable development plan for your selected LDC country to move towards a more sustainable future. This plan should consist of programs, policies, and aid that can be provided by the ICM within a country based on their demographic, natural resources, economic, social and political conditions.

Task 3: Evaluate the effect your 20-year sustainability plan has on your country's sustainability measure created in Task 1. Predict the change that will occur over the 20 years in the future by implementing your plan in your evaluation. Based on the selected country, you may need to consider additional environmental factors such as climate change, development aid, foreign investment, natural disasters, and government instability. The ICM would like to get the "most bang for their buck", so determine which programs or policies produce the greatest effect on the sustainability measure for your country. Identifying highly effective strategies to be implemented is the ultimate goal of the ICM to create a more sustainable world.

Task 4: Write a 20-page report (summary sheet does not count in the 20 pages) that explains your model, your sustainability measure, your sustainability development plan, and the effect of your plan based on your model and the country's environment. Be sure to detail the strengths and weaknesses of the model. The ICM will use your report to invest in sustainability development intervention strategies for specific LDC countries. Good luck in your modeling work!

Possible Resources

UN sustainable development knowledge platform (http://sustainabledevelopment.un.org)

Ecological footprint (http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_basics_overview/)

World Bank Data (http://data.worldbank.org)

International Institute for Sustainable Development (https://www.iisd.org/sd/)

References

World Commission on Environment and Development (WCED). 1987. Our Common Future. New *York: Oxford University Press, 1987, 8*.

United Nations. The future we want. Resolution adopted by the General Assembly. 66th Session of the General Assembly, 123rd plenary meeting; 2012 July 27. New York: UN; 2012 Sep 11 (Resolution A/RES/66/288) [cited 2013 Jul 23]. Available at: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/66/288&Lang=E.

Other useful Sources

Bell, Simon and Stephen Morse. 2008. Sustainability Indicators: measuring the immeasurable. *Earthscan,* London.

Daly, Herman. 1990. Towards some operational principles of sustainable development. *Ecological Economics*, 2(1990) 1-6.

Kates, Robert W., Thomas M. Parris, and Anthony A. Leiserowitz. 2005. What is sustainable Development: Goals indicators, values, and practices. *Environment: Science and Policy for Sustainable Development*, Volume 47, Number 3, pages 8–21.