CEE 6490 – Spring 2016
ILO-6. Multi-Objective Optimization + Visualization
DUE: March 22, 2016

Lake Maggiore is one of the biggest and most used lakes and reservoirs in Italy. What is the shape of the Pareto-optimal surface to the Lake Maggiore reservoir multi-objective optimization problem with four objectives as shown in Figure 1 and described in the text below? Describe the relationship among the objectives and recommend + justify a reservoir release policy (release as a function of storage and other factors) that balances among the four objectives.

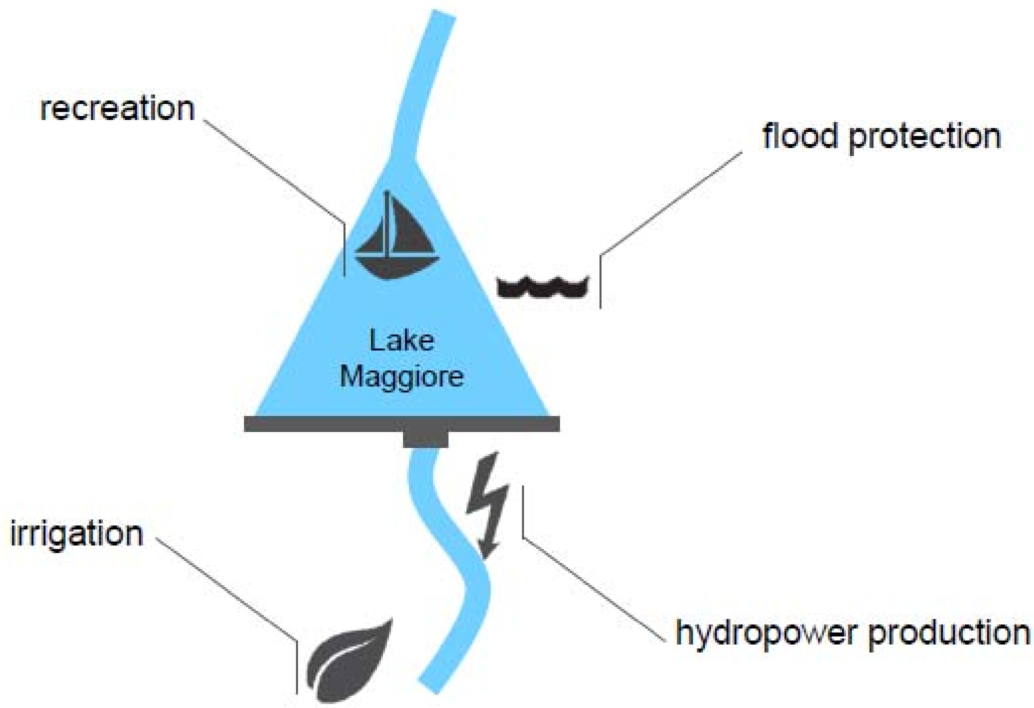

Figure 1. Simplified Lake Maggiore system, with main management objectives.

To complete the ILO:

1. Further background information about the problem is on Page 2.
2. You do not have to worry about generating the alternatives (Pareto or otherwise).
3. Instead, use the file ILO6_alts.csv, which is a csv file that contains approximately 1,000 rows representing 1,000 potential alternatives.
4. Download and install DiscoveryDV to use to visualize the potential alternatives using the instructions that start on Page 3.

Problem Background

STAKEHOLDERS

The stakeholders considered in the simplified system presented in Figure 1 are the following ones:

- **Downstream hydropower producers;**
- **Downstream farmers;**
- **Urban centers on the lake shores;**
- **Representatives of the recreational sector**.

Management Objectives

The four management objectives are:

- Downstream hydropower producers want to maximize hydropower production to meet energy demand;
- Downstream farmers want to maximize crop production;
- Urban centers on the lake shore want to minimize the intensity of flooding events;
- Representatives of the recreation sector want to maximize the volume of water available in the lake for recreation activities in conditions of low lake storage.

Performance Indicators

Four simple performance indicators are defined for each management objective

- **Average unmet hydropower demand** [m^3/d]: as hydropower producers want their water demand to be met in order to maximize hydropower production, this indicator needs to be minimized. In this simplified example, the hydropower water demand is set to 50 m3/day;
- **Average unmet irrigation demand** [m^3/d]: as farmers want their water demand to be met in order to maximize crop production, this indicator needs to be minimized. In this simplified example, the irrigation demand is set to 50 m3/day;
- **Average flood event intensity** [m]: this indicator needs to be minimized as people living in the urban centers on the lake shores would like to avoid flood events. In this simplified example, the flooding threshold is set to a reservoir level of 50 m;
- **Average storage deficit with respect to a minimum threshold** [m^3]: stakeholders representing the recreational sector are willing to minimize such indicator, as they would like to have enough water stored in the reservoir in order to perform recreational activities, such as navigation. In this simplified example, the threshold is set to 50 m3.

Decision Variables

The decision variables are parameters that define a policy where release from Lake Maggorie is a function of reservoir storage and other parameters (related to the demands and physical characteristics). These parameters define the rule reservoir operators should follow to release water from the reservoir. The policy is represented as a piece-wise linear function (Figure 2) and controls of the problem are the parameters with ranges:

- x1 = slope of release curve under shortage conditions $\in[0, \Pi/4]$
- x2 = reservoir storage volume where reservoir operators start to spill $\in[50, 150]$

- x3 = slope of release curve under spill conditions ∈[0, Π/2]

The performance indicators are evaluated under several combinations of the three controls. In the lab activity, you will visualize, analyze and compare such alternatives in terms of objective values.

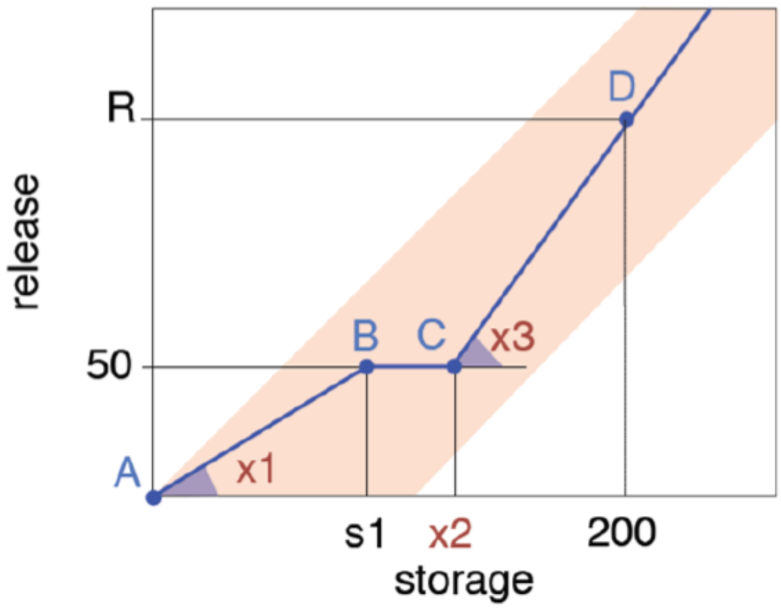

Figure 2. Piece-wise linear fixed-class policy for simplified Lake Maggiore reservoir operation.

<u>Steps to Use DiscoveryDV</u>

1. **GETTING STARTED**
    a. In order to get started you need to install *DiscoveryDV* by accessing the **[DiscoveryDV_Win64_0.47.exe]** file in Dropbox and following the installation procedure. Please, also register at the DecisionVis website (https://www.decisionvis.com/) and request the software for **Academic** use. A free Beta version of the software will be released to you upon registration.

    b. After completing the installation, open **DiscoveryDV**. At the first access you will be required to insert **User, Institution,** and **License** data. Insert the data provided by the class instructor in an email.

    c. Download the file ILO6_alts.csv from Canvas and open with a text editor, Excel, or similar file. The file contains 1,000+ alternatives (rows) generated by a genetic algorithm which represent dominated and non-dominated alternatives. The column data is:

        i. Columns #1 to 4: the four objectives.
        ii. Columns #5 to 7: the three decision variables

d. In order to start the visualization of your alternatives in the objective space with DiscoveryDV, you need to create a view and import the data in file **ILO6_alts.csv**.

   i. In the Storyboard window, double click ***New…***, then select **Page001** and drag and drop **Page001** in the big empty window on the right side of the software window.
   ii. At the top of the Page001 window, click on **Data -> Load Data File**, select the **ILO6_alts.csv** file and click **OK.** You will notice that in the **Storyboard** window (bottom-left) the item **Page001** will appear.
   iii. *How many visualization dimensions (i.e., objectives) can the software represent? How many dimensions is the Lake Maggorie data set?*

   11, 7

e. In the combos labeled **X:** and **Y:** at the bottom of the window, select two of the objectives to plot. *What is the relationship between these two objectives?* Explore the data by varying the two objectives in the plot and record your observations of the relationships. There is a week correlation between lower flood intensity and less unmet irrigation demand.

2. 3-OBJECTIVES VISUALIZATION

a. Now let's consider the following three indicators: **hydropower revenues**, **irrigation revenues**, and **fish survival.** Set the following options:

   - x-axis: *FloodIntensity*
   - y-axis: *UnmetIrrDemand*
   - z-axis: *UnmetRecreationDemand*

   You will end up with a 3-D visualization you can play with by turning the cube and looking at the points from different perspectives.

b. Identify the Pareto front for the three objectives loaded. Right click on the white space of your objective space and select **Perform Pareto Sort.** The selected option will represent with dark color the points belonging to the Pareto front. Analyze what you see: *is there just one optimal point or many, composing a Pareto front?* IMPORTANT: in the **Storyboard** window, examine the elements under **Pareto Sort**: they are your objectives. Double-check they all present the option **sense** set to "**min"**. If needed, double click the entry to change.

3. 4-OBJECTIVES VISUALIZATION

c. Let's now consider all the four objectives: **hydropower revenues**, **irrigation revenues**, **fish survival** and **flooded area.** Set the following options:

   - x-axis: *FloodIntensity*
   - y-axis: *UnmetIrrDemand*
   - *z*-axis: *UnmetHydroDemand*
   - Color: *UnmetRecreationDemand*

Identify the Pareto front: in the Storyboard window, right-click on **Pareto Sort.** Do not forget to check out that the option **sense** is set to **min** for this objective.

Vary the selections for X, Y, Z, and color, and explore the relationships. Record your observations.

4. ANALYZING Decision Variables

a. Let's now consider the controls of our problem, *i.e.*, x1, x2 and x3. Set the following options for representation:
   - x-axis: *FloodIntensity*
   - y-axis: *UnmetIrrDemand*
   - Color: *x1 (slope of release curve)*

   Look at the two extreme point of the Pareto front in this 2-D representation:
   - The point with minimum value with respect to *UmetIrrDemand*;
   - The point with minimum value with respect to *FloodIntensity*.

   You should notice that both points are red, which means that for both alternatives, the control x1 is equal to 0.785, i.e., $\Pi/4$. Think about the physical meaning of that, looking at Figure 2:
   - stakeholders interested only in flood protection, would like to release always the maximum release (*i.e.*, the whole storage) even for low values of the storage values;
   - Stakeholders interested in irrigation want their water demand to be always satisfied. When the storage is too low for satisfying their demand, they want to get the maximum water available, *i.e.*, the whole storage, in order to cover the demand as much as possible.

b. Perform the same analysis of point 4.a, but now consider the parameter **x2** and then parameter **x3**.

c. Continue interactively exploring using the plot tools. Consider other objectives and parameters. You should now be able to answer the questions posed at the beginning of the HW.

CEE 6490, ILO Grading Rubric ILO-6 Date: ______________ Student: _______________________________

Category (Max. Score)	No Evidence	Doesn't Meet Standard	Nearly Meets Standard	Meets Standard	Exceeds Standard	Self-Score	Instructor Score
Title (1)	Absent 0	Evidence of two or less 0	Evidence of three 0	Evidence of four 1	Title – can assess main point from title alone; Name, Instructors' Names, Course, Date, Neatly finished 1		
Introduction (3)	Absent, no evidence 0	There is no clear introduction or main topic. 1	Introduction states the main topic but either: 1. Does not give a full overview, Or: 2. Too detailed, leading to annoying repetition later. 2	The introduction states the main topic and previews the structure of the report. 2	The introduction states the main topic and previews the structure of the report. Good overview of the problem and solution approach. Gives enough detail to motivate the reader to continue reading. 3		
Organization and structural development of the idea: procedure, results, conclusions (10)	No content provided. 0	Paragraphs fail to develop the main idea. No section headers or guide to help the reader understand how material is organized. 1 – 5	Organization of ideas not fully developed. Paragraphs lack supporting detail sentences. No transitions and/or ineffective section headers. 6 - 7	Paragraph development present but not perfected. Each paragraph has sufficient supporting detail sentences. Few transitions. 8	Writer demonstrates logic and sequencing of ideas through well-developed section headers, paragraphs, and transitions. The first sentence of each paragraph is the summary sentence. 9 - 10		
Technical Correctness (70)	Questions not addressed. 3 – 42%	The writer has no clue what they are talking about. 45 – 58%	Sketchy: left out required design points. Did not work on this as much as you should have, and it shows. Many important answers are incorrect. 61 – 79%	Discussion lacks adequate detail, but all the necessary points are covered and nearly all answers are correct. 82 – 88%	Provides what was explicitly asked for. The function of each piece is demonstrated to the reader in adequate, but not overwhelming, detail. Answers are correct and reasonable. 91 – 100%		
	a) Problem overview (15)						
	b) Description of Pareto front and tradeoffs among objectives (30)						
	c) Recommended reservoir release policy (10) and justification (15)						
	d)						
	e)						

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Category (Max. Score)	No Evidence	Doesn't Meet Standard	Nearly Meets Standard	Meets Standard	Exceeds Standard	Self-Score	Instructor Score
Word Usage and Format (10)	Not applicable	Numerous and distracting errors in punctuation, capitalization, spelling, sentence structure, word usage, significant figures, tables, and figures. Data vomited onto page(s). Unacceptable / unprofessional at the graduate level. 1 – 5	Misspelled words, poor English grammar and word choice. Main body of report is either longer or significantly less than one page. Figures are too small and/or under-labeled, although they are usually of acceptable quality and focus. Tables incoherent or not cohesive. Bad font sizes. Too much or too little data in appendices. Could be improved by being more meticulous. 6 - 7	Almost no errors in punctuation, capitalization, spelling, sentence structure, word usage, significant figures, and presentation of figures, tables, and appendices. Main body of report is one page or less 8	Punctuation, capitalization, spelling, sentence structure, word usage, and significant figures all correct. Main body of report is one page or less. Clear, consistent fonts. Good word processing skills. Figures have adequate contrast. Informative figure and table titles and legends. Figures have appropriate axis tick spacing, labels, units, and legends. Table columns cohesive, labeled, and specify units. Document is stapled. Appendices, if provided, are separated by topic, and each have a title, discussion, and proper formatting and display of information 9 - 10		
Conclusion (4)	Absent 0	Incomplete and/or not focused. 1	The conclusion does not adequately restate the main results. 2	The conclusion restates the main results. 3	The conclusion restates the main results, and is an effective summary. 4		
References (2)	Absent 0	Numerous errors, off-the-wall sources used. 0	Some errors in citing format; more sources should be cited. 1	Prior work cited with few errors. 2	All prior work and data sources are cited in the correct format with no errors. 2		
TOTAL (100)							