Lecture 1: Modeling

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1. Introduction

Managers make decisions to tackle both tactical and strategic challenges. Tactical problems are for instance managing a financial portfolio, planning advertising, manufacturing a good, matching supply with demand, recruiting and training employees and so on. Strategic problems encompass for instance building a new factory, entering/exiting a market, structuring an organization and so on. Another way to classify decision problems would be to make the distinction between optimization at a micro level and optimization at a macro level. In the case of advertising decisions for example, optimizing digital ads placements and budget differs from optimizing advertising expenditures across different media, e.g., TV, online, print, and so on. Optimization at the "macro" level allows for instance some hidden costs of varying allocations of marketing budgets across different channels.

Managerial decision-making necessitates formal tools to not only identity courses of actions, but also structure the decision process and understand the potential perils that would arise along the way. Specifically, several analytical frameworks exist to *frame* specific decision opportunities into "typical" problems. Consider for instance the case of two brand managers responsible for selling two different products, i.e., diapers and fashion (Rudi and Netessine 2018). Both managers must decide, among other things, at which price they should sell their respective products. On the one hand, pricing decisions in both cases require understanding the different customer segments that exist in the market and how demands will respond on to price changes. On the other hand, however, both face totally different problems. In the case of diapers, historical sales data exist and demand for this mature product is driven by needs. On the contrary, in the case of fashion, no historical sales data exist about new fashion and demand is driven by desire. As a result, different approaches must be adopted to price these two different products. Specifically, the pricing problem for diapers can be framed as a static non-linear static optimization problem, while the pricing problem for fashion can be framed as dynamic markdown pricing problem.

Solving a decision problem requires (1) identifying the key features and relationships of the problem, (2) constructing the appropriate analytical framework or model that will help (3) characterizing an acceptable (if not optimal) solution for actions. The goal of this class is to impart students with modeling skills necessary to tackle various decision problems. The content of this class is divided into two parts. The first part covers optimization tools that have been successfully applied to analytically analyze and solve business problems, i.e., linear programming, non-linear optimization and dynamic optimization (both deterministic and stochastic). The second part of the class covers more economics approaches to decision-making, i.e., decision making under risk and uncertainty, strategic thinking (game theory) incentives designs and dynamic decision-making.

2. Models

Karl Weick, a famous management scholar, once told the story of a unit of the Hungarian army that got lost in a snowstorm in the Alps. After three days in the snow, the soldiers lost any hope of finding their way back. At this point, one of them produced a map, which they used to find their way back to their base camp. After reaching their camp, they realized that the map (or the model) was not a map of the Alps, but of the Pyrenees. Even though the model (map) was wrong, it was still useful in structuring the decision process that helped them come home. "The purpose of models is not to fit data but to sharpen the questions", thus even though all "models are wrong, some are useful". These two quotes attributed to Samuel Karlin and George Box, respectively, summarize why models are powerful, i.e., they help to identify relationships that were not necessarily obvious, they structure the decision problem and they allow guiding actions. In this class, we will seek to frame decision problems into optimization and economic models

2.1. Building Blocks

Optimization and economic models share three common building blocks, i.e., (1) definition of the decision variable(s), (2) definition of the objective function(s) and (3) identification of potential constraints. Mathematically, we will consider models that can be framed, in the most general form as

Maximize	$f(x, \theta)$
Subject to	$g(x, \theta)$

with the notation

$f(.)$: Objective Function
$g(.)$: Constraints
x: Decision variables
θ: Parameters

where, the goal of optimization is to determine the optimal decision, i.e. x^* that yields the highest objective function $f(.)$ given the set of constraints $g(.)$. Decision models vary based on the mathematical structure of the functions $f(.)$ and $g(.)$, the types of the decision variables and parameters, as well as on what is known and unknown to the decision makers. Table 1 below provides examples that will be discussed in class.

	Decisions	**Objectives**	**Constraints**
Managing blood	Advertising and Inventory	Bringing blood donation levels close to targets	Blood is perishable
Incentivizing sales people	Total Cash compensation and incentives	Maximizing profit	Turnover, shirking, fairness
Competitive pricing	Price	Maximizing market-share	Competitors, profitability
Pricing Perishable Products	Pricing over time	Maximizing profit	Selling all quantities before end of season
Inventory Decision	Production levels	Minimizing Inventory Costs	Production Capacity
Supply Chain Coordination	Contracts	Maximizing Efficiency	Business rules and practices
Asset Management	Buying and Selling Stocks	Maximizing Returns/Minimizing Risk	Budget Constraint
Nurse staffing	Assignment of nurses to shifts	Minimizing costs	Everyone getting along
Wine Analytics	Advanced selling of wine before bottling	Maximizing Profit	Quality rating risk
Lead Marketing	Allocation of resources between marketing and sales	Maximizing profitability of a conversion funnel	Budget constraints
Sports League Structures	Season schedule	Minimizing Cost	Half of the games at home, half of the games on the road
Selling Digital Ads	Pricing mechanism and slot allocation	Revenues	Limited number of slots, extracting rents
Love Analytics	Matching	Happiness	A lot

Table 1: Decision Analytics Examples

Table 2 provides a sample of different tools that exist to tackle the decision problems presented in Table 1.

Tool	Decision x	Objective $f(.)$	Constraint $g(.)$
Linear Programming I	$x \in R^+$	$c_1x_1 + c_2x_2$	$a_1x_1 + a_2x_2 < b$
Linear Programming II	$x = \{0,1\}$	$c_1x_1 + c_2x_2$	$a_1x_1 + a_2x_2 < b$
Non-Linear Programming	$x \in R^+$	$f'' \neq 0$	$g(x)$
Dynamic Optimization	$x_1, x_2, \dots x_T$	$\Sigma_t \Pi_t(x_t)$	$\Pi_t = g(\Pi_{t-1})$
Stochastic Optimization	$x_1, x_2, \dots x_T$	$\Sigma_t \mathbb{E}[\Pi_t(x_t)]$	$\Pi_t = g(\Pi_{t-1}) + \epsilon$
Game Theory and incentives Design	My decision (x) vs. your decision (y)	$f(x,y)$	$g(x,y)$

Table 2: Decision Analytics Tools

One way to approach a modeling is to match the decision problem with the appropriate tool. Once the matching occurs, the decision maker of analyst (i.e., you) must identify the course of actions that provides an acceptable decision.

3. Concluding Remarks

Each session will introduce new analytical tools for decision-making. The first part of the class will cover:

- Linear Programming
- Non Linear Programming
- Dynamic Optimization

The second part of the class will cover

- Decision analysis and decision under risk and uncertainty
- Game theory, incentives and mechanism designs
- Dynamic decision-making.

The mathematical foundations of the class will be in convex optimization, see, e.g., the book *Convex Optimization* by Boyd and Lieven, which is available here.

Furthermore, throughout the quarter I will post notes, in addition to the lecture notes and selected readings. Notes and readings will be posted a week prior to class. Finally, even though the class is neither an optimization, nor a programming class, will use optimization and programming. To this end, we will use modeling and optimization tools available in R and Python such as

CVXPY (http://www.cvxpy.org/en/latest/)
PuLP (https://pypi.python.org/pypi/PuLP)
PYOMO (http://www.pyomo.org/)

References

Boyd, Stephen; Vandenberghe, Lievem. *Convex Optimization*. 2009. Cambridge University Press

Williams, Paul H. *Model Building in Mathematical Programming*. 2013 (5th Edition). Wiley