THE UNIVERSITY OF HONG KONG
FACULTY OF BUSINESS AND ECONOMICS

PhD Course Syllabus

Course Code/Title: **IIMT6020**

Optimization Methods for Business Analytics

Course Description: Optimization methods are central to business decision-making. The goal of this course is twofold. First, it aims to lay a solid foundation of optimization theory, with emphasis on analysis of properties of optimization problems and optimization problem formulation for various application contexts. Second, the course aims to provide students the exposure to the foremost research work that apply optimization in the literature of business analytics.

Course Objectives:

1. Equip students with a solid foundation of optimization theory.
2. Train the students in optimization problem formulation for various application contexts.
3. Provide the students the exposure to important research work in business analytics that applies optimization.

Pre-requisite:

Assessment: 100% coursework

Remarks: All PhD courses are non-credit-bearing and will be assessed on a pass/fail basis.

Course Learning Outcomes (CLOs) On completion of this course, students should be able to:	Aligned PLOs*				
	1	2	3	4	5
1. Able to formulate real-world decision-making problems into optimization models	✓			✓	✓
2. Able to implement state-of-the-art algorithms to solve real-world decision-making problems	✓	✓	✓	✓	✓
3. Able to critique research work in business analytics	✓			✓	✓
4. Able to complete a mini research project in the area of business analytics to address an interesting research question using optimization methods	✓	✓	✓	✓	✓

***Programme Learning Outcomes (PLOs) for Research Postgraduate Programme:**

1. Demonstrate critical understanding, at an advanced level, of up-to-date knowledge and research methodology of a particular field
2. Implement effective academic and personal strategies for carrying out research projects independently and ethically
3. Contribute original knowledge in response to issues in their specialist area
4. Communicate research findings at a diverse range of levels and through a variety of media
5. Evaluate one's own research in relation to important and latest issues in the field

COURSE DETAILS *(subject to change at instructor's discretion)*

Year / Semester:	2023-24, Semester 1 (first half) and Semester 2 (second half)
Time / Venue:	TBA
Instructor:	Dr. Liao Wang
	Email: lwang98@hku.hk
	Office: KKL-806 (by appointment)

I. Teaching and Learning Activities

In-class and Out-of-class Activities *(e.g. lectures, papers reading, writing proposal)*	Expected hour	% of student study effort
1. Interactive lectures	36	30
2. Reading papers	24	20
3. Solving problem sets	30	25
4. Group discussion	30	25
Total	120	100%

II. Assessment

Assessment Components *(e.g. assignments, proposal, presentation, examination)*	Weight	CLOs to be assessed			
		1	2	3	4
1. In-class discussion	10%	✓		✓	✓
2. Homework assignments	40%	✓	✓	✓	
3. Course project (presentation and report)	50%	✓	✓	✓	✓
Total	100%				

Students will be assessed based on the following performance standards:

Course Grade	Performance Standard
Pass	• Actively participate in class discussions and articulate their research idea or understanding • Solve problem sets in the homework assignments with excellent analytical skills and accurate computation • Provide persuasive, original, insightful and well-reasoned recommendations that clearly follow from the analysis and effectively address the key issue • Complete a mini research project: identify an interesting research question in a business area/business analytics, and solve it with optimization methods in an original and rigorous manner • Deliver a clear presentation on the course project

Fail	Students unable to satisfy two areas or more listed above would receive a Fail grade

III. Course Content and Tentative Schedule

Tentative Teaching Schedule

Week	Topic
1	Introduction; structure of optimization problem; existence of optima; local theory of optimization
2	Convexity and convex optimization; projection theorem
3	Duality theory; convexity and duality
4	Sensitivity analysis; supermodularity and Topkis theorem
5	Optimization problem formulation 1
6	Optimization problem formulation 2
7	Modern Portfolio Theory
8	Risk Measures
9	Procurement Problem with Unreliable Suppliers
10	Stochastic Optimization
11	From Predictions to Prescriptions
12	Reinforcement Learning

IV. Required/Recommended Textbook/Readings

Textbooks/References

- S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge University Press, 2004. Available online at http://www.stanford.edu/~boyd/cvxbook.

- D. Bertsimas and J.N. Tsitsiklis, *Introduction to Linear Optimization*. Dynamic Ideas and Athena Scientific, Belmont, Massachusetts, March, 2008.

- D. P. Bertsekas, *Nonlinear Programming*, 2nd Edition. Athena Scientific, 1999.

- D.M. Topkis, Minimizing a Submodular Function on a Lattice. *Operations Research* **26**(2): 305-321, 1978.

Modern Portfolio Theory

- H. Markowitz. Portfolio Selection. *Journal of Finance*, **7**(1):77–91, 1952.
- H. Konno and H. Yamazaki. Mean-absolute deviation portfolio optimization model and its applications to Tokyo stock market. *Management Science*, **37**(5):519–531, 1991.
- F. Black and R. Litterman. Global portfolio optimization. *Financial Analysts Journal*, 48(5):28–43, 1992.

- T. L. Lai, H. Xing, and Z. Chen. Mean–variance portfolio optimization when means and covariances are unknown. *Annals of Applied Statistics*, **5**(2A):798–823, 2011.
- M. Ao, Y. Li, and X. Zheng. Approaching mean-variance efficiency for large portfolios. *Review of Financial Studies*, **32**(7):2890–2919, 2019.

Risk Measures

- P. Artzner, F. Delbaen, J-M Eber and D. Heath. Coherent Measures of Risk. *Mathematical Finance,* **9**(3): 203-228, 1999.
- C. Acerbi. Spectral measures of risk: A coherent representation of subjective risk aversion. *Journal of Banking & Finance,* **26**(7): 1505-1518, 2002.
- R.T. Rockafellar and S. Uryasev. Conditional value-at-risk for general loss distributions. *Journal of Banking & Finance,* **26**: 1443–1471, 2002.

Procurement Problem with Unreliable Suppliers

- M. Dada, N.C. Petruzzi and L.B. Schwarz. A Newsvendors Procurement Problem when Suppliers Are Unreliable. *MSOM,* **9**(1): 9-32, 2007.
- A. Federgruen and N. Yang. Selecting a Portfolio of Suppliers Under Demand and Supply Risks. Operations Research, **56**(4): 916-936, 2008.
- A. Federgruen and N. Yang. Optimal Supply Diversification Under General Supply Risks. Operations Research, **57**(6): 1451-1468, 2009.
- Q. Feng, J. G. Shanthikumar. Supply and Demand Functions in Inventory Models. Operations Research, **66**(1):77-91, 2017.

Gradient Methods for Stochastic Optimization

- M. J. Kochenderfer and T. A. Wheeler. *Algorithms for Optimization*. MIT Press. 2019.

From Predictions to Prescriptions

- D. Bertsimas, J. Dunn, and N. Mundru. Optimal prescriptive trees. *INFORMS Journal on Optimization*, **1**(2):164–183, 2019.
- G. Ban and C. Rudin. The big data newsvendor: Practical insights from machine learning. *Operations Research*, **67**(1):90–108, 2019
- D. Bertsimas and N. Kallus. From predictive to prescriptive analytics. *Management Science*, **66**(3):1025–1044, 2020

Reinforcement Learning

- R. S. Sutton and A. G. Barton. *Reinforcement Learning: An Introduction*. 2nd edition. MIT Press. 2018.
- E. Calvano, G. Calzolari, V. Denicolò, and S. Pastorello. Artificial intelligence, algorithmic pricing, and collusion. *American Economic Review*, **110**(10):3267–3297, 2020.

<u>Pointer to More References</u>

Digital Marketing Optimization

- J. Feldman, S. Muthukrishnan, M. Pal, and C. Stein. Budget optimization in search-based advertising auctions. *EC '07: Proceedings of the 8th ACM Conference on Electronic Commerce*, pp. 40–49, 2007.
- Z. Abrams, O. Mendelevitch, and J. A. Tomlin. Optimal delivery of sponsored search advertisements subject to budget constraints. *EC '07: Proceedings of the 8th ACM Conference on Electronic Commerce*, pp. 272–278, 2007.

Sports League Structure Optimization

- B. Macdonald and W. Pulleyblank. Realignment in the NHL, MLB, NFL, and NBA. *Journal of Quantitative Analysis in Sports*, **10**(2):250–240, 2014.
- P. Pardalos, F. Rendl, and H. Wolkowicz (1994). The quadratic assignment problem: A survey and recent developments. In P. Pardalos and H. Wolkowicz, editors, *Quadratic Assignment and Related Problems*, volume 16, pp. 1–42. DIMACS Series in Discrete Mathematics and Theoretical Computer Science, 1994.

Algorithmic Framework for Regression and Classification

- D. Bertsimas and A. King. An algorithmic approach to linear regression. *Operations Research*, **64**(1):2–16, 2016.
- D. Bertsimas and A. King. Logistic regression: From art to science. *Statistical Science*, **32**(3):367–384, 2017.
- D. Bertsimas and M. Copenhaver. Characterization of the equivalence of robustification and regularization in linear and matrix regression. *European Journal of Operational Research*, **270**(3):931–942, 2018.
- D. Bertsimas, J. Dunn, C. Pawlowski, and Y. D. Zhuo. Robust classification. *INFORMS Journal on Optimization*, **1**(1):2–34, 2019.
- D. Bertsimas and M. L. Li. Scalable holistic linear regression. *Operations Research Letters*, 48(3):203–208, 2020.

Optimal Trees and Explainable Machine Learning

- D. Bertsimas and J. Dunn. Optimal trees. *Machine Learning*, **106**(7):1039–1082, 2017.
- X. Hu, C. Rudin, and M. Seltzer. Optimal sparse decision trees. In *Advances in Neural Information Processing Systems*, pp. 7265–7273, 2019.
- C. Rudin. Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead. *Nature Machine Intelligence*, **1**:206–215, 2019.

- D. Bertsimas, A. Orfanoudaki, and H. Wiberg. Interpretable clustering: An optimization approach. *Machine Learning*, 2020

Individualized Treatment Rules

- Y. Zhao and D. Zeng, and A. R. Rush and M. R. Kosorok. Estimating individualized treatment rules using outcome weighted learning. *Journal of the American Statistical Association*, **107**(499):1106–1118, 2012.
- G. Chen, D. Zeng, and M. R. Kosorok. Personalized dose finding using outcome weighted learning. *Journal of the American Statistical Association*, **111**(516):1509–1521, 2016.
- M. R. Kosorok and E. B. Laber. Precision medicine. *Annual Review of Statistics and Its Application*, **6**:263–286, 2019.

Bayesian Optimization and Automated Machine Learning

- B. Shahriari, K. Swersky, Z. Wang, R. P. Adams, and N. de Freitas. Taking the human out of the loop: A review of Bayesian optimization. *Proceedings of The IEEE*, **104**(1):148–175, 2016.
- P. I. Frazier. Bayesian optimization. In *Recent Advances in Optimization and Modeling of Contemporary Problems*, pp. 255–278, 2018.

Multi-armed Bandit Problem

- A. Slivkins. Introduction to multi-armed bandits. *Foundations and Trends® in Machine Learning*, **12**:1–286, 2019.
- T. Lattimore and C. Szepesvári. *Bandit Algorithms*. Cambridge University Press. 2020.

M. Nambiar, D. Simchi-Levi, and H. Wang. Dynamic learning and pricing with model misspecification. *Management Science*, **65**(11):4980–5000, 2019.

V. Course Policy

The University Regulations on academic dishonesty will be strictly enforced! Academic dishonesty is behaviour in which a deliberately fraudulent misrepresentation is employed in an attempt to gain undeserved intellectual credit, either for oneself or for another. It includes, but is not necessarily limited to, the following types of cases:

a. Plagiarism - The representation of someone else's ideas as if they are their own. Where the arguments, data, designs, etc., of someone else are being used in a paper, report, oral presentation, or similar academic project, this fact must be made explicitly clear by citing the appropriate references. The references must fully indicate the extent to which any parts of the project are not one's own work. Paraphrasing of someone else's ideas is still using someone else's ideas, and must be acknowledged. Please check the University Statement on plagiarism on the web: http://www.hku.hk/plagiarism/

b. Unauthorized Collaboration on Out-of-Class Projects - The representation of work as solely one's own when in fact it is the result of a joint effort.

c. Cheating on In-Class Exams - The covert gathering of information from other students, the use of unauthorized notes, unauthorized aids, etc.

d. Unauthorized Advance Access to an Exam - The representation of materials prepared at leisure, as a result of unauthorized advance access (however obtained), as if it were prepared under the rigors of the exam setting. This misrepresentation is dishonest in itself even if there are not compounding factors, such as unauthorized uses of books or notes.

You are expected to do your own work whenever you are supposed to. Incident(s) of academic dishonesty will NOT be tolerated. Cheating or plagiarism of any kind would result in an automatic FAIL grade for the course plus strict enforcement of all Faculty and/or University regulations regarding such behaviour.