Decomposition Methods for Large-Scale Adaptive Robust Optimization:
Applications to Operating Room Planning under Uncertainty

PhD Thesis Proposal in **Operations Research**

Université de Technologie de Troyes
LIST3N Laboratory

Research Context and Objectives

Operating Rooms (ORs) represent one of the most critical and resource-intensive units within hospitals, accounting for up to 40% of hospital expenses and generating up to 70% of hospital revenues [15]. The effective management of OR scheduling faces significant challenges due to multiple objectives [12] and inherent uncertainties in surgery durations, recovery times, and resource availability. These uncertainties, coupled with the interconnected nature of downstream resources (Post-Anesthesia Care Units (PACU), Intensive Care Units (ICU)) [1], create a complex optimization challenge that significantly impacts healthcare delivery efficiency and patient outcomes. While traditional deterministic approaches to OR scheduling fail to capture the stochastic nature of healthcare operations, and purely stochastic methods often become computationally intractable for real-world instances [13], Adaptive Robust Optimization (ARO) offers a promising framework by combining the tractability of robust optimization with the flexibility of recourse decisions [5]. OR managers often struggle with accurate predictions of key metrics like length of stay and emergency cases, which can have multiple peaks in their distributions. Historical data may not reliably represent upcoming weeks' patterns, and using simplified uni-modal distributions can lead to poor planning decisions that affect both patient care—particularly in complex surgeries—and hospital efficiency [14]. The problem of OR planning considering downstream resources is particularly challenging, being a special case of the hybrid flow shop problem, which is proven to be $\mathcal{NP}$-hard [8, 15]. The candidate will conduct extensive analyses and comparisons of ambiguity sets and uncertainty sets for OR problems [6]. The thesis will aim to develop novel approaches for large-scale ARO problems, combining tactical and operational decision levels of OR planning (Master Surgical Schedule [11, 9], allocation scheduling [7], and advance scheduling [16, 2]) with downstream resource management, PACU and ICU.

The primary objectives include developing practical solutions for hospital operations, implementing new decomposition methods for two-stage/multi-stage ARO problems, evaluating solution quality through algorithmic analysis, and incorporating machine learning techniques to improve optimization time [4]. The candidate will implement decomposition algorithms such as Benders decomposition variants [3, 10], column-and-constraint generation methods [17], and propose hybrid algorithms combining exact and heuristic approaches. The purpose will be to propose concrete solution approaches for scheduling and assignment problems under uncertainty and resource capacity constraints, while developing practical decision support tools for hospital managers.

Methodology and Research Plan

The proposed research should follow a structured progression, building from theoretical foundations to practical implementation. The first year would be dedicated to establishing a solid theoretical framework through a comprehensive literature review of ARO, decomposition methods, OR/ICU/PACU planning and scheduling literature. This phase should culminate in the development of decomposition approaches and initial formulation of OR-specific ARO models. During the second year, the focus would likely shift to algorithmic development and implementation, including the creation and testing of solution approaches, extensive computational experimentation. The final year would aim to bridge theory and practice through real-world case studies, development of practical decision support tools, and dissemination of research findings through peer-reviewed publications and the thesis manuscript.

Scientific Challenges

The research would present several interconnected scientific challenges spanning theoretical, computational, and practical dimensions. From a theoretical perspective, the work should address the fundamental complexity of proving convergence for novel decomposition methods in the context of ARO for OR planning and scheduling under uncertainty. This would include developing tight bounds for solution quality and analyzing how different uncertainty set structures might impact problem complexity and solution approaches. The computational aspects would likely present equally demanding challenges, particularly in efficiently handling large-scale instances. This should necessitate developing sophisticated techniques and managing the inherent trade-offs between solution quality and computational efficiency. The practical implementation would introduce additional complexities around incorporating real-world constraints and objectives while ensuring solution robustness. These challenges would be further compounded by the need to design intuitive decision support tools that could be effectively utilized by OR managers.

Expected Contributions

The research would aim to deliver significant contributions. The theoretical contributions would advance the field of OR planning and scheduling through new decomposition and hybrid algorithms specifically designed for ARO, accompanied by rigorous convergence results and a novel framework integrating machine learning techniques with optimization methods. From an algorithmic perspective, the work would produce efficient implementation strategies for large-scale problems, innovative hybrid solution approaches combining exact and heuristic methods. The practical impact would be demonstrated through comprehensive decision support systems for hospital managers for implementing robust scheduling systems in practice.

Required Skills and Evaluation Criteria

Candidates should hold a Master's degree or Engineering degree in **Operations Research**, **Applied Mathematics**, or **Computer Science**, with a strong focus on mathematical optimization and modeling techniques. Candidates will be evaluated through a comprehensive examination covering:

1. **Mathematical Programming**
   - Linear and Integer Programming
   - Duality Theory
   - Decomposition Methods

2. **Operations Research**
    - Robust Optimization
    - Stochastic Programming
    - Metaheuristics
    - Healthcare Operations Management
3. **Technical Skills**
    - Programming (Julia/Python/C++)
    - Mathematical Modeling
    - Commercial Solvers (CPLEX, Gurobi, Hexaly, etc.)

Research Environment

The PhD will be conducted within the **LIST3N** laboratory (**OPTI** team) at the Université de Technologie de Troyes, benefiting from:

- Strong expertise in optimization and operations research
- Access to high-performance computing facilities
- Collaboration with healthcare partners providing real-world case studies and validation opportunities
- International research network and collaborations with leading researchers and practitioners in the field

Contact Information and Application Process

Supervisors:

- **Dr. Salma Makboul** (salma.makboul@utt.fr)
- **Prof. Alice Yalaoui** (alice.yalaoui@utt.fr)

Application Documents:

- Detailed Curriculum Vitae
- Motivation Letter
- Academic Transcripts (Bachelor and Master levels)

Please send all documents to both supervisors.

Location: Université de Technologie de Troyes, Troyes, France
Duration: 3 years
Start Date: September 2025
Application Deadline: **April 30, 2025**

References

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