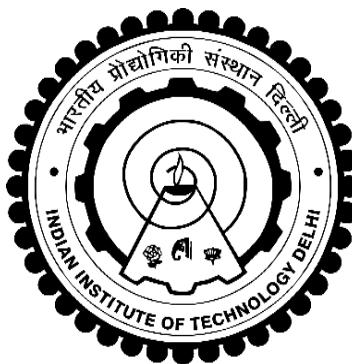


PLANNING AND SCHEDULING OF PROCESS OPERATIONS UNDER UNCERTAINTY

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DEPARTMENT OF CHEMICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
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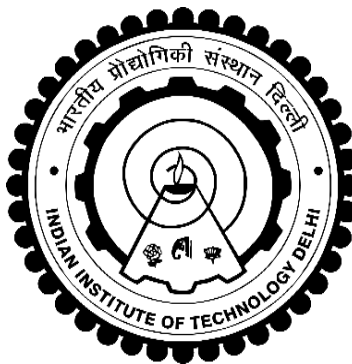
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Submitted

*in fulfillment of the requirements of the degree of Doctor of Philosophy
to the*



INDIAN INSTITUTE OF TECHNOLOGY, DELHI
September 2021

I would like to dedicate this thesis to my parents.

Without whom, this could not have been possible.

CERTIFICATE

I am satisfied that the thesis presented by **Mr. Edo Begna Jiru** on “***Planning and Scheduling of Process Operations under Uncertainty***” is worthy of consideration for the award of the degree of Doctor of Philosophy and is a record of the original bonafide research work carried out under my guidance and supervision and that the results contained in it have not been submitted in part or full to any other university or institute for the award of any degree/diploma.

I certify that he has pursued the prescribed course of research.



12 Oct 2021

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ABSTRACT

In the real industrial application, optimization of planning and scheduling is an ongoing dynamic process where unexpected disruption of the optimization parameters is inevitable. The objective of this thesis is to develop a general methodology to consider uncertain parameters in production planning and scheduling problems. Different challenges that arise at the level of planning and scheduling are associated with model formulation issues, and computational times when solving large-scale problems. Nevertheless, the implementation of such models improves the overall efficiency of manufacturing systems.

In the first part, we consider the problem of integration of production scheduling and maintenance activities. The approach is based on unit-specific continuous time-domain representation using state-task-network (STN) process representation leading to mixed integer linear programming (MILP) formulation. Between the two models considered, it is observed that model M1 gives the optimal solution with a smaller number of events when compared to the other model M2.

In the second part, we formulate practical reactive scheduling approaches for multipurpose batch plants. In this work, a two-stage solution technique is formulated for short-term rescheduling problems using an efficient MILP model. Two models with three types of disturbances are considered. It is observed that model M1 gives better profit when compared to model M2 for the case of unit breakdown.

In the third part, a robust MILP model for planning of carbon capture and storage (CCS) retrofit is developed to maximize CO₂ emission reduction. In the model, the end time of operating life of CO₂ sources, maximum storage capacity for different sinks, and compensatory power makeup,

carbon footprint are considered as uncertain parameters. When compared with the worst-case based robust approach, the robust MILP formulation provides significant solution options.

In the fourth part, we present an innovative approach for nominal short-term scheduling of multi-stage multiproduct batch plants based on a unit-specific continuous time-based MILP model. The novelty in the presented formulation is to explore the possibility of allowing the processing of orders across different stages to be at the same event point. Three different objectives are solved. The obtained results show that the developed model is much more effective in finding the optimal solutions using a fewer number of events than its global event-based counterpart.

All the proposed methodologies are validated on examples from the literature. The improved and converged objective function values are obtained with a lesser number of events.

Keywords: Planning and Scheduling, Preventive scheduling, Reactive scheduling, Robust optimization, Carbon capture and storage, Multi-stage scheduling

सार

वास्तविक औद्योगिक अनुप्रयोग में, योजना और समय-निर्धारण का अनुकूलन एक सतत गतिशील प्रक्रिया है जहां अनुकूलन मापदंडों का अप्रत्याशित व्यवधान अपरिहार्य है। इस थीसिस का उद्देश्य उत्पादन योजना और शेड्यूलिंग समस्याओं में अनिश्चित मापदंडों पर विचार करने के लिए एक सामान्य कार्यप्रणाली विकसित करना है। योजना और शेड्यूलिंग के स्तर पर उत्पन्न होने वाली विभिन्न चुनौतियाँ मॉडल निर्माण मुद्दों और बड़े पैमाने की समस्याओं को हल करते समय कम्प्यूटेशनल समय से जुड़ी होती हैं। फिर भी, ऐसे मॉडलों के कार्यान्वयन से विनिर्माण प्रणालियों की समग्र दक्षता में सुधार होता है।

पहले भाग में, हम उत्पादन शेड्यूलिंग और रखरखाव गतिविधियों के एकीकरण की समस्या पर विचार करते हैं। दृष्टिकोण राज्य-कार्य-नेटवर्क (एसटीएन) प्रक्रिया प्रतिनिधित्व का उपयोग करके इकाई-विशिष्ट निरंतर समय-डोमेन प्रतिनिधित्व पर आधारित है जो मिश्रित पूर्णांक रैखिक प्रोग्रामिंग (एमआईएलपी) तैयार करने के लिए अग्रणी है। विचार किए गए दो मॉडलों के बीच, यह देखा गया है कि मॉडल M1 अन्य मॉडल M2 की तुलना में कम संख्या में घटनाओं के साथ इष्टतम समाधान देता है।

दूसरे भाग में, हम बहुउद्देशीय बैच संयंत्रों के लिए व्यावहारिक प्रतिक्रियाशील शेड्यूलिंग दृष्टिकोण तैयार करते हैं। इस काम में, एक कुशल MILP मॉडल का उपयोग करके अल्पकालिक पुनर्निर्धारण समस्याओं के लिए दो-चरण समाधान तकनीक तैयार की जाती है। तीन प्रकार की गड़बड़ी वाले दो मॉडल माने जाते हैं। यह देखा गया है कि यूनिट ब्रेकडाउन के मामले में मॉडल एम2 की तुलना में मॉडल एम1 बेहतर लाभ देता है।

तीसरे भाग में, कार्बन कैप्चर और स्टोरेज (सीसीएस) रेट्रोफिट की योजना के लिए एक मजबूत MILP मॉडल CO₂ उत्सर्जन में कमी को अधिकतम करने के लिए विकसित किया गया है। मॉडल में, CO₂ स्रोतों के परिचालन जीवन का अंतिम समय, विभिन्न सिंक के लिए अधिकतम भंडारण क्षमता, और प्रतिपूरक

शक्ति मेकअप, कार्बन फुटप्रिंट को अनिश्चित मापदंडों के रूप में माना जाता है। जब सबसे खराब स्थिति आधारित मजबूत दृष्टिकोण के साथ तुलना की जाती है, तो मजबूत एमआईएलपी फॉर्मूलेशन महत्वपूर्ण समाधान विकल्प प्रदान करता है।

चौथे भाग में, हम एक इकाई-विशिष्ट निरंतर समय-आधारित MILP मॉडल के आधार पर बहु-स्तरीय बहु-उत्पाद बैच संयंत्रों के नाममात्र अल्पकालिक शेड्यूलिंग के लिए एक अभिनव दृष्टिकोण प्रस्तुत करते हैं। प्रस्तुत फॉर्मूलेशन में नवीनता एक ही घटना बिंदु पर विभिन्न चरणों में आदेशों के प्रसंस्करण की अनुमति देने की संभावना का पता लगाने के लिए है। तीन अलग-अलग उद्देश्यों को हल किया जाता है। प्राप्त परिणाम बताते हैं कि विकसित मॉडल अपने वैश्विक घटना-आधारित समकक्ष की तुलना में कम संख्या में घटनाओं का उपयोग करके इष्टतम समाधान खोजने में अधिक प्रभावी है।

सभी प्रस्तावित कार्यप्रणाली साहित्य से उदाहरणों पर मान्य हैं। कम संख्या में ईवेंट के साथ बेहतर और अभिसरण उद्देश्य फ़ंक्शन मान प्राप्त किए जाते हैं।

कीवर्ड: प्लानिंग और शेड्यूलिंग, प्रिवेंटिव शेड्यूलिंग, रिएक्टिव शेड्यूलिंग, मजबूत ऑप्टिमाइजेशन, कार्बन कैप्चर और स्टोरेज, मल्टी-स्टेज शेड्यूलिंग

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