

RESOURCE CONSTRAINED OPTIMAL OPERATION OF INDUSTRIAL PROCESSES

ROHIT OMAR



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**RESOURCE CONSTRAINED OPTIMAL OPERATION OF
INDUSTRIAL PROCESSES**

by

Rohit Omar

Department of Chemical Engineering

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in fulfillment of the requirements for the degree of Doctor of Philosophy

to the



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Dedicated to

My Spiritual master H.H. Gopal Krishna Goswami Maharaj and my parents

CERTIFICATE

I am satisfied that the thesis presented by **Mr. Rohit Omar** on “*Resource Constrained Optimal Operation of Industrial Processes*” 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 award of any degree/diploma.

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



Prof. Munawar A. Shaik
Associate Professor
Department of Chemical Engineering
Indian Institute of Technology, Delhi
New Delhi - 110016

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(Rohit Omar)

ABSTRACT

Continuous and semi-continuous plants cater to large demands to produce different fast moving consumer goods (FMCG), petrochemicals, polymers and fertilizer products. Make and pack production processes handle products that are consumed immediately and sold in large quantities. Several researchers have solved scheduling problems in this area with different modeling approaches. However, there are still challenging concerns for large scale plants. Among the different time representations available, the unit-specific event-based continuous time representation has evolved as one of the most efficient formulation. The objectives of this thesis are to generalize and enhance previous scheduling models for better handling of sequencing constraints, different storage policies such as finite intermediate storage (FIS), unlimited intermediate storage (UIS), and no intermediate storage (NIS) or zero wait (ZW), integration of maintenance and scheduling, and handling of mixed batch and continuous processes.

In this thesis, we present models for short-term scheduling of continuous/semi-continuous plants based on conditional sequencing, where a consumption task is conditionally aligned to a production task only if it receives material from the production task, otherwise if material is received from storage then sequencing is relaxed. In contrast to the rigorous modeling of storage adapted in the literature, in this work we propose an approximate modeling of storage, without the need for considering storage as a separate task, leading to reduction in number of events based on conditional sequencing. Four-index binary and continuous variables are used to handle conditional sequencing and approximate modeling of storage by modifying the material balances and sequencing constraints in the earlier models. Additionally, the conditional sequencing model has been extended to handle integration of planned maintenance and scheduling operations, resulting in Gantt charts which avoid unnecessary unit idle times.

The proposed approaches are validated using different instances of a motivating example along with literature examples resulting in improved objective function value and/or the converged objective value is found using lesser number of events. The proposed model has been extended to handle mixed batch and continuous processes with resource constraints, which has been demonstrated on two case studies resulting in better objective values. The scheduling model has also been applied to single-stage continuous plants. The proposed models result in better model statistics in many instances and give better objective values requiring either same or lesser number of events.

Keywords: Scheduling, Optimization, Unit-Specific Events, State-task-networks, Conditional Sequencing, Approximate Modeling of Storage, Planned Maintenance, Continuous Plants, Mixed Batch and Continuous Process.

सार

निरंतर और अर्ध-निरंतर पौधे विभिन्न तेजी से बढ़ते उपभोक्ता सामान (एफएमसीजी), पेट्रोकेमिकल, पॉलिमर और उर्वरक उत्पादों का उत्पादन करने के लिए बड़ी मांगों को पूरा करते हैं। उत्पादन और उत्पादन प्रक्रियाएं उन उत्पादों को संभालती हैं जो तुरंत खपत होती हैं और बड़ी मात्रा में बेचा जाता है। कई शोधकर्ताओं ने अलग-अलग मॉडलिंग दृष्टिकोणों के साथ इस क्षेत्र में शेड्यूलिंग समस्याओं को हल किया है। हालांकि, बड़े पैमाने पर संयंत्रों के लिए अभी भी चुनौतीपूर्ण चिंताएं हैं। उपलब्ध विभिन्न समय अभ्यावेदन के बीच, इकाई-विशिष्ट घटना-आधारित निरंतर समय निरूपण सबसे कुशल सूत्रीकरण के रूप में विकसित हुआ है। इस थीसिस के उद्देश्य अनुक्रमण बाधाओं की बेहतर हैंडलिंग के लिए पिछले शेड्यूलिंग मॉडल को सामान्य बनाना और बढ़ाना है, विभिन्न भंडारण नीतियां जैसे कि परिमित मध्यवर्ती भंडारण (FIS), असीमित मध्यवर्ती भंडारण (UIS), और कोई मध्यवर्ती भंडारण (NIS) या शून्य प्रतीक्षा (ZW), रखरखाव और शेड्यूलिंग का एकीकरण, और मिश्रित बैच और निरंतर प्रक्रियाओं से निपटने।

इस थीसिस में, हम सशर्त अनुक्रमण के आधार पर निरंतर / अर्ध-निरंतर पौधों के अल्पकालिक शेड्यूलिंग के लिए मॉडल पेश करते हैं, जहां उपभोग कार्य सशर्त रूप से उत्पादन कार्य से जुड़ा होता है, यदि यह उत्पादन कार्य से सामग्री प्राप्त करता है, अन्यथा यदि सामग्री प्राप्त होती है भंडारण से फिर अनुक्रमण को आराम मिलता है। साहित्य में अनुकूलित भंडारण के कठोर मॉडलिंग के विपरीत, इस काम में हम भंडारण के एक अनुमानित मॉडलिंग का प्रस्ताव रखते हैं, भंडारण को एक अलग कार्य के रूप में विचार किए बिना, सशर्त अनुक्रमण के आधार पर घटनाओं की संख्या में कमी के लिए अग्रणी। चार-सूचकांक द्विआधारी और निरंतर चर

का उपयोग सशर्त अनुक्रमण और भंडारण के अनुमानित मॉडलिंग को संभालने के लिए किया जाता है, जो पहले के मॉडल में सामग्री संतुलन और अनुक्रमण बाधाओं को संशोधित करके भंडारण का अनुमानित मॉडलिंग करता है। इसके अतिरिक्त, सशर्त अनुक्रमण मॉडल को नियोजित रखरखाव और शेड्यूलिंग संचालन के एकीकरण को संभालने के लिए बढ़ाया गया है, जिसके परिणामस्वरूप गैंट चार्ट हैं जो अनावश्यक इकाई निष्क्रिय समय से बचते हैं।

प्रस्तावित दृष्टिकोण अलग-अलग उदाहरणों के साहित्य उदाहरणों के साथ-साथ साहित्य उदाहरणों के उपयोग से मान्य किए जाते हैं, जिसके परिणामस्वरूप बेहतर उद्देश्य फंक्शन मूल्य और / या परिवर्तित उद्देश्य मान घटनाओं की कम संख्या का उपयोग करके पाया जाता है। प्रस्तावित मॉडल को मिश्रित बैच और संसाधन बाधाओं के साथ निरंतर प्रक्रियाओं को संभालने के लिए विस्तारित किया गया है, जिसे दो केस अध्ययनों पर प्रदर्शित किया गया है जिसके परिणामस्वरूप बेहतर उद्देश्य मान हैं। शेड्यूलिंग मॉडल को एकल-चरण निरंतर पौधों पर भी लागू किया गया है। प्रस्तावित मॉडल कई उदाहरणों में बेहतर मॉडल आंकड़े देते हैं और बेहतर उद्देश्य मान देते हैं, जिसमें समान या कम घटनाओं की आवश्यकता होती है।

कीवर्ड: शेड्यूलिंग, ऑप्टिमाइज़ेशन, यूनिट-स्पेसिफिक इवेंट्स, स्टेट-टास्क-नेटवर्क, कॉन्डिशनल सीक्वेंसिंग, स्टोरेज की अनुमानित मॉडलिंग, प्लान्ड मेंटेनेंस, कंटीन्यूअस प्लांट्स, मिक्स्ड बैच और कंटीन्यूअस प्रोसेस।

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ABBREVIATIONS

CPU	Computational Processing Unit
CW	Cooling Water
DFIS	Dedicated Finite Intermediate Storage
FFIS	Flexible Finite Intermediate Storage
FIS	Finite Intermediate Storage
FMCG	Fast Moving Consumer Goods
GA	Genetic Algorithm
MILP	Mixed Integer Linear Programming
MINLP	Mixed Integer Non-Linear Programming
MRP	Material Requirement Planning
NIS	No Intermediate Storage
RMIP	Relaxed Mixed Integer Programming
RTN	Resource-task-network
SSN	State-sequence-network
STN	State-task-network
UIS	Unlimited Intermediate Storage
ZW	Zero Wait