# DYNAMIC SCHEDULING OF CRUDE OIL UNLOADING AND BLENDING USING GENETIC ALGORITHM

**DEBASHISH PANDA**

DEPARTMENT OF CHEMICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
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# DYNAMIC SCHEDULING OF CRUDE OIL UNLOADING AND BLENDING USING GENETIC ALGORITHM

***by***

**DEBASHISH PANDA**
**Department of Chemical Engineering**

**Submitted**
**In fulfillment of the requirement of DOCTOR OF PHILOSOPHY**
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I would like to dedicate this thesis to my parent

# Certificate

This is to certify that the thesis titled "**Dynamic Scheduling of Crude Oil Unloading and Blending using Genetic Algorithm**" being submitted by Mr. Debashish Panda in the Department of Chemical Engineering, Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy, in chemical Engineering, is a record of the original, bonafide research work carried out by him under my guidance and supervision. In my opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree. The results contained in this thesis have not been submitted for the award of any other degree, associateship or similar title of any university or institute.

Dr. Manojkumar Ramteke

Department of Chemical engineering

Indian Institute of Technology Delhi

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# Abstract

Crude oil supply about 33% of the total energy consumption worldwide and is predominantly (>50%) processed in marine access refineries. Therefore, crude oil scheduling which enables the efficient processing of the crude to increase the profitability is an important problem. It often becomes challenging due to the presence of combinatorial constraints, discrete variables and uncertainties. The common uncertainties which are present in the refineries are product demand, ship arrival delay and tank unavailability. The schedule available for a nominal condition may not remain feasible under uncertain condition. Therefore, it is necessary to develop algorithms which can generate schedules under uncertain conditions.

First, the demand uncertainty in crude oil refinery is studied. A proactive two-stage approach is developed to solve such optimization problems. A discrete-time model is used with structure adapted genetic algorithm (SAGA) for solving single- and multi-objective scheduling optimizations. In the first stage, an initial schedule is generated with the nominal parameters provided a priory. The same schedule is then checked and accepted in the second stage only if it is robust with respect to demand uncertainty. The increased demand of 10% can be utilized in robust schedule to improve the profitability by 9, 9, 8 and 5.5%, respectively compared to nominal schedule for examples 1, 2, 3 and 4. Second, a reactive approach is developed in which the uncertainty is not known before generating the schedule. The schedule is kept same up to the realization of uncertainty and after that the rescheduling is carried out to incorporate the uncertainty. Third, the pros and cons of using preventive and reactive scheduling approaches to handle a commonly encountered tank unavailability uncertainty are analyzed. Based on these, a new hybrid approach which combines both the features from preventive and reactive approach is developed. The comparison shows that the profit values of reactive and hybrid approaches of

SAGA are close to the exact optimum solutions obtained using MINLP formulation with average deviations of 2 and 3 %, respectively. The comparison of the preventive approach shows 7 % average deviation compared to MINLP formulation. Fourth, the uncertainty in the downstream operation in a refinery is handled using graphical genetic algorithm. The uncertainties such as component quality and order demand fluctuations are handled. The objective function in the single objective formulation is the maximization of profit for first three case studies. However, in multi-objective optimization, an additional objective of minimization of fluctuation in crude oil supply to crude distillation units is used as it provides better control and operability of the plant for the first three case studies. The objective function for the fourth case study is to minimize operating cost for single objective formulation. On an average, results show 10, 10, and 5% reduction in operating cost by rescheduling with respect to that for without rescheduling for example 1, 2, and 3, respectively. Also, the obtained reschedules are 83, 85, and 86 % similar to the nominal schedules for example 1, 2, and 3 respectively which facilitate the smooth implementation of the reschedule. However, in multi-objective optimization, an additional objective of minimization of fluctuation in blender processing rate is added along with minimizing operating cost.

# सार

दुनिया भर में कुल ऊर्जा खपत का लगभग ३३% कच्चे तेल की आपूर्ति करता है और मुख्य रूप से (>५0%) समुद्री एक्सेस रिफाइनरियों में संसाधित होता है। इसलिए, कच्चे तेल का समय-निर्धारण, जो लाभप्रदता बढ़ाने के लिए कच्चे तेल के कुशल प्रसंस्करण को सक्षम बनाता है, एक महत्वपूर्ण समस्या है। यह अक्सर दहनशील बाधाओं, असतत चर और अनिश्चितताओं की उपस्थिति के कारण चुनौतीपूर्ण हो जाता है। रिफाइनरियों में मौजूद आम अनिश्चितताएं उत्पाद की मांग, जहाज के आगमन में देरी और टैंक की अनुपलब्धता हैं। नाममात्र की स्थिति के लिए उपलब्ध शेड्यूल अनिश्चित स्थिति में संभव नहीं हो सकता है। इसलिए, एल्गोरिदम विकसित करना आवश्यक है जो अनिश्चित परिस्थितियों में शेड्यूल उत्पन्न कर सकता है।

सबसे पहले, कच्चे तेल रिफाइनरी में अनिश्चितता का अध्ययन किया जाता है। इस तरह की अनुकूलन समस्याओं को हल करने के लिए एक सक्रिय दो-चरण दृष्टिकोण विकसित किया जाता है। एक असतत-समय मॉडल का उपयोग एकल और बहुउद्देश्यीय समयबद्धन अनुकूलन को हल करने के लिए संरचना अनुकूलित आनुवंशिक एल्गोरिथ्म (एसएजीए) के साथ किया जाता है। पहले चरण में, एक प्रारंभिक अनुसूची नाममात्र मापदंडों के साथ उत्पन्न होती है जो एक पुजारी प्रदान करती है। उसी अनुसूची को तब दूसरे चरण में जांचा और स्वीकार किया जाता है, जब वह अनिश्चितता की मांग के संबंध में मजबूत हो। १0% की बढ़ी हुई मांग को ९, ९, ८ और ५. ५% तक लाभप्रदता में सुधार करने के लिए मजबूत अनुसूची में उपयोग किया जा सकता है, क्रमशः उदाहरण १, २, ३ और ४ के लिए नाममात्र अनुसूची की तुलना में। दूसरा, एक प्रतिक्रियात्मक दृष्टिकोण विकसित किया गया है जिसमें शेड्यूल जनरेट करने से पहले अनिश्चितता ज्ञात नहीं है। अनुसूची को अनिश्चितता की प्राप्ति तक ही रखा जाता है और उसके बाद अनिश्चितता को शामिल करने के लिए पुनर्निर्धारण किया जाता है। तीसरा, एक आम तौर पर सामना करना पड़ा टैंक अपरिहार्य अनिश्चितता को संभालने के लिए निवारक और प्रतिक्रियाशील समयबद्धन दृष्टिकोण का उपयोग करने के पेशेवरों और विपक्षों का विश्लेषण किया जाता है। इनके आधार पर, एक नया संकर दृष्टिकोण जो निवारक और प्रतिक्रियाशील दृष्टिकोण से दोनों विशेषताओं को जोड़ता है, विकसित किया गया है। तुलना से पता चलता है कि एसएजीए के प्रतिक्रियाशील और संकर दृष्टिकोणों के लाभ मूल्य क्रमशः २ और ३% के औसत विचलन

के साथ MINLP सूत्रीकरण का उपयोग करके प्राप्त सटीक इष्टतम समाधानों के करीब हैं। प्रतिबंधात्मक दृष्टिकोण की तुलना में MINLP फॉर्मूलेशन की तुलना में ७% औसत विचलन दिखाई देता है। चौथा, रिफाइनरी में डाउनस्ट्रीम ऑपरेशन में अनिश्चितता को ग्राफिकल आनुवंशिक एल्गोरिथ्म का उपयोग करके नियंत्रित किया जाता है। घटक गुणवत्ता और ऑर्डर डिमांड में उतार-चढ़ाव जैसी अनिश्चितताओं को नियंत्रित किया जाता है। एकल उद्देश्य सूत्रीकरण में वस्तुनिष्ठ कार्य पहले तीन मामलों के अध्ययन के लिए लाभ का अधिकतमकरण है। हालांकि, बहुउद्देश्यीय अनुकूलन में, कच्चे तेल की आपूर्ति में कच्चे आसवन इकाइयों में उतार-चढ़ाव को कम करने का एक अतिरिक्त उद्देश्य उपयोग किया जाता है क्योंकि यह पहले तीन मामलों के अध्ययन के लिए संयंत्र का बेहतर नियंत्रण और संचालन क्षमता प्रदान करता है। चौथे मामले के अध्ययन के लिए उद्देश्य समारोह एकल उद्देश्य निर्माण के लिए परिचालन लागत को कम करना है। औसतन, परिणाम १0, १0, और ५% की कमी को क्रमशः १, २, और ३ उदाहरण के लिए पुनर्निर्धारण किए बिना उस के संबंध में पुनर्निर्धारण द्वारा परिचालन लागत को दर्शाता है। इसके अलावा, प्राप्त किए गए पुनर्निर्धारण क्रमशः ८३, ८५, और ८६% नाममात्र अनुसूचियों के समान हैं, उदाहरण के लिए क्रमशः १, २ और ३, जो पुनर्निर्धारित के सुचारू कार्यान्वयन की सुविधा प्रदान करते हैं। हालांकि, बहु-उद्देश्यीय अनुकूलन में, परिचालन लागत को कम करने के साथ-साथ ब्लेंडर प्रसंस्करण दर में उतार-चढ़ाव को कम करने का एक अतिरिक्त उद्देश्य जोड़ा जाता है।

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# Nomenclature

| | |
|---|---|
| B | Number of blender |
| $C_c$ | Cost factor for each changeover |
| $C_d$ | Demurrage cost factor |
| CDU | Crude distillation unit |
| $C_i$ | Cost factor associated if the total inventory in the tanks is less than the safety stock limit, $L$ |
| $C_n$ | Amount of crude processed of $n^{th}$ type |
| $CP_u$ | Total amount of crude processed in $u^{th}$ CDU |
| DE | Differential evolution |
| e(b,m,t) | Connection from the blender $b$ to product tank $m$ at any time period $t$ |
| e(b,n,t) | Connection of blender $b$ to component tank $n$ at time period $t$ |
| e(b,p,t) | Connection from the blender $b$ producing the product type $p$ at any time period $t$ |
| e(m,b,t) | Connection from the product tank $m$ to blender $b$ to at any time period $t$ |
| e(m,o,t) | Connection from the product tank $m$ to order $o$ to at any time period $t$ |
| e(n,b,t) | Connection from a component tank $n$ to blender $b$ at any time period $t$ |
| $e_i$ | Edge at $i^{th}$ location |
| $F_{1,\ nominal}$ | Objective function 1 for profit maximization |
| $f_{u,j,t}$ | Amount of crude fed to $u^{th}$ CDU from $j^{th}$ tank at any time period t |
| GA | Genetic algorithm |
| $J$ | Total number of VLCCs to be unloaded |
| KC | Key component |
| $KC_{l,r,}$ | Value of $l^{th}$ key component in $r^{th}$ unit at time period $t$ |
| $K_i$ | Large constant used in hard or bracketed penalties for constraint violations |

| | |
|---|---|
| L | Safety stock limit |
| *M* | Total number of changeovers |
| N | Number of component tank |
| N | Total number of crude parcels processed |
| $N_{GEN1}$ | Number of generations used for robust optimization loop |
| $N_{GEN2}$ | Total number of generations used in preventive SAGA |
| O | number of order |
| *Q* | Total number of quality parameters |
| $R_{m,t}$ | Binary variable which takes the value of 1 if there is a changeover in two successive periods, otherwise takes the value of 0 |
| *S* | Total number of tank |
| SAGA | Structure adapted genetic algorithm |
| SBM | Single buoy mooring |
| T | Time horizon |
| $t_j^a$ | Arrival periods of *j*th VLCC |
| $t_j^u$ | Unloading periods of *j*th VLCC |
| *U* | Total number of CDUs |
| VDU | Vacuum distillation unit |
| VLCC | Very large crude carrier |
| $V_{s,t}$ | Inventory in the sth tank at any period *t* |
| $W_i$ | Weight of corresponding ith edge |
| $X_{b,t}$ | Processing rate of blender *b* at time period *t* |
| $X_n$ | Selling price of nth crude type |