대규모 산업의 공급사슬 최적화를 위한 새로운 범위이동 접근법

송제훈[1], 이그나시오 이 그로스만[2], 박선원[1]
한국과학기술원 생명화학공학과[1], 카네기멜론대학교 화학공학과[2]

A New Rolling Horizon Approach for Supply Chain Optimization of Large Scale Industry

Jehoon Song[1], Ignacio E. Grossmann[2], Sunwon Park[1]
Department of Chemical and Biomolecular Engineering, KAIST[1]
Department of Chemical Engineering, Carnegie Mellon University[2]

Introduction

Supply Chain Management (SCM), regarded as a crucial management paradigm for enterprise's survival in the 21st century, is a win-win strategy among enterprises. It pursues cost reductions and profit improvements by maximizing customer satisfaction. This is accomplished by removing unnecessary or inefficient elements in supply chains using Information Technology (IT). Supply Chain Optimization in contrast is a systematic and mathematical approach that supports optimal choice among various alternatives to achieve the goal of supply chains with a global visibility. Accordingly, SCO plays an important role for decision-makers in various industries in that its results can provide guidelines for the optimal planning of execution of supply chains.

Not less important is the oil refinery industry because its large scale operation and complex supply chains. Therefore, there would be scope to maximize economical benefits through SCO. However, there are still few developments for the large scale supply chains of refinery industry. Several works deal with planning, scheduling and design on individual sections if the whole supply chains are divided into three sections such as source, production, and distribution. In order to make more profits or reduce more costs on the whole supply chains, they should be considered at the same time.

In this paper, we develop an extended SCO model for refinery industry. It consists of several echelons because the supply chains from crude oil suppliers to customers involve storage and blending tank network before Crude Distillation Unit (CDU), and product distribution network after the CDU. Accordingly, it has a large number of integer decision variables, which cause complexity for solving a Mixed Integer Linear Programming (MILP) problem. Additionally, we consider transportation delays of materials that make the MILP problem more difficult to solve because the time horizon must be extended. Since the proposed problem cannot be solved in reasonable time due to the many integer variables, we propose a technique to decompose the problem. We use a rolling horizon approach. However, it is not a new approach originally. So we add aggregation concept into the rolling horizon approach.

SCO Model for Refinery Industry

A typical supply chains for refinery industry is shown in Figure 1. The assumptions used by Lee et al.[1], Park et al.[2], and Song et al.[3] are used for the mathematical formulation of the model. The objective of this problem is to maximize the total profit. the objective function, total profit, is expressed as follows: Total profit = Revenue - Crude oil purchase cost - Crude oil transportation cost - Tank inventory cost - Changeover cost - Operating cost - Distribution inventory cost - Product transportation cost - Shortage penalty cost.

The constraints used in this model are as follows[1-3].

$$VS_{it} = VS_{it-1} + \sum_v FVS_{vit} - \sum_j FSB_{ijt}, \quad \forall i,t \qquad VS_{it} \le VS_i^{max}, \quad \forall i,t$$

$$VS_{it} \ge VS_i^{min}, \quad \forall i,t \qquad FVS_{vit} = FVS_{vi}^{max} \cdot YVS_{vit}, \quad \forall v,i,t$$

$$FSB_{ijt} = FSB_{ij}^{max} \cdot YSB_{ijt}, \quad \forall v,i,t \qquad YVS_{vit} \le LVS_{vit}, \quad \forall v,i,t$$

$$YSB_{ijt} \le LSB_{ijt}, \quad \forall i,j,t \qquad VB_{jt} = VB_{jt-1} + \sum_i FSB_{ijt} - \sum_l FBC_{jlt}, \quad \forall j,t$$

$$VB_{jt} \le VB_j^{max}, \quad \forall j,t \qquad VB_{jt} \ge VB_j^{min}, \quad \forall j,t$$

$$FBC_{jlt} \le FBC_{jl}^{max} \cdot YBC_{jlt}, \quad \forall j,l,t \qquad FBC_{jlt} \ge FBC_{jl}^{min} \cdot YBC_{jlt}, \quad \forall j,l,t$$

$$YBC_{jlt} \le LBC_{jl}, \quad \forall j,l,t \qquad \sum_j YBC_{jlt} = 1, \quad \forall l,t$$

$$YSB_{ijt} \le 1 - \sum_l YBC_{jlt}, \quad \forall i,j,t \qquad ZBC_{jlt} \ge YBC_{jlt-1} - YBC_{jlt}, \quad \forall j,l,t$$

$$VB_{jt} \cdot KB_{jk} = VB_{jt-1} \cdot KB_{jk} + \sum_i FSB_{ijt} \cdot KS_{ik} - \sum_l FBC_{jlt} \cdot KB_{jk}, \quad \forall j,k,t$$

$$VP_{pt} = VP_{pt-1} + PROD_{pt} - \sum_d FPD_{pdt}, \quad \forall p,t \qquad VP_{pt} \le VP_p^{max}, \quad \forall p,t$$

$$PROD_{pt} = \sum_j \sum_l (PROR_{jlp} \cdot FBC_{jlt}), \quad \forall p,t$$

$$VD_{pdt} = VD_{pdt-1} + FPD_{pdt-\beta} - \sum_g FDG_{pdgt}, \quad \forall p,d,t \qquad VD_{pdt} \le VD_{pd}^{max}, \quad \forall p,d,t$$

$$VG_{pgt} = VG_{pgt-1} + \sum_d FDG_{pdgt-\gamma} - \sum_c FGC_{pgct}, \quad \forall p,g,t \qquad VG_{pgt} \le VG_{pg}^{max}, \quad \forall p,g,t$$

$$\sum_g FGC_{pgct} \le DM_{pct}, \quad \forall p,c,t, \qquad \sum_d FDG_{pdgt} \le \sum_c DM_{pct} \cdot LGC_{gc}, \quad \forall p,g,t$$

$$\sum_c FGC_{pgct} \le VG_{pgt-1}, \quad \forall p,g,t \qquad \sum_g FDG_{pdgt} \le DM_{pdt-1}, \quad \forall p,d,t$$

$$\sum_d FPD_{pdt} \le VP_{pt-1}, \quad \forall p,t$$

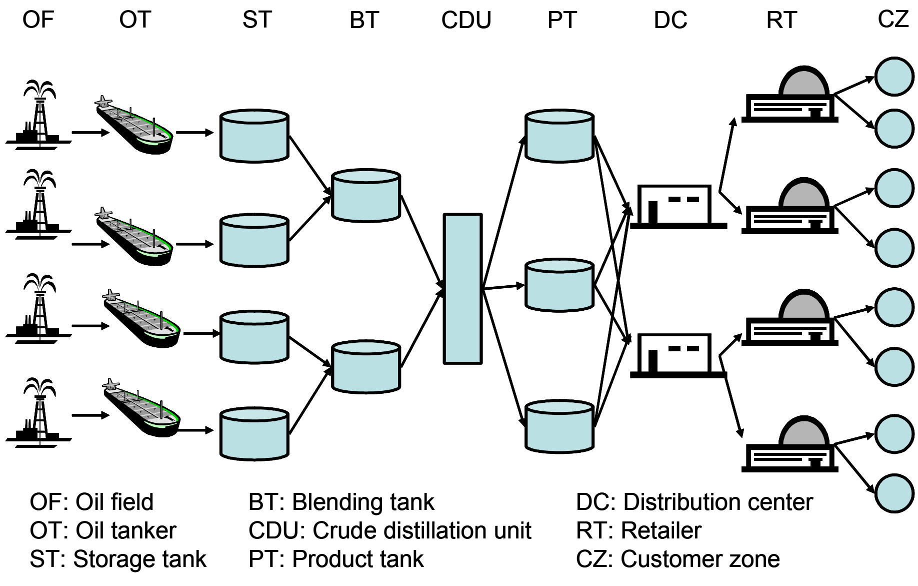

Figure 1. Typical supply chain for refinery industry.

Solution Strategy

Honkomp et al.[4] pointed out one of the reasons that make the problem difficult to solve is that the problem size becomes huge while considering industrial scale. Bassett et al.[5] presented several decomposition methods for the solution of a large scale scheduling problem. They mainly focused on time-based decomposition approaches, especially rolling horizon approach. Even though we cannot guarantee that the approach will give us the optimal solution, there are many papers saying it is useful when the whole optimization is impossible to solve in reasonable time[6-10]. In this paper, we propose a new rolling horizon approach to solve a supply chain optimization problem for large scale refinery industry. The concept is shown in Figure 2. The strategy is to solve several short-term (e.g. 15 days) optimization problems instead of solving over the whole (e.g. 30 days) optimization horizon at just one time. In order to consider the rest of the horizon after the 15th day (see optimization 1 in Figure 2), we aggregate the remaining days into one day, which has the average value of the demands. This aggregation means that we can consider the whole horizon without so much addition of computational burden. After solving optimization 1 problem, just 5 days are fixed as a part of total solution. The rest of the results are discarded. In this way, optimization 2 problem (starting from the 6th day) is solved. If there is no intervals to be aggregated (e.g. optimization 4-6), we just solve without aggregation.

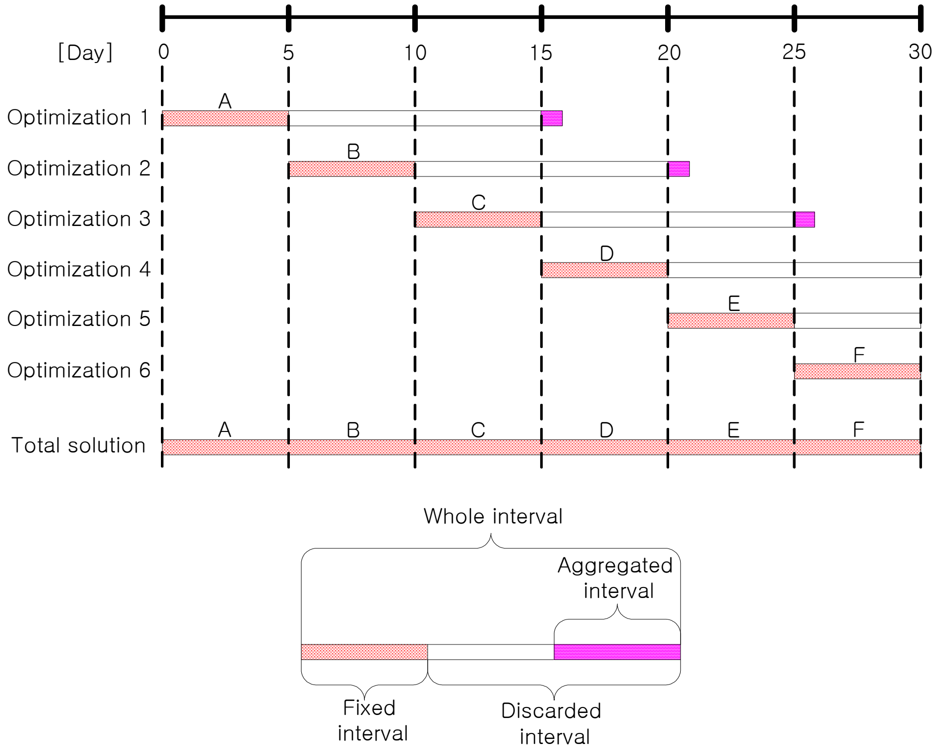

Figure 2. Rolling horizon approach with aggregation concept.

Illustrative Example

The whole supply chains include four oil fields, four oil tankers which transport four different crude oils respectively, four storage tanks, two blending tanks, one CDU, three products in three product tanks, two distribution centers, four retailers, and eight customer zones. The SCO model involves 780 discrete variables, 3021 continuous variables, and 4431 equations. This MILP model was solved with CPLEX 7.0 in GAMS 3.0[11] on a PC operated with Pentium 4 2.4GHz. The optimal criterion was 0.00001 in the model.

Varying the fixed interval, we solved the whole 30 day optimization problem with a rolling horizon approach. The results are shown in Table 1. In this example, the objective values of all problems but 15 day fixed interval problem are same as the 30 day fixed interval problem, which is the original optimization problem. However The CPU time decreased dramatically compared with the original problem.

Table 1. Total profit and CPU time of each optimization problem with various fixed interval.

Fixed interval at each optimization	Total profit	Total profit gap (%)	CPU time (sec.)	CPU time ratio (%)
30 day (whole)	19656.3	-	11240.5	100
15 day	19655.9	0.002	1.9	0.017
5 day	19656.3	0.000	5.3	0.047
3 day	19656.3	0.000	9.6	0.085
1 day	19656.3	0.000	34.3	0.305

Conclusion

A rolling horizon with the aggregation concept approach for supply chain optimization of large scale refinery industry is addressed in this paper. The optimization problem which has a difficulty to solve in reasonable time due to so long optimization horizon can be solved in relatively short time, although the optimality is not guaranteed. However, there is not so much difference in objective function values in this model. We can easily solve an optimization problem involving a long time horizon, if we must get feasible but near optimal solution fast.

Acknowledgement

This work was partially supported by the Brain Korea 21 Project and the Center for Ultramicrochemical process systems sponsored by KOSEF and SK Engineering and Construction Co., Ltd.

References

1. Lee, H., Pinto, J. M., Grossmann, I. E. and Park, S.: *Ind. Eng. Chem. Res.*, **35**, 1630(1996).
2. Park, H., Bok, J.-K. and Park, S.: *J. of Chem. Eng. Japan*, **34**, 411(2001).
3. Song, J., Park, H., Lee, D.-Y. and Park, S.: *Ind. Eng. Chem. Res.*, accepted.
4. Honkomp, S., Lombardo, S., Rosen, O. and Pekny, J. F.: *Comput. Chem. Eng.*, **24**, 323(2000).
5. Bassett, M. H., Pekny, J. F. and Reklaitis, G. V.: *AIChE J.*, **42**, 3373(1996).
6. Dimitriadis, A. D., Shah, N. and Pantelides, C. C.: *Comput. Chem. Eng.*, **21**, S1061(1997).
7. Stauffer, L. and Liebling, Th. M.: *Ann. Oper. Res.*, **69**, 323(1997).
8. Singer, M.: *Comput. Oper. Res.*, **28**, 193(2001).
9. Lin, X., Floudas, C. A., Modi, S. and Juhasz, N. M.: *Ind. Eng. Chem. Res.*, **41**, 3884(2002).
10. Wilkinson, S. J., Shah, N. and Pantelides, C. C.: *Comput. Chem. Eng.*, **19**, S583(1995).
11. Brook, A., Kendrick, D., Meeraus, A. and Raman, R.: "GAMS - a user's guide", GAMS Development Corp., Washington, DC(1998).