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Inclusion of Long-term Production Planning/Scheduling into Real-time Optimization

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Abstract: This work focuses on making the best possible decision at the RTO level, when it is not economically viable to have implemented a full Production scheduling and business planning optimization. It attempts to merge some of the longer-term decisions that are done in the production scheduling and inventory management into the RTO, thereby minimizing the total cost of implementations while attempting to get some of the benefits that a full production/inventory scheduling activity would bring. In the current work a decision on inventory levels is done within RTO by solving the optimization problem over a longer horizon and by augmenting the objective function for RTO with inventory cost based on historical average of marginal cost. The objective function in RTO is based on minimization of costs, and minimization of the proposed objective function leads to an overall reduction of long term marginal cost. A case study is presented in which average marginal cost is considered greater and lower than the current cost of production and shows that the long term marginal cost reduces over a period of time.

Keywords: Real-time Optimization, Scheduling and Planning, Inventory Management, Marginal Cost

1. INTRODUCTION

In industrial setting different levels of optimization problems are solved to make a decision. Five different levels of optimization are shown in Figure 1 as: PID Control, MPC, RTO, Production Scheduling and Business Planning (Darby *et al.*, 2011). However, doing all the optimizations is not economically viable and hence only some of the levels can be implemented. But to take advantage of some of the longer-term decisions made in Production Scheduling and Business Planning in the RTO level; RTO optimization can be augmented with relevant costs and solved over a longer horizon.

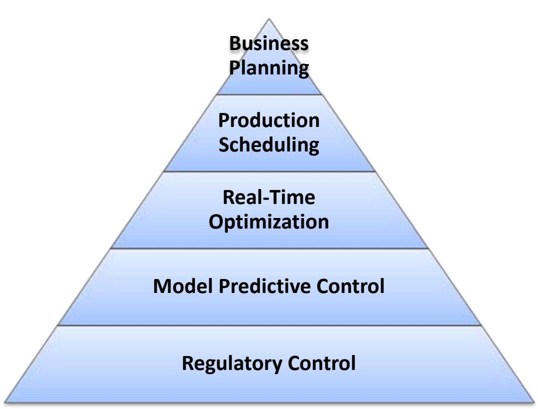

Figure 1: Different Levels of Optimization

In the current work RTO is used to make decisions on plant production rates given a system of multiple plants making same product and varying plant efficiency with respect to cost. This kind of system usually is given direction about daily/weekly production targets from the business operations. However, sometimes these targets change and it becomes impossible for the system of plants to meet them. To plan for this uncertainty it becomes important to carefully decide on inventory levels when keeping infinite inventory is not an option. The challenge in increasing/decreasing the inventory levels is compounded by the fact that cost of production is highly fluctuating depending on when the extra product is produced. The cost of production can fluctuate due to various reasons, viz. contractual terms especially caused by the cost of utilities and raw material. In this work a methodology is presented to account for changing production cost over a longer horizon, while deciding on the inventory levels. Another important factor which changes the cost of production is that the RTO is performed over a system of plants, which means each plant has its individual costs which varies depending on the efficiency. So in this work two decisions are made i) which asset to use and ii) when to produce, to capture two levels of optimization. Rawlings and Amrit, 2009 have proposed combining RTO and MPC level by using an economic objective function, similarly in the current work, decision on inventory level is made within RTO by using an economic objective function valid over a longer horizon.

Xenos *et al.*, 2015, have proposed an integrated RTO scheme for a network of compressors, whereby they decide solve load sharing for each compressor in short-term and scheduling and planning in long-term. The integration scheme solves two separate optimization problems for short

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and long-term.

Section 2 describes the problem in detail and develops the objective function to combine the two levels of optimization in order to decide on the inventory levels. Section 3 and 4 discusses the impact of marginal production cost on inventory and how the modified objective function results in reducing the long term marginal costs.

2. PROBLEM DESCRIPTION

2.1 System of Plants

Consider a system of plants and each plant produces same product Pr_j , represented by $P_i, i \in [1,2, \dots , n_{plants}]$. It is important these plants meet daily and weekly production targets set by business personal, possibly arising from a higher level of optimization. In order to meet these in optimal way, a RTO is used to decide how much to produce at each plant given their minimum and maximum capacities. The objective here can be either to maximize revenue or minimize cost. In most cases, lets consider the objective is to minimize cost, then the problem becomes as follows:

$$\min_{F_i(k)} \left(\sum_{i=1}^{n_{plants}} Plant\ Cost_i + \sum_{j=1}^{n_{penalty\_cons}} PenaltyCost_j \right) \tag{1}$$

Subject to

$$\sum_{i=1}^{n_{plants}} F_i(k) = Production_{target}(k)\ \forall k = [1,2,3 \dots p] \tag{2}$$

$$F_{min} \le F_i \le F_{max} \tag{3}$$

$$|F_i(k) - F_i(k-1)| \le \Delta F_{max} \tag{4}$$

Where, $Plant\ Cost_i$ is material and utility cost and $PenaltyCost_j$ is a term to account for some of the soft constraints, especially ramp constraints, $F_i(k)$ is production rate at each plant i bounded by $F_{min}$and F_{max} , and sum all the production $F_i(k)$ should meet the daily target $Production_{target}$, k is the time step in the prediction horizon p, which is a constant, ΔF_{max} is the maximum allowable change in production rate at every plant. Thus the daily production target is a combined set-point for the system of plants and it should be satisfied at every time step k in the prediction horizon p. Above optimization (1) can easily be changed to include discrete decision variables to account for equipment switch on/off. However in the current formulation discrete variables have been ignored. Current formulation also assumes that if a plant is on then it should atleast run at the minimum rate and that the optimizer does not have the option to turn on/off the plant. The solution of Eq. 1, is expected to run the cheaper plants first and then the more expensive plants. However due to the minimum rate constraint (Eq. 3) even the more expensive plant will be producing some part of the product. Currently the order of k varies between 15-60 minutes and p varies between 24 h to 1 week depending on the type of system, however it stays constant for a given system.

Another key aspect of evaluating the objective function is the plant models; which relates the amount of raw materials and utility is required to run the each of the plant i at $F_i(k)$. These plant models can be developed either once or updated in real-time parallel to the RTO.

2.2 RTO with inventory Decision

In Eq. *1*, the system of plants is producing at the level of daily target, however if there is a sudden change in the target which is impossible to meet even if all the plants run at maximum capacity. In that scenario, it becomes important to decide on the inventory levels. In order to decide on these levels cost related to developing the inventory needs to be included in Eq. *1*. If the inventory is decided to be increased by some level ΔV in the entire prediction horizon, p, then the cost of using the inventory can be shown as follows:

$$\begin{aligned} &Inventory\ Cost = \overline{MP} * \Delta V \\ &\Delta V = \textstyle\sum_{k=1}^{p} \sum_{i=1}^{n_{plants}} (F_i(k) - Production_{target}(k)) \\ &or\ \Delta V = V_f - V_i \end{aligned} \tag{5}$$

where, $\overline{MP}$ is the historical average marginal cost of developing the inventory in the past n_{MC}, days, and ΔV is result of change in final and initial volume of the inventory V_f and V_i respectively. Inventory cost really represents the cost of building the inventory, however the effect of this cost is different depending on whether the inventory is being depleted or filled. Then Eq. *1* can be augmented with *5*, leading to *6*, where V_f is bounded by V_{min} and V_{max}.

$$\min_{F_i(k),\ V_f} \sum_{i=1}^{n_{plants}} Plant\ Cost_i + \sum_{j=1}^{n_{penalty_{cons}}} PenaltyCost_j - \overline{MP} * (V_f - V_i) \tag{6}$$

$$\text{Subject to} \qquad V_{min} \le V_f \le V_{max}, Eq. 2-4 \tag{7}$$

In eq. 6, if V_f increases at the end of prediction horizon, then the cost of producing extra volume in the prediction horizon is already included in the $\sum Plant\ Cost_i$ and $\sum Penalty\ Cost_j$, and inventory cost represents the cost of building the inventory in past, however the inventory is being built in present. The effect of inventory cost is to compare the current marginal cost MP with historical average of marginal cost, $\overline{MP} * \Delta V$. If the optimizer decides to fill the inventory, then the current marginal cost is lower than $\overline{MP}$, and this results in reducing the objective function. Similarly if the optimizer decides to lower the inventory then it is purely done because currently it is expensive to build the inventory. This behaviour is shown in Figure 2, where point A represents when $MP < \overline{MP}$ and point C represents when $MP > \overline{MP}$. Point B represents the scenario when $MP \sim \overline{MP}$ in the prediction horizon, p.