A heuristic reactive scheduling strategy for recovering from refinery supply chain disruptions

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Abstract

Supply chain management is one key area that has gathered much interest from both the academic and business communities. Today's many uncertainties require that supply chains be nimble and resilient in reacting to disruptions for sustainable operations. We look at a refinery supply chain and present a strategy for recovering from disruptions by heuristic rescheduling. This is important as refinery scheduling for a real world industrial size problem typically requires a significantly large amount of time to generate an optimal schedule. Our method takes much less time to generate near optimal schedule than total rescheduling in handling disruptions. We illustrate our method using a refinery with 3 CDUs, 6 crudes, 8 tanks, 2 crude categories, one 3-parcel VLCC, and three single-parcel vessels arriving in a 120 h horizon and two disruptions: tank unavailability and a vessel delay.

Introduction

As today's refineries face extremely competitive business climates and uncertain oil markets, it is crucial for them to be able to respond effectively and promptly to market forces while maintaining reliable operations. Crude oil scheduling is one of the most important elements in many refineries' supply chain. Optimal crude oil scheduling can enable cost reduction and profit maximization by managing crude oil intelligently, minimizing CDU changeovers, and avoiding ship demurrage. Therefore, short-term crude oil scheduling has recently been of significant interest in the academic and business communities. There have been research works done in scheduling various phases of the crude oil movement, from the unloading from tankers up to the distribution of products.

Given crude arrival data, production targets and operational constraints, a near-optimal crude operation schedule can be determined. However, most of the research so far [e.g. 2, 3, 5, 7, 8, 9] was deterministic and did not consider uncertainties. It is also observed that literature for scheduling under uncertainties [1, 4] is mainly for batch plants. Refineries are different from batch plants in many aspects, this paper therefore focuses on disruptions in crude oil scheduling.

The typical scheduling horizon in a refinery is one to two weeks, and it is not uncommon for unexpected events to occur and disrupt the schedule at hand. These disruptions could be a delay in tanker arrival time, unavailability of processing equipment, changes in product demands, etc. In some cases, disruptions could lead to the current schedule becoming infeasible, for example a ship arrival delay could lead to an out-of-crude situation. At the present time, even with the best method or algorithm, it takes a significantly large amount of time to generate an optimal (or near optimal) schedule for a real world industrial size problem. It is therefore not desirable to reschedule and run the whole optimization again every time a disruption occurs. This was the motivation for this paper to propose a heuristic reactive scheduling strategy to handle disruptions.

Previously, Mishra et al. [6] developed an agent-based decision support system to manage disruptions in a refinery supply chain. They implemented agents that emulate various entities in the refinery supply chain. In the event of disruption, the agents respond by interacting with one another (through collaboration and negotiation) to identify a holistic response. This could be emergency crude procurement, negotiation with customer for delay in product delivery, rescheduling refinery operations, etc. This paper focuses on the rescheduling strategy. Our work takes into account the changes to the refinery in response to the disruption, and modifies the schedule to best incorporate these changes.

Problem Statement

Figure 1 shows the refinery configuration. This work is based on the discrete-time formulation of crude oil scheduling by Reddy et al. [8], which considered the unloading of crude oil from large multi-parcel tankers via an SBM (Single Buoy Mooring) line or from smaller single-parcel ships via jetties up to the charging of crude oil to CDUs. Given the optimal operation schedule from the mathematical program by Reddy et al. [8], and the disruptions, generate optimal (or near optimal) new schedule(s) accommodating the disruptions.

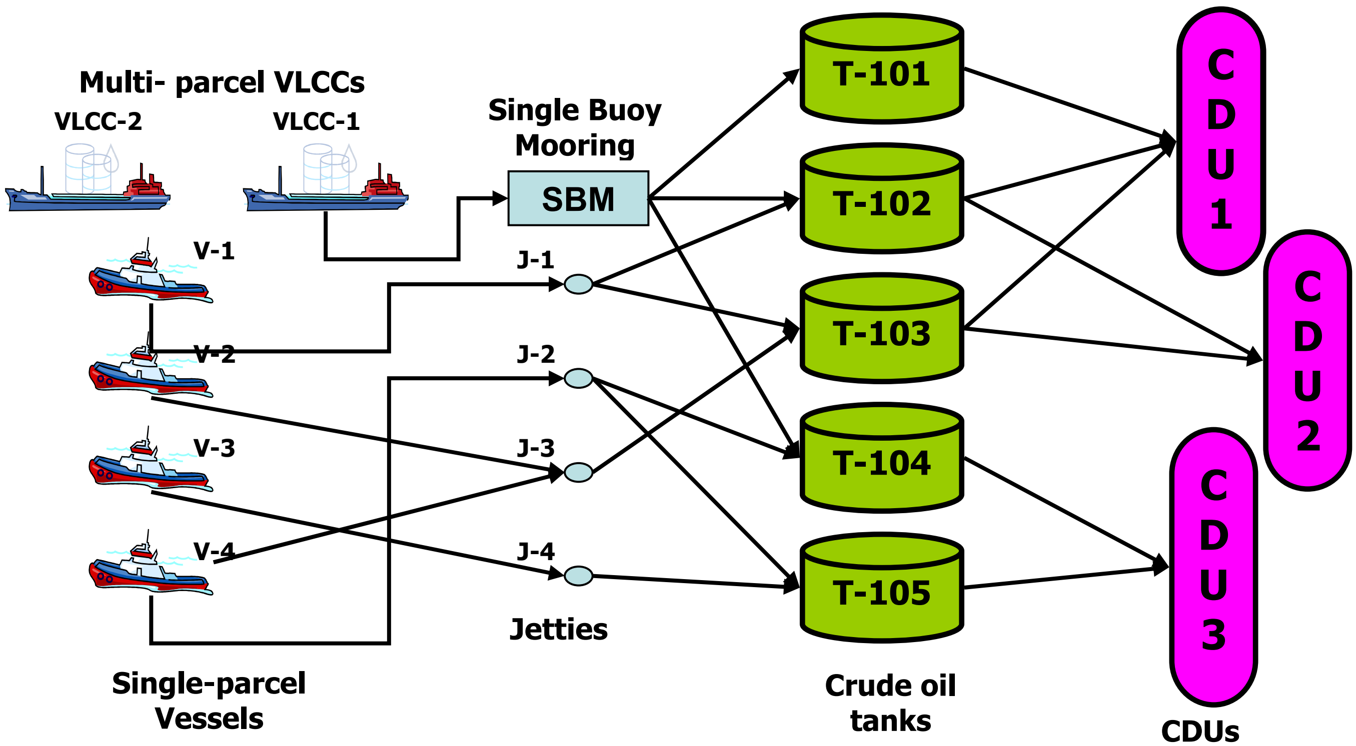

Figure 1: Refinery Configuration

Methodology

This paper proposes a method to modify a given schedule to accommodate a given change and seeks optimality without running the whole optimization again or by solving a smaller optimization problem.

The proposed method is a multi-step approach. The inputs to the approach are the original situation, the corresponding optimal schedule (which was previously determined), and the disruptions that have since occurred. First, we check the feasibility of the disrupted schedule. Second, we employ a heuristic rescheduling strategy to improve optimality of the disrupted schedule. This step is critical when the disrupted schedule becomes infeasible and optional when it remains feasible. The following steps outline the proposed strategy:

1. identify point(s) of infeasibility (if any),
2. identify class of disruption,
3. perform rescheduling action(s) based on the class of disruption, and
4. evaluate objective value.

We group disruptions into several classes based on the necessary corrective actions. For example, to deal with changes in timing (e.g. ship arrival delays), relative positions of the blocks of operation as mapped by the original schedule are maintained while adjusting the lengths of the blocks and the volumes involved in the blocks. In response to unavailability of equipment (e.g. pumps, tanks, CDUs, etc.), we seek alternate processing strategies that can retain the blocks of operation from the original schedule. To handle changes in demands, we keep the relative positions of the blocks while adjusting the volume involved in the blocks. The key here is to preserve the characteristic of the original schedule, which is the map of the blocks of operations scheduled. It should be noted, however, that there are limits (e.g. flow rate limits, volume limits, etc.) that have to be obeyed and these are considered as hard constraints by the proposed algorithm. Then we evaluate the objective value of the new schedule. These heuristics are based on the observation that generally the objective values do not change much for little changes in the schedule characteristic.

In cases where these heuristics fail to yield an adequate schedule, alternative schedules are considered. Alternate schedules are generated by perturbing portions of the original schedule beginning from a few periods away from the time of the disruption and optimizing only for the neighborhood, for a few periods after the disruption. The rationale is that the system could absorb the disruption after some time and hence the later part of the schedule could remain intact. The major advantage of our method is that it takes much less time to generate near optimal schedule than total rescheduling in handling disruptions. In this paper, we will describe the proposed framework and illustrate it with several case studies.

Heuristics Example

Due to space constraint, only one set of heuristics for one class of disruption (i.e. vessel delay) is shown here.

<u>A parcel-unloading operation PU is disrupted due to a vessel delay</u>

1. If TVmin (minimum tank volume) of the destination tank of PU is violated, have to unload to the destination tank of PU.
    - Find earliest period after new vessel arrival time where tank is free (not charging any CDU).
    - Check at that time TVmin already violated?
        - No: reschedule PU at that period, go to 2
        - Yes: go to 3
2. No TVmin violation, can unload to other eligible tanks which are free (not charging any CDU).
    - If the destination tank of PU not free the first period after new vessel arrival time and other tanks are free, then
    - Check TVmax (maximum tank volume) of that tank, unload before Tmax (maximum allowable unloading time) of parcel.
        - Yes: PU at that period. Done.
        - No: go to 3.
3. Some CDU-charging operation CC has to be shortened,
    - Find CC1, other tank feeding the CDU of CC, see if CC1 volume can be increased for a period where CC will be shortened for PU.
    - Check TVmin, TCmax of tank of CC1
    - Yes: done
    - No: continue
    - Find CC2 to the CDU of CC that can be extended to cover the period where CC is shortened for PU.
    - Check TVmin, TCmax of tank to CC2
    - Yes: done
    - No: continue
    - Find eligible tanks that can feed the CDU of CC for that period, create CC3
    - Check TVmin, TCmax of tank to CC3
    - Yes: done
    - No: need for major rescheduling.

Case Study

We consider the case for a refinery with 3 CDUs, 6 crudes, 8 tanks, 2 crude categories, one 3-parcel VLCC, and three single-parcel vessels arriving in a five-day horizon (15 eight-hour slots) and two disruptions: tank unavailability and a vessel delay. Table 1 shows the vessel arrival schedule. Figure 2 shows the optimal operation schedule and its tank volume profile. Table 2 lists the two disruptions.

Table 1: Vessel Arrival Schedule

Parcel	Crude	Volume	Arrival Time
1	2	10	2
2	6	100	2
3	1	100	2
4	4	90	2
5	2	125	4
6	5	125	4
7	3	100	6

Tank	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15	
	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p
1	-20	3	-20	3	10	1	100	3	20	5																				
2					90	2	10	2			-20	2	-20	2	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1
3									80	4	20	6																		
4	-20	1	-20	1	-20	1	-20	1	-20	1	-20	1	-20	1	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2
	-20	2	-20	2	-20	2	-20	2	-20	2																				
5									10	4	105	6			-25	2	-25	2	-25	2	-25	2	-25	2	-25	2	-25	2	-25	2
6											105	5	100	7			-50	3	-50	3	-50	3	-30	3	-20	3	-20	3	-20	3
7					-20	3	-3.2	3	-3.2	3	-3.2	3	-3.2	3	-3.2	3														
8							-16.8	3	-16.8	3	-16.8	3	-16.8	3	-16.8	3														

Tank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	250	230	210	220	320	340	340	340	340	340	340	340	340	340	340	340
2	250	250	250	340	350	350	330	310	277.5	245	212.5	180	147.5	115	82.5	50
3	300	300	300	300	300	380	400	400	400	400	400	400	400	400	400	400
4	350	310	270	230	190	150	130	110	102.5	95	87.5	80	72.5	65	57.5	50
5	250	250	250	250	250	260	365	365	340	315	290	265	240	215	190	165
6	100	100	100	100	100	100	205	305	305	255	205	155	125	105	85	65
7	100	100	100	80	76.8	73.6	70.4	67.2	64	64	64	64	64	64	64	64
8	250	250	250	250	233.2	216.4	199.6	182.8	166	166	166	166	166	166	166	166

Figure 2: Optimal Schedule and Tank Volume Profile for the Case Study

Table 2: Disruptions

No.	Disruptions
1	Parcel 7, scheduled to arrive at time 6, is delayed. New arrival time is time 8.
2	Tank 7 will be unavailable for five periods starting from time 6.

Due to disruption 1, Parcel 7 cannot be unloaded into Tank 6 as it is charging CDU 3 from period 9 onwards. This leads to out-of-crude situation in Tank 6 and the schedule becomes infeasible. Figure 3a and 3b are the new schedules generated with their tank volume profiles. Table 3 compares the objective value of the schedules. As shown in Table 3, there is only a small profit loss in the new schedules as compared to the original schedule.

Tank	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15	
	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p
1	-20	3	-20	3	10	1	100	3	20	5			-3.2	3	-3.2	3	-3.2	3	-3.2	3										
2					90	2	10	2			-20	2	-20	2	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1
3									80	4	20	6																		
4	-20	1	-20	1	-20	1	-20	1	-20	1	-20	1	-20	1	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2
	-20	2	-20	2	-20	2	-20	2	-20	2																				
5									10	4	105	6			-25	2	-25	2	-25	2	-25	2	-25	2	-25	2	-25	2	-25	2
6											105	5					100	7			-50	3	-50	3	-50	3	-30	3	-20	3
7					-20	3	-3.2	3	-3.2	3	-3.2	3	TANK UNAVAILABLE																	
8							-16.8	3	-16.8	3	-16.8	3	-16.8	3	-16.8	3	-16.8	3	-16.8	3										

Tank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	250	230	210	220	320	340	340	336.8	333.6	330.4	327.2	327.2	327.2	327.2	327.2	327.2
2	250	250	250	340	350	350	330	310	277.5	245	212.5	180	147.5	115	82.5	50
3	300	300	300	300	300	380	400	400	400	400	400	400	400	400	400	400
4	350	310	270	230	190	150	130	110	102.5	95	87.5	80	72.5	65	57.5	50
5	250	250	250	250	250	260	365	365	340	315	290	265	240	215	190	165
6	100	100	100	100	100	100	205	205	205	305	305	255	205	155	125	105
7	100	100	100	80	76.8	73.6	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4
8	250	250	250	250	233.2	216.4	199.6	182.8	166	149.2	132.4	132.4	132.4	132.4	132.4	132.4

Figure 3a: New Schedule 1 and the Corresponding Tank Volume Profile

Tank	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15	
	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p	Vol	u/p
1	-20	3	-20	3	10	1	100	3	20	5																				
2					90	2	10	2			-20	2	-20	2	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1	-32.5	1
3									80	4	20	6																		
4	-20	1	-20	1	-20	1	-20	1	-20	1	-20	1	-20	1	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2	-7.5	2
	-20	2	-20	2	-20	2	-20	2	-20	2																				
5									10	4	105	6			-25	2	-25	2	-25	2	-25	2	-25	2	-25	2	-25	2	-25	2
6											105	5					100	7			-50	3	-50	3	-50	3	-30	3	-20	3
7					-20	3	-3.2	3	-3.2	3	-3.2	3	TANK UNAVAILABLE																	
8							-16.8	3	-16.8	3	-16.8	3	-20	3	-20	3	-20	3	-20	3										

Tank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	250	230	210	220	320	340	340	340	340	340	340	340	340	340	340	340
2	250	250	250	340	350	350	330	310	277.5	245	212.5	180	147.5	115	82.5	50
3	300	300	300	300	300	380	400	400	400	400	400	400	400	400	400	400
4	350	310	270	230	190	150	130	110	102.5	95	87.5	80	72.5	65	57.5	50
5	250	250	250	250	250	260	365	365	340	315	290	265	240	215	190	165
6	100	100	100	100	100	100	205	205	205	305	305	255	205	155	125	105
7	100	100	100	80	76.8	73.6	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4
8	250	250	250	250	233.2	216.4	199.6	179.6	159.6	139.6	119.6	119.6	119.6	119.6	119.6	119.6

Figure 3b: New Schedule 2 and the Corresponding Tank Volume Profile

Table 3: Objective Value of the Schedules

Schedule	**Profit**
Original	1,849
New schedule 1	1,841
New schedule 2	1,842

Concluding Remarks

The proposed heuristic rescheduling approach has several advantages; most notably it requires much less time to generate near optimal schedule than total rescheduling in response to disruptions. Furthermore, the method will generate a number of feasible schedules so the user has the freedom to choose. Another potential benefit is the method can provide insights for full optimization, limiting the search space based on the schedules generated.

However, there are some obvious limitations. The method only works for the classes of disruptions considered, i.e. we need to specifically code the heuristics for each class of disruption. The approach might fail if corrective actions for two disruptions conflict each other. The heuristics may fail to find a feasible schedule. This implies that major rescheduling is required.

We have shown that heuristic rescheduling is a fast and efficient way to manage abnormal situations in a refinery supply chain. It is one puzzle piece in the bigger picture of supply chain disruption management. Future work will be the integration of this rescheduling system into an online disruption management system.

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