Asset Performance Networks

TRADE-OFF ECONOMICS IN REFINERY AND PLANT TURNAROUNDS

- TOWARD A DYNAMIC DECISION-MAKING MODEL -

By

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Executive Summary

Plant turnaround economics are highly complex. There are many variables which impact the overall business performance of a turnaround and multiple trade-offs need to be considered. Decision-making in this very dynamic environment however has often been based on assumptions. This paper explores the fundamental relationships between the major cost-contributing factors such as shift-patterns, labor productivity, and turnaround duration, fixed costs, quality and lost opportunity costs. Once basic relationships between these variables are established the paper then proposes a generic ***turnaround trade-off model*** and a case study is then presented to illustrate –through the use of sensitivity analysis- the impact of specific trade-off decisions upon overall economic viability of the turnaround. This research study is based on more than five hundred turnaround events with detailed performance data.

I. Introduction

Turnarounds are considered critical events within the maintenance framework of plants. In recent years, major transformations in planning rigor for maintenance outages and changing attitudes toward turnaround preparedness have measurably improved the economic viability of refineries for some companies despite rising crude prices, escalating material costs, tightening labor markets, and stricter environmental regulations [1] [2]. Whereas pre-planning methodologies and risk management concepts for outages have improved, the actual understanding and implications of trade-off decisions and interdependencies between resource constraints during outage execution are still largely undefined in quantitative terms.

This paper attempts to answer some of the underlying questions involved in effective decision-making for turnarounds. The relatively short execution timeframes of turnarounds largely inhibits corrective actions mid-performance. However, turnaround managers need tools to assess impacts that specific decisions may have on the financial outcome of a turnaround. A turnaround trade-off model will allow companies and teams to adopt a turnaround strategy that helps to understand and optimize trade-offs. The tool is based on the analysis of the factors that most affect safety, cost, and duration of a turnaround.

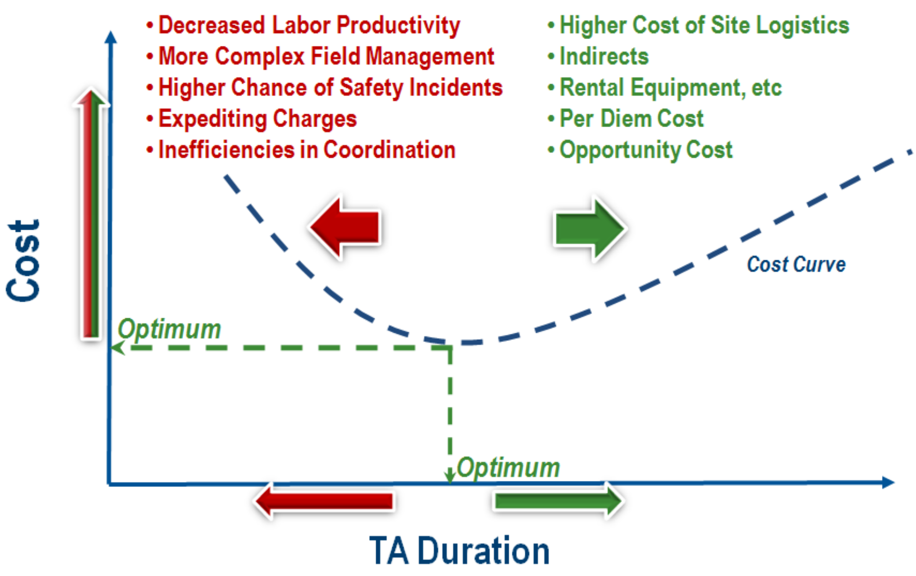

Figure 1

As shown in Figure 1, a turnaround can be optimized with respect to turnaround cost and duration, assuming a frozen scope. For example, decreasing turnaround duration by increasing work intensity will result in an increase of turnaround cost due to a decrease in labor productivity, inefficiencies in field coordination, etc.; whereas longer turnaround duration also results in an increased turnaround cost due to increased per diems, indirect costs, and lost opportunity cost. However there are many more factors that drive turnaround performance as depicted in Figure 2. These include such factors as labor skill, contractor availability, work scope, extent of discovery work, and site congestion. This paper will identify the key factors in determining the optimal turnaround performance.

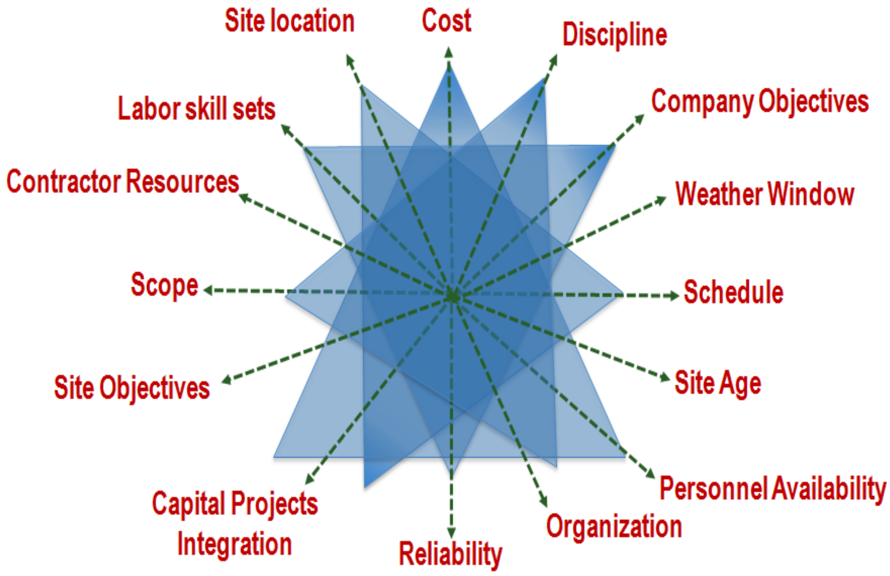

Figure 2

II. Database

This detailed study is based on a sample of 200 turnarounds from a proprietary turnaround database population of more than 500 unique plant outages [3]. Seventy-five (75) percent of these turnarounds occurred in North America with some data collected from chemical facilities. All turnarounds are categorized by more than 50 individual performance variables such as planned hours, actual hours, safety incidents, and turnaround duration in days (planned and actual). The average size of the turnarounds is 231,000 labor hours.

III. Data Analysis – Creating the Model

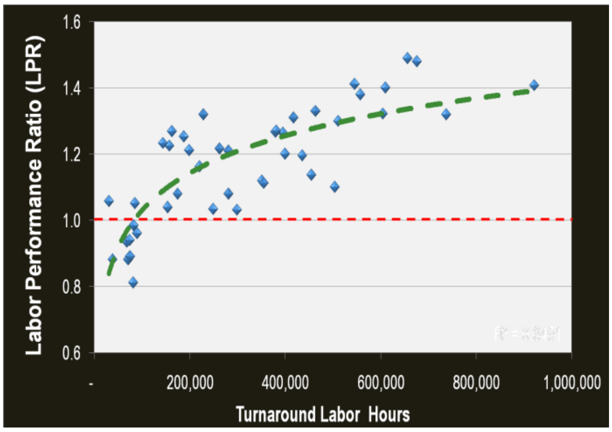

Figure 3

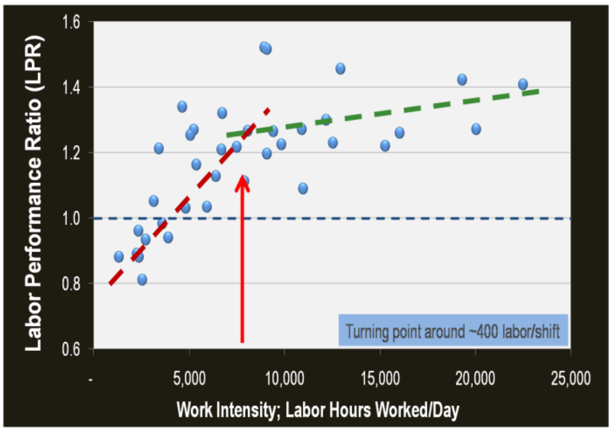

Figure 4

The following highlights the key findings from our analysis and identifies the key inputs and relationships that will be included in our trade-off model.

LABOR PERFORMANCE DETERIORATES WITH SIZE
Figure 3 shows the relationship between labor performance and turnaround size. Labor performance is measured as the Labor Performance Ratio[1] (LPR) which is defined as the actual labor hours divided by estimated hours (adjusted for approved scope change). Labor hours are defined as direct field hours for maintenance and capital expended during the shutdown window. Seventy five (75) percent of turnarounds in the database exceeded their labor hour target. On average, these turnarounds expended an additional twenty-three (23) percent of labor hours above and beyond the estimated hours. However, size does matter when it comes to assessing the probability of experiencing labor overruns, as the level of overruns increases with turnaround size.

LABOR PERFORMANCE DETERIORATES WITH WORK INTENSITY
Figure 4 shows that higher work intensity adversely impacts the LPR. There is a strong relationship between the hours worked per day during a turnaround and the LPR. Put simply, as the average number of work hours increases, labor performance deteriorates and shows an inflection point at around 400 personnel per shift. Several studies on the effect of overtime on labor productivity have been conducted to either dispel or support claims of fatigue with extended schedules.

[1] The Labor Performance Ratio (LPR) is calculated by dividing Actual Hours Incurred by Planned Hours.

SAFETY PERFORMANCE IS DRIVEN BY WORK INTENSITY

Fatigue increases the potential for safety incidents, as it can be seen in Figure 5. We used our entire industry database to evaluate the impact of duration on safety performance. Turnarounds longer than 2 weeks have a Recordable Incident Rate (RIR) that is twice that seen for turnarounds shorter than 2 weeks. Safety incidents are defined as the sum of recordable events and first aids. Including safety considerations in trade-off decisions typically evokes strong reactions from plant stakeholders, especially, if one attempts to monetize safety incidents from a theoretical perspective. Nevertheless, the data are relatively clear about this relationship: the more hours worked in a given day, the higher the risk of safety incidents.

INDIRECT LABOR AND TOTAL TURNAROUND HOURS

Intuitively many industry participants may agree that larger turnarounds require more planning as well as supervision. The data suggest that the ratio of support hours increases by about 1 percent for each additional 20,000 labor hours for turnarounds up to 400,000 labor hours. This ratio increases linearly to about 25-27 percent and reach an upper limit at about 30 percent as shown in Figure 6.

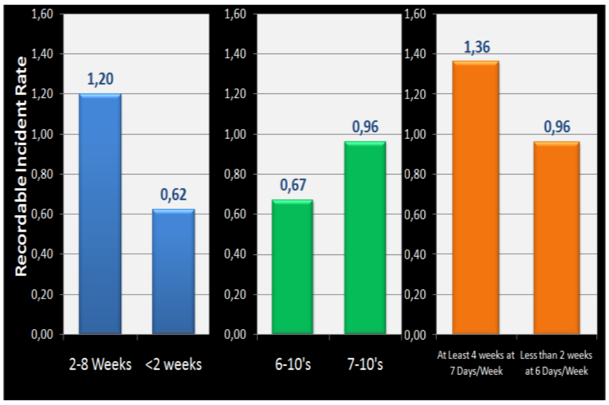

Figure 5

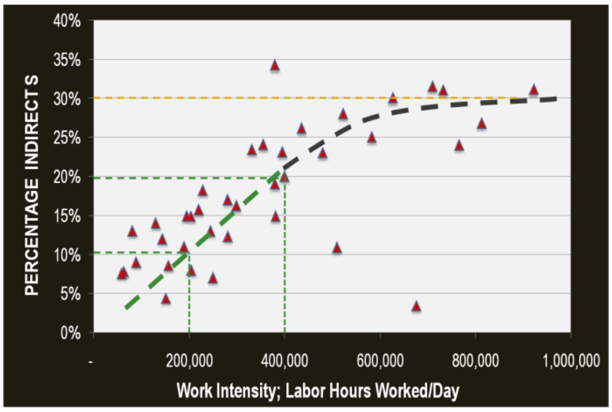

Figure 6

SCHEDULE VERSUS LABOR HOURS

The average turnaround duration in the dataset is 36 days with a range of 15 to 70 days. There is a relationship between more labor hours and longer durations but that there is also wide variability. A key driver of this variability is the differing labor productivities across turnarounds. Our detailed analysis of turnarounds indicates that the actual productive working time *("wrench time")* during a typical 10 hour shift ranges from 5 to 6 hours. There are a number of factors both predictable and unpredictable that reduce the actual time on tools. These include breaks, safety meetings, travelling to worksite, permitting and Lock-Out Tag-Out (LOTO). Unpredictable factors include waiting on materials, waiting on other crafts, process equipment not ready, etc...

LABOR PERFORMANCE AND SHIFT PATTERN

Much literature exists on the topic of fatiguing of craft personnel and loss of productivity due to extended overtime [4]. Available studies mostly agree on the longer-term, adverse effect of overtime, but can vary significantly on the degree of productivity decline across the measurement timeframe.

According to the selected sample, the six days per week, 10 hours per day shift pattern (6-10), offers by far the most predictable scenario among the three presented shift types in terms of outcome. Labor hour performance for the 6-10 shifts is tightly spread around the mean with only modest variability and small range among the individual values. The observed variances increase significantly from 6-10 to the 7-10 and 7-12 shift patterns. The collected sample of turnarounds however did not indicate a significant difference when comparing the mean of both 7-day shift types. In fact, the average Labor Performance value for 7-12 shifts is slightly lower than the 7-10 mean.

Figure 7 includes 6 distinct productivity patterns associated with a specific shift type [5]. The chart includes 5-10 and 6-10 shift productivity lines, which are characterized by a significant initial drop through the first 28 days. After this period, labor productivity stabilizes. The short-lived recapturing of momentum noticeable after the first week, has frequently been explained by the increasing level of adjustment of personnel to the extended work schedule before true fatigue finally erodes such gains and productivity declines become inevitable.

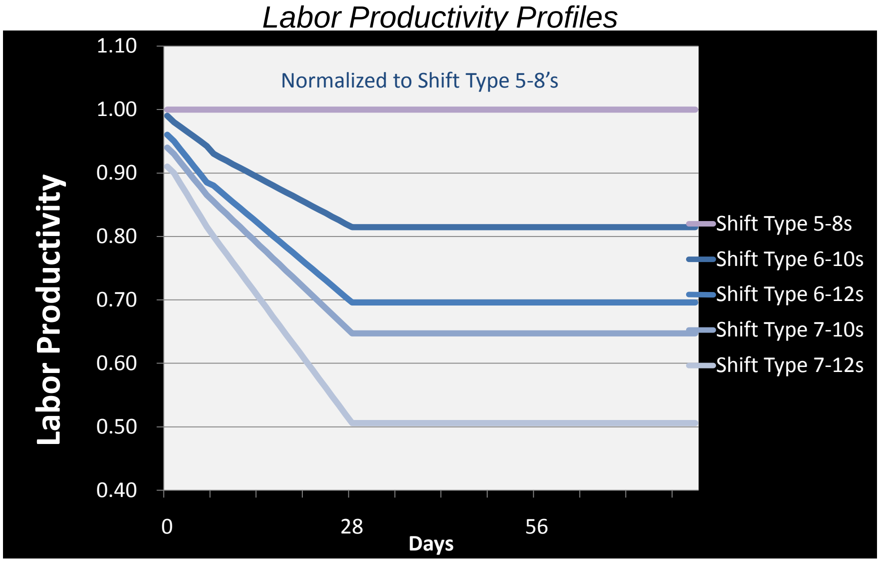

Figure 7

IV. Trade-Off Model - Case Study

This section uses the relationships identified in the preceding section and industry data to develop a turnaround trade-off model. We have created a case study to highlight the various trade-offs involved in successfully executing a turnaround. In order to create reasonable and workable scenarios a base case is established to which all other alternatives can be compared.

BASE CASE ASSUMPTIONS

A base case turnaround duration of 36 calendar days (CDs) has been chosen, with planned daily hours (direct and immediate supervisor) of about 9,000, working in shifts of 6 days per week and 10 hours per day (6-10) for a total of 350,000 earned value hours ('true' scope). The number of earned value hours is important in order to determine how many actual hours it would take in other scenarios to earn the same 350,000 hours. The number of planned personnel will be kept constant for the other shift type pattern scenarios in this simulation. In other words, "how many days and how much money does it take or save if I switch to a different work schedule with the same number of men"? Table 1 summarizes the main assumptions.

Table 1

Base Case Assumptions			
Turnaround Duration	36 CD	Safety Incident Cost	50,000 US$ each
Planned Personnel	1,134	Materials	22% of total costs
Turnaround Size	350,000 Hrs	Site Logistics	2% of total costs
Shift Type	6-10's	Equipment	8% of total costs
Average Craft Rate	60 US$ /Hr [6]	Labor (DL + IL)	68% of total costs
Indirects Rate	90 US$/Hr [6]	Refining Capacity	200,000 BPSD
Supervision Portion	20% of DL	Refining Margin	2 US$/BBL
Per Diem Rate	110 US$/day [6]		

MODEL RESULTS

Figure 9 shows the results of the different scenarios for different shift pattern types: 5-8, 6-12, 7-10, 7-12 and 7-14 shift patterns compared to the base case which is 6-10. The figure records relevant summary data of both inputs and turnaround outcomes. The Relative Opportunity Cost in the table is based on the duration in days, plant output capacity for a refined product of 200,000 BPSD and refinery margin of $2.00 per barrel.

There is naturally a clear trade-off dynamic between duration (days) and other performance or input variables such as labor hours, premium time, revenue, and safety. The value of time within this context is determined by two prevailing factors: time-sensitive costs and lost revenue. This model includes per diem costs as the major time-sensitive component, but other costs could easily be added to adjust the model. One possible way to evaluate the efficacy of switching from one work schedule to another is the analysis of marginal costs for each reduced day. For instance, switching from the base case of 6-10 to a 7-12 work schedule reduces overall duration by 1 calendar day but adds close to $14 MM to final TA costs (including opportunity costs). In other words, each day of schedule reduction was bought for approximately $14 MM in additional costs with a refining margin of $2.00 per barrel. Figure 10 shows the impact of refining margin on the optimal turnaround cost. The results highlight the following:

- A 6-10 shift pattern turns out to be the most economic favorable strategy at any margin ranging from $2 to $12 per barrel.
- 7-12 shift patterns are the least economically favorable strategy.
- Increased work intensity does not necessarily decrease turnaround duration. Just adding two hours per day and/or adding one day per week does not significantly shorten the turnaround duration, which is mainly due to lower labor productivity. Furthermore labor and per diem costs increase as work intensity increases.
- The number of safety incidents increase as work intensity increases. Recordable incidents have a cost impact. In our model, each incident has a cost penalty and has been modeled for $50,000. Increasing labor intensity (7-12 and 7-14 shifts) does reduce the turnaround duration, however; it also increases the total turnaround cost while slightly favoring the "lost opportunity costs". The latter effect is more pronounced for higher refining margins.

	5-8's	6-10's	6-12's	7-10's	7-12's	7-14's
TA Duration CD	45	36	36	36	35	32
Labor Costs	$20.362	$26.643	$33.321	$33.867	$41.009	$44.174
Per Diem Costs	$5.615	$4.492	$4.616	$4.492	$4.367	$3.993
Equipment Rental	$4.005	$3.134	$3.134	$3.134	$3.047	$2.786
Site Logistics	$1.001	$0.784	$0.784	$0.784	$0.762	$0.697
Materials	$8.620	$8.620	$8.620	$8.620	$8.620	$8.620
Relative Labor Cost	-24%	0%	25%	27%	54%	66%
Relative Per Diem Cost	28%	0%	0%	0%	-3%	-11%
Safety Incidents	*3.6*	*4.9*	*6.0*	*5.7*	*7.1*	*8.7*
Safety Costs	$0.182	$0.245	$0.299	$0.287	$0.354	$0.433
TA Cost	**$39.908**	**$43.918**	**$50.658**	**$51.183**	**$58.159**	**$60.702**
Relative Opportunity Cost	$4.000	-	-	-	$(0.400)	$(1.600)
TA Cost (incl. Lost Prod)	**$43.908**	**$43.918**	**$50.658**	**$51.183**	**$57.759**	**$59.102**

Figure 8

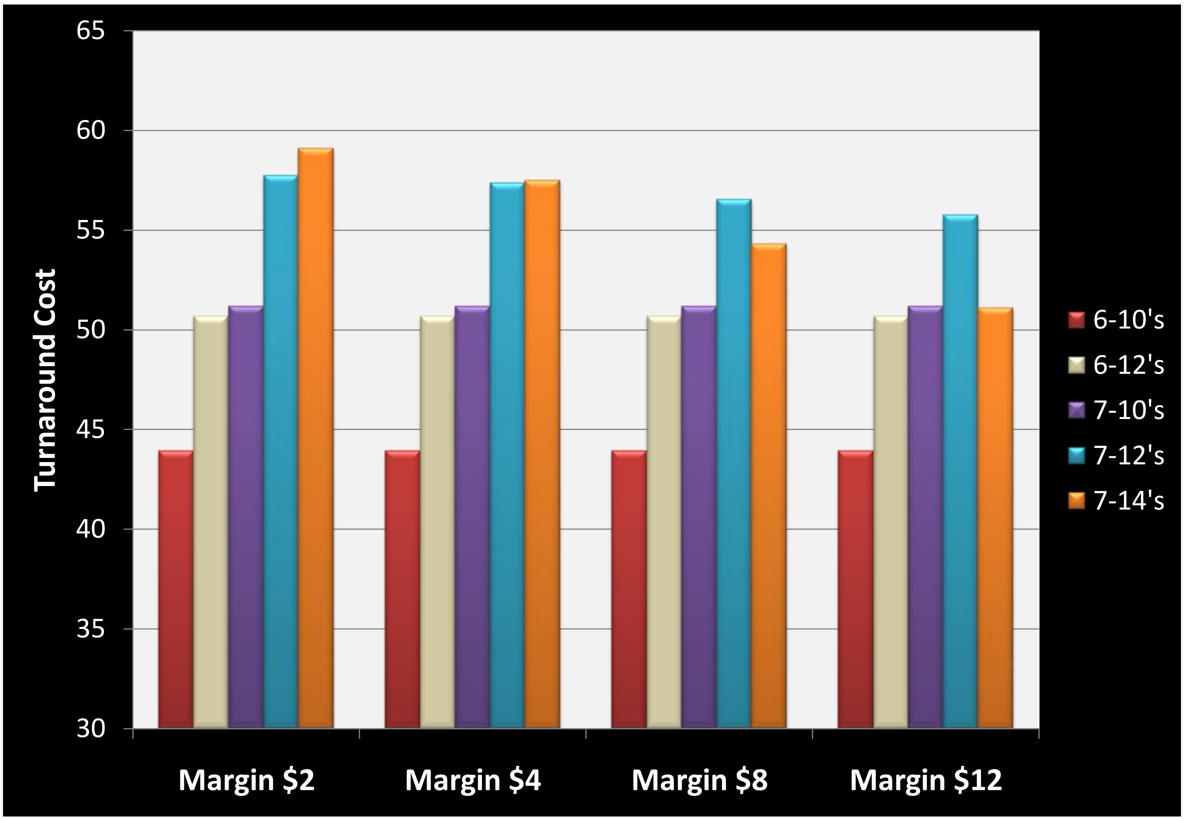

Figure 9

Conclusions

Over the last five years, turnaround performance has been characterized by a large degree of overruns in terms of both cost and schedule. Large, highly complex, turnarounds in particular, have had difficulty in meeting cost and schedule targets. The model presented in this paper provides decision makers with some insights in what strategies are optimal for economic performance and quantifies the trade-offs. The specifics and circumstances of turnarounds will always be unique and therefore requiring adjustments to the most sophisticated models on a case-by-case basis. However, basic dependencies between cost, time, and quality (or alternatively safety, revenue, or scope) describe the economic trade-off. Simulation tools like the turnaround trade-off model presented here can help demonstrate the impact of labor shifts on performance.

Endnotes

[1] "Maximizing Plant Productivity", Debakey, Samman, Mohammad, Edmundson, and Blanchard, PTQ Revamps & Operations, 2001
[2] "Study measures effect on leading indicators on plant turnarounds", Bobby Vichich, Oil+Gas Journal, May 21, 2007
[3] Proprietary turnaround database (time range is 2003-2008), Asset Performance Networks, LLC, Bethesda, MD.
[4] "Calculating Loss of Productivity Due to Overtime Using Published Charts – Fact or Fiction", The Revay Report, Nov. 2001, Brunies and Emir
[5] Scheduled Overtime Effect on Construction Projects," Report C-2, The Business Roundtable, Nov. 1980
[6] Average Craft Rate, Indirect Rate, and Per Diems are a composite historical average from 2003-08 using the Asset Performance Networks Industry Turnaround Database.