CHAPTER 7

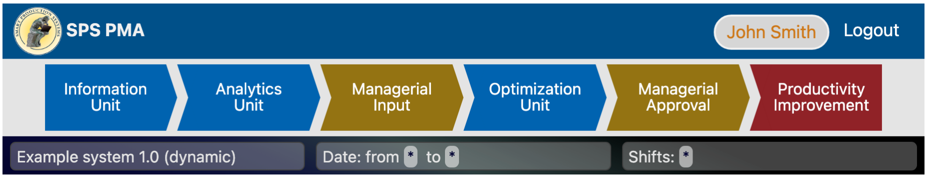
Smart Transmission Case Machining Line

Goal: The goal of this and three subsequent chapters is to demonstrate the process of making production systems smart and designing continuous improvement projects in PMA-based SPS environment. These demonstrations are carried out in terms of four out of the six production systems discussed in Chapter 3. Specifically, the current chapter addresses the transmission case machining line, while the others address the electronic board production system, the ignition control module assembly system, and the automotive underbody assembly. The remaining two systems, i.e., the galvanization plant and the automotive paint shop system, are presented at www.smartproductionsystems.com under the *Resources* tab.

7.1 Preliminaries

This chapter and the subsequent Chapters 8-10 are intended to demonstrate the process of making production systems smart and the operation of PMA-based SPS. Each of them is devoted to a different type of production systems. The current chapter is devoted to a production line with cycle time overruns; Chapter 8 to a system with hardware-unlimited buffers; Chapter 9 to an assembly system with insufficient buffering; finally, Chapter 10 to a multi-job production system. Mathematical models of these systems have been derived in Chapter 3.

The material included in each of these chapters has a similar structure and follows the PMA-based SPS workflow shown in Figure 6.4 (replicated here as Figure 7.1 for the reader's convenience): More specifically, first, the mathematical model of the system at hand is briefly reviewed and, using the *Information Unit*, uploaded in PMA. This provides the system with the capabilities of self-diagnosis and autonomous design of continuous improvement projects, i.e., makes it smart. Then, the *Analytics Unit* evaluates the System Health and other performance characteristics. Based on this information, various scenarios of potential performance improvement are formulated and entered into the *Managerial Input* module. Next, the continuous improvement projects corresponding to each scenario are calculated by the *Optimization Unit* and offered to the managerial/engineering personnel via the *Managerial Approval* module. Finally, the approved improvement project is "implemented" by changing the system's mathematical model accordingly, and the *Productivity Improvement* module evaluates the resulting performance.



Example system 1.0 (dynamic)
Date: from * to *
Shifts: *

Figure 7.1: PMA-based SPS workflow

❖ If the mathematical model of the system at hand is precise enough, the improved system will perform in a similar manner on the factory floor.

As far as the machines' reliability model is concerned, in all systems considered here it is assumed to be exponential. Note that, if in reality, the machines were non-exponential, but with coefficients of variation of up- and downtime less than 1 (which, as discussed in Chapter 2, Subsection 2.2.1, is the practical case), the improved systems would behave at least as good as those predicted under the exponential assumption.

Finally, it should be pointed out that the smart production systems discussed in this and the subsequent Chapters 8-10 operate in the intermittent regime with static data structure (see Chapter 6, Section 6.2). This is because the systems' data provided in Chapter 3, belong to specific time intervals, and the continuous improvement projects are intended to ensure the desired behavior for the immediate future. If the performance deteriorates again, a new dataset must be collected, uploaded in PMA, and a new improvement project must be designed. If the systems considered were monitored continuously, thereby providing the dynamic data structure, the designed PMA-based SPS would be able to operate in the continuous regime as well.

Since Chapter 7 is the first in the series of chapters demonstrating PMA-based SPS operation, it is presented here with more details than in the subsequent chapters.

7.2 The System and Its Mathematical Model

The mathematical model of Transmission Case Machining (TCM) line considered here has been introduced in Chapter 3, Section 3.2. It is an asynchronous serial line comprised of 12 unreliable CNC machines separated by 11 small buffers. Seven of these machines experience random cycle overruns, which are assumed to obey the cycle overrun model introduced in Chapter 2, Section 2.2.

The structural model of this system (along with buffers capacity) and the parametric model of its machines are given in Figure 3.1 and Table 3.3 of Chapter 3, respectively, and are replicated here as Figure 7.2 and Table 7.1.

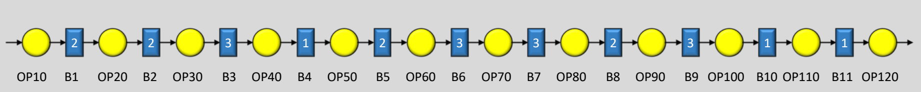
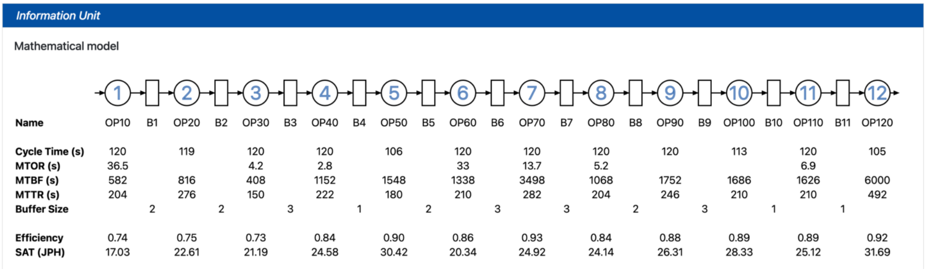


Figure 7.2: Structural model of TCM line

Table 7.1: Parametric model of TCM line machines

	τ (sec)	T_{up} (min)	T_{down} (min)	e	p_{OR}	k_{OR}	T_{OR} (sec)	SAT (JPH)
OP10	120	9.7	3.4	0.740	0.456	0.667	36.5	17.03
OP20	119	13.6	4.6	0.747	0.000	0.000	0.0	22.61
OP30	120	6.8	2.5	0.731	0.332	0.105	4.2	21.19
OP40	120	19.2	3.7	0.838	0.170	0.137	2.8	24.58
OP50	106	25.8	3.0	0.896	0.000	0.000	0.0	30.42
OP60	120	22.3	3.5	0.864	0.431	0.638	33.0	20.34
OP70	120	58.3	4.7	0.925	0.292	0.392	13.7	24.92
OP80	120	17.8	3.4	0.840	0.280	0.154	5.2	24.14
OP90	120	29.2	4.1	0.877	0.000	0.000	0.0	26.31
OP100	113	28.1	3.5	0.889	0.000	0.000	0.0	28.33
OP110	120	27.1	3.5	0.886	0.308	0.188	6.9	25.12
OP120	105	100.0	8.2	0.924	0.000	0.000	0.0	31.69

Uploading these data in PMA results in the mathematical model presented by a screenshot in Figure 7.3. It is selected as the *Active System*, which is the basis for subsequent analyses and designs reported below.



Information Unit

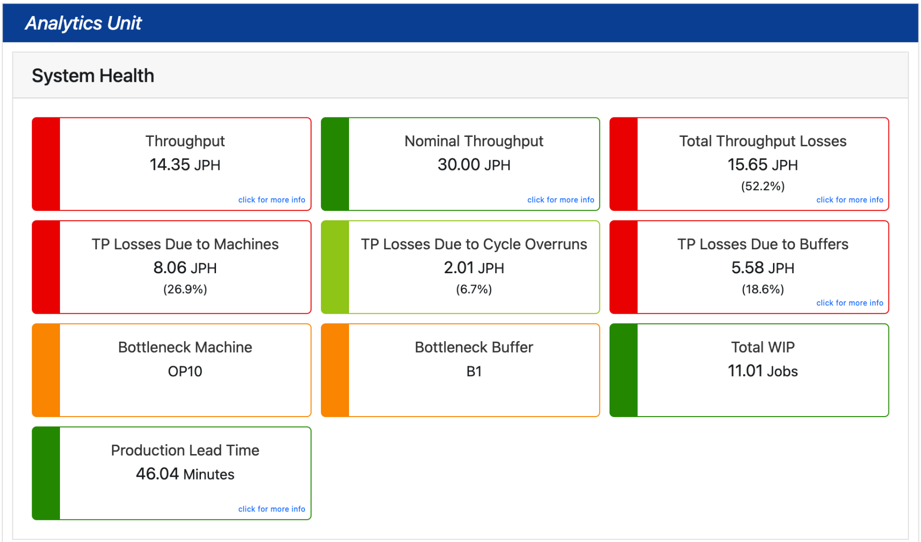
Mathematical model

Name	OP10	B1	OP20	B2	OP30	B3	OP40	B4	OP50	B5	OP60	B6	OP70	B7	OP80	B8	OP90	B9	OP100	B10	OP110	B11	OP120
Cycle Time (s)	120		119		120		120		106		120		120		120		120		113		120		105
MTOR (s)	36.5				4.2		2.8				33		13.7		5.2						6.9		
MTBF (s)	582		816		408		1152		1548		1338		3498		1068		1752		1686		1626		6000
MTTR (s)	204		276		150		222		180		210		282		204		246		210		210		492
Buffer Size		2		2		3		1		2		3		3		2		3		1		1	
Efficiency	0.74		0.75		0.73		0.84		0.90		0.86		0.93		0.84		0.88		0.89		0.89		0.92
SAT (JPH)	17.03		22.61		21.19		24.58		30.42		20.34		24.92		24.14		26.31		28.33		25.12		31.69

Figure 7.3: Mathematical model of TCM line

7.3 System Health & Improvement Considerations

Clicking on AU presents the list of AU outputs, namely, *System Health*, *Performance Analysis*, and *What-if Analyses*. Clicking on the first two present the screens shown in Figures 7.4 and 7.5.



Analytics Unit

System Health

Throughput
14.35 JPH
click for more info

Nominal Throughput
30.00 JPH
click for more info

Total Throughput Losses
15.65 JPH
(52.2%)
click for more info

TP Losses Due to Machines
8.06 JPH
(26.9%)

TP Losses Due to Cycle Overruns
2.01 JPH
(6.7%)

TP Losses Due to Buffers
5.58 JPH
(18.6%)
click for more info

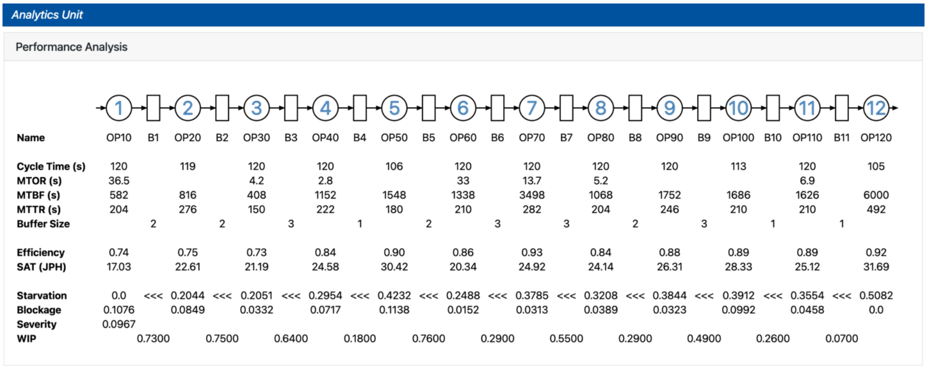
Bottleneck Machine
OP10

Bottleneck Buffer
B1

Total WIP
11.01 Jobs

Production Lead Time
46.04 Minutes
click for more info

Figure 7.4: System Health of TCM line



Analytics Unit

Performance Analysis

Name	OP10	B1	OP20	B2	OP30	B3	OP40	B4	OP50	B5	OP60	B6	OP70	B7	OP80	B8	OP90	B9	OP100	B10	OP110	B11	OP120
Cycle Time (s)	120		119		120		120		106		120		120		120		120		113		120		105
MTOR (s)	36.5				4.2		2.8				33		13.7		5.2						6.9		
MTBF (s)	582		816		408		1152		1548		1338		3498		1068		1752		1686		1626		6000
MTTR (s)	204		276		150		222		180		210		282		204		246		210		210		492
Buffer Size		2		2		3		1		2		3		3		2		3		1		1	
Efficiency	0.74		0.75		0.73		0.84		0.90		0.86		0.93		0.84		0.88		0.89		0.89		0.92
SAT (JPH)	17.03		22.61		21.19		24.58		30.42		20.34		24.92		24.14		26.31		28.33		25.12		31.69
Starvation	0.0	<<<	0.2044	<<<	0.2051	<<<	0.2954	<<<	0.4232	<<<	0.2488	<<<	0.3785	<<<	0.3208	<<<	0.3844	<<<	0.3912	<<<	0.3554	<<<	0.5082
Blockage	0.1076		0.0849		0.0332		0.0717		0.1138		0.0152		0.0313		0.0389		0.0323		0.0992		0.0458		0.0
Severity	0.0967																						
WIP		0.7300		0.7500		0.6400		0.1800		0.7600		0.2900		0.5500		0.2900		0.4900		0.2600		0.0700	

Figure 7.5: Performance Analysis of TCM line

As one can see:

- The nominal throughput is 30 JPH, while the actual one is 14.35 JPH, implying that the total throughput losses are 15.65 JPH (i.e, 52.25%).
- The reasons for these losses are the machines' downtime (8.06 JPH or 26.9%) and cycle overrun (2.01 JPH or 6.7%) as well as insufficient buffers' capacity (5.58 JPH or 18.6%).
- The bottleneck machine is OP10 and the bottleneck buffer is B1 (which is not of the smallest capacity among all buffers).
- Since the total part processing time (i.e., the sum of all machines' cycle time) is 23.4 min and the sum of all buffers' capacity is 23, the total *WIP* in the system and the production lead time are of acceptable values.

These observations lead to the following conclusions:

- Throughput losses alleviation should be the goal of continuous improvement.
- This can be accomplished either by improving machines performance (i.e., decreasing their downtime and cycle overrun), or increasing buffers capacity, or both.
- Based on the throughput losses due to machines and buffers, the priority of improvement actions may be as follows: first con-

sider decreasing machines downtime, then increasing buffers capacity, and, finally, decreasing cycle overrun.

- However, due to practical considerations, increasing buffers' capacity might be too costly and, in addition, may lead to an undesirable increase of the total *WIP* and production lead time.
- Therefore, the remaining parameters to be considered first for potential improvements are the machines' downtime and cycle overruns.
- Since the cycle overruns in the system at hand are mostly due to machines' operators, while the machines downtime is mostly due to mechanical/electrical breakdowns, a reasonable priority of improvement actions may be first decreasing cycle overruns and then reducing downtime.

Based on these considerations, the management would need to explore a number of potential improvement scenarios, prior to selecting one of them for implementation. This is carried out in the next section.

7.4 Improvement Scenarios and Resulting Continuous Improvement Projects

Clearly, the extent of the desired system improvement would depend on the market conditions. From this point of view, two situations may be considered: *demand-limited* and *demand-unlimited* markets. The former is characterized by a defined by the management desired productivity improvement (PI), and the problem would be to find the smallest action space (AS), which results in the desired productivity. The latter is intended to determine what is the largest throughput, which can be attained under the largest practically available AS.

Based on the notion of PMA-based SPS modes of operation (introduced in Chapter 6, Subsection 6.2.1) the demand-limited and demand-unlimited markets are formalized as PI&AS-constrained and AS-constrained scenarios, respectively. Both of these are discussed below.

Demand-limited market: Here we analyze three groups of PI& AS-constrained scenarios: the first one is based on decreasing cycle overrun only, the second on decreasing *MTTR* only, and, the third based on decreasing both cycle overrun and *MTTR* simultaneously. In all considered scenarios, it is assumed that PI calls for a 20% *TP* improvement.

Cycle overrun reduction only:

Scenario 1: PI&AS-constrained. Along with the PI mentioned above, it consists of AS, which allows for the total cycle time overrun reduction of all machines by at most 80% (i.e., by at most 82 sec). This scenario and the resulting continuous improvement project (calculated by OU) are illustrated in Figure 7.6. As one can see, under this scenario, while AS is fully utilized (by decreasing the cycle overrun of six machines appropriately), the desired *TP* cannot be achieved.

A similar result is obtained assuming that AS allows for 100% of the total overrun reduction. Therefore, the conclusion is:

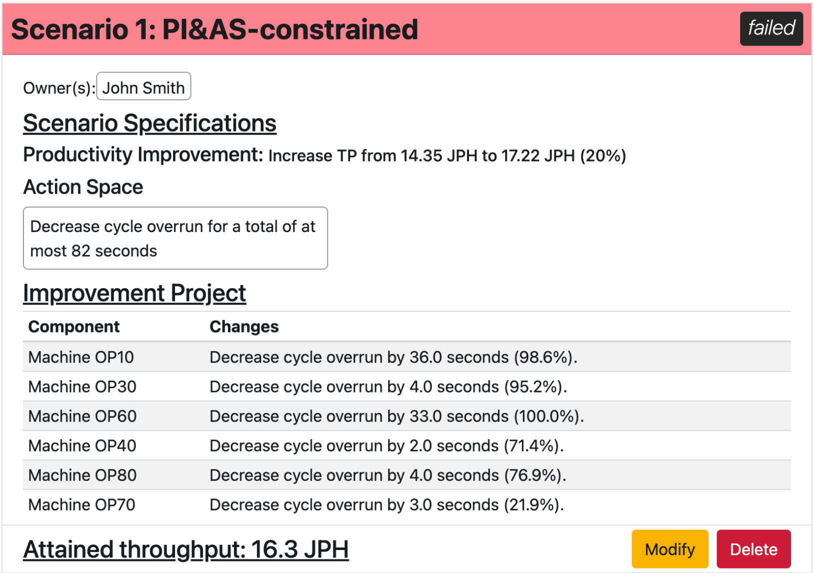
> Eliminating the cycle overruns entirely does not lead to the desired PI.

MTTR reduction only:

Scenario 2: PI&AS-constrained. Here AS allows for *MTTR* reduction of one machine by at most 30%. As shown in Figure 7.7 the resulting continuous improvement project also does not lead to the desire *TP*.

A similar result is obtained assuming that AS allows for up to 100% *MTTR* reduction of one machine. Thus, again the conclusion is that:

> Eliminating the downtime of any single machine entirely does not lead to the desired PI.



Scenario 1: PI&AS-constrained

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Increase TP from 14.35 JPH to 17.22 JPH (20%)

Action Space

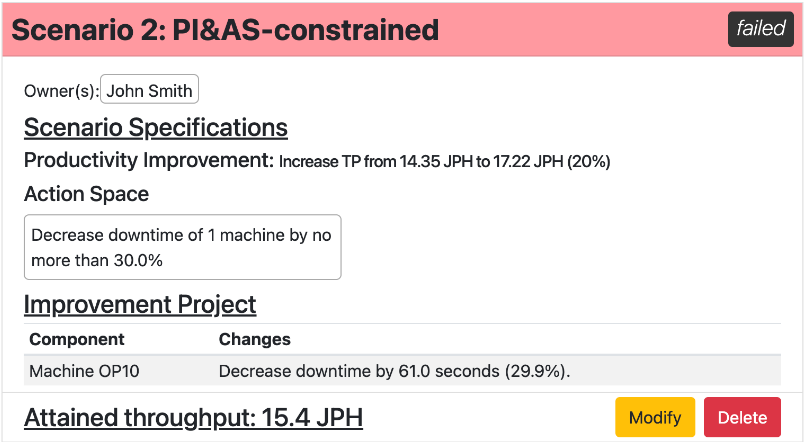
Decrease cycle overrun for a total of at most 82 seconds

Improvement Project

Component	Changes
Machine OP10	Decrease cycle overrun by 36.0 seconds (98.6%).
Machine OP30	Decrease cycle overrun by 4.0 seconds (95.2%).
Machine OP60	Decrease cycle overrun by 33.0 seconds (100.0%).
Machine OP40	Decrease cycle overrun by 2.0 seconds (71.4%).
Machine OP80	Decrease cycle overrun by 4.0 seconds (76.9%).
Machine OP70	Decrease cycle overrun by 3.0 seconds (21.9%).

Attained throughput: 16.3 JPH

Figure 7.6: TCM line Scenario 1 and resulting improvement project



Scenario 2: PI&AS-constrained

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Increase TP from 14.35 JPH to 17.22 JPH (20%)

Action Space

Decrease downtime of 1 machine by no more than 30.0%

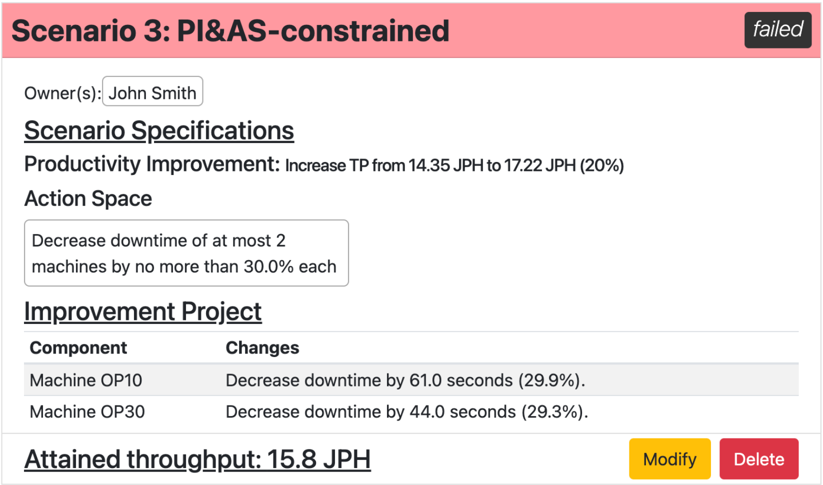
Improvement Project

Component	Changes
Machine OP10	Decrease downtime by 61.0 seconds (29.9%).

Attained throughput: 15.4 JPH

Figure 7.7: TCM line Scenario 2 and resulting improvement project

Scenario 3: PI&AS-constrained. The AS of this scenario consists of *MTTR* reduction of at most two machines by at most 30% each. As shown in Figure 7.8, although the resulting improvement project fully utilizes this AS, the desired performance improvement again cannot be achieved. However, the situation is changing if AS is enlarged as shown in the next scenario.



Scenario 3: PI&AS-constrained failed

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Increase TP from 14.35 JPH to 17.22 JPH (20%)

Action Space

Decrease downtime of at most 2 machines by no more than 30.0% each

Improvement Project

Component	Changes
Machine OP10	Decrease downtime by 61.0 seconds (29.9%).
Machine OP30	Decrease downtime by 44.0 seconds (29.3%).

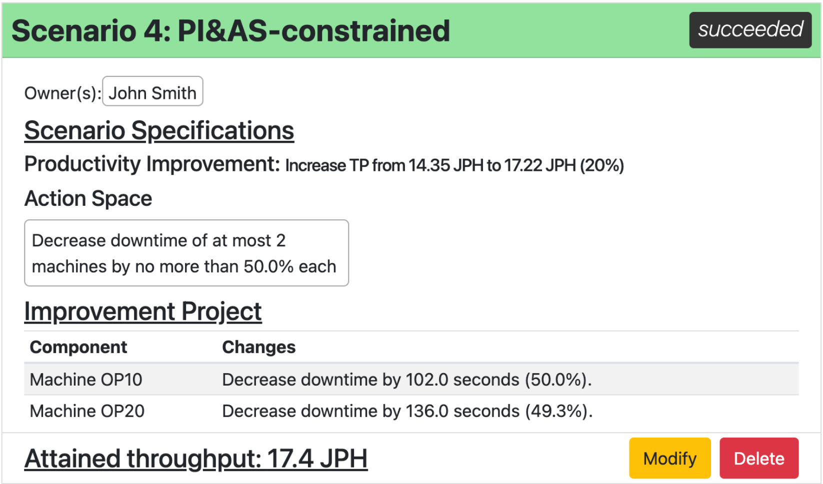
Attained throughput: 15.8 JPH

Figure 7.8: TCM line Scenario 3 and resulting improvement project

Scenario 4: PI&AS-constrained. Here AS again allows for *MTTR* reduction of at most two machines, but by no more than 50% each. As illustrated in Figure 7.9, the resulting continuous improvement project results in the desired system improvement and, in addition, the AS is fully utilized.

Thus,

> Decreasing *MTTR* by 50% of two appropriately selected machines (one of which is the system's bottleneck) does lead to the desired PI.



Scenario 4: PI&AS-constrained

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Increase TP from 14.35 JPH to 17.22 JPH (20%)

Action Space

Decrease downtime of at most 2 machines by no more than 50.0% each

Improvement Project

Component	Changes
Machine OP10	Decrease downtime by 102.0 seconds (50.0%).
Machine OP20	Decrease downtime by 136.0 seconds (49.3%).

Attained throughput: 17.4 JPH

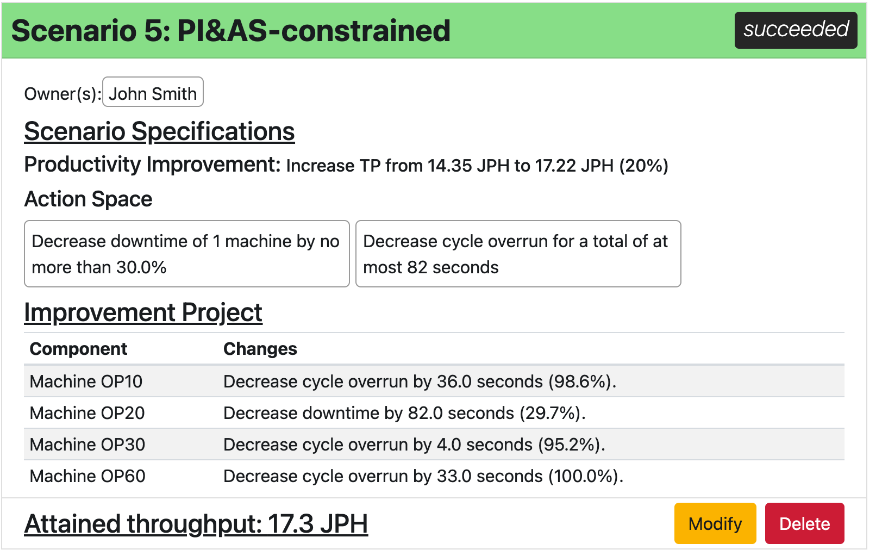
Figure 7.9: TCM line Scenario 4 and resulting improvement project

Cycle overrun and MTTR reduction simultaneously:

Scenario 5: PI&AS-constrained. Here AS allows for the total cycle overrun reduction by at most 80% and one machine *MTTR* reduction by at most 30%. As shown in Figure 7.10, the resulting improvement project indeed leads to the desired system performance, and the AS is practically fully utilized.

Scenario 6: PI&AS-constrained. AS considered here consists of at most 50% reduction of both total cycle overrun and one machine's *MTTR*. As shown in Figure 7.11, the resulting continuous improvement project leads to the desired system performance, and AS is almost totally utilized.

❖ Note that, while Scenarios 4-6 all lead to the desired PI, none of them supersedes the others as far as the "size" of AS is concerned.



Scenario 5: PI&AS-constrained

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Increase TP from 14.35 JPH to 17.22 JPH (20%)

Action Space

Decrease downtime of 1 machine by no more than 30.0%

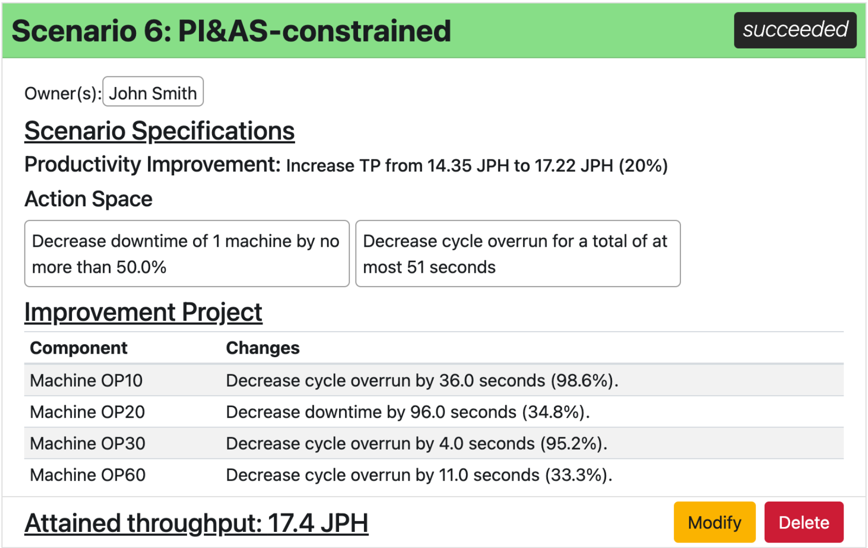
Decrease cycle overrun for a total of at most 82 seconds

Improvement Project

Component	Changes
Machine OP10	Decrease cycle overrun by 36.0 seconds (98.6%).
Machine OP20	Decrease downtime by 82.0 seconds (29.7%).
Machine OP30	Decrease cycle overrun by 4.0 seconds (95.2%).
Machine OP60	Decrease cycle overrun by 33.0 seconds (100.0%).

Attained throughput: 17.3 JPH

Figure 7.10: TCM line Scenario 5 and resulting improvement project



Scenario 6: PI&AS-constrained

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Increase TP from 14.35 JPH to 17.22 JPH (20%)

Action Space

Decrease downtime of 1 machine by no more than 50.0%

Decrease cycle overrun for a total of at most 51 seconds

Improvement Project

Component	Changes
Machine OP10	Decrease cycle overrun by 36.0 seconds (98.6%).
Machine OP20	Decrease downtime by 96.0 seconds (34.8%).
Machine OP30	Decrease cycle overrun by 4.0 seconds (95.2%).
Machine OP60	Decrease cycle overrun by 11.0 seconds (33.3%).

Attained throughput: 17.4 JPH

Figure 7.11: TCM line Scenario 6 and resulting improvement project

Based on the above, it can be concluded that:

> Decreasing *MTTR* of the bottleneck machine to an appropriate degree, along with decreasing the total cycle overruns to an appropriate degree, does lead to the desired PI.

Demand-unlimited market: To address this case, the largest practically available AS must be introduced. In general, it may be the AS defined by the internal PMA constraints, programmed in PMA by SPS designers. However, it can be either too large or too small from the point of view of the system at hand and the market conditions, as perceived by the Operations Manager. In this situation, various other AS-constrained scenarios can be considered to explore the maximum achievable throughputs. Four of such scenarios are considered next.

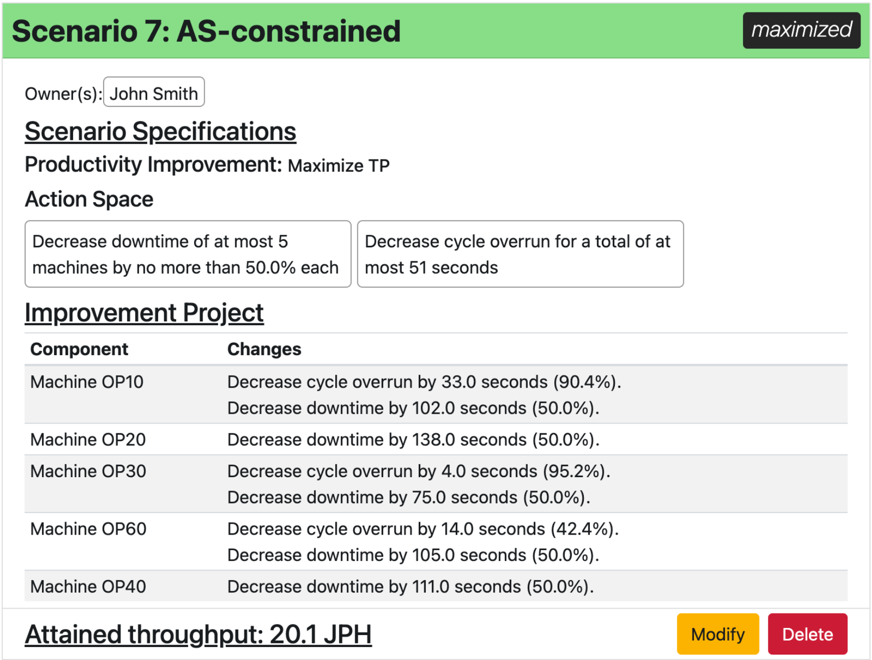
Scenario 7: AS-constrained. The AS of this scenario consists of reducing *MTTR* of at most five machines by no more than 50% each and reducing the total cycle overrun by no more than 50%. The resulting continuous improvement project, shown in Figure 7.12, leads to TP = 20.1 JPH, which is 40% above the original system's throughput.

Three more AS-constrained scenarios have been considered. In each of them AS consisted of reducing the total cycle overrun by no more that 50% (i.e., by 51 sec). In addition,

Scenario 8 includes *MTTR* reduction of all 12 machines by no more than 50% each. This scenario results in $TP = 22.3$ JPH, i.e., 55% above the original system TP.

Scenario 9 includes **total** *MTTR* reduction of all 12 machines by no more than 50% (i.e., by 1443 sec). This leads to $TP = 25$ JPH, i.e., 74% above the original system TP, which is relatively close to the system's nominal throughput (i.e., 30 JPH). The problem with this scenario is that it requires *MTTR* reduction of some of the machines by 100%, which is hardly possible in practice. Therefore,

Scenario 10 also includes total *MTTR* reduction of all 12 machines by no more than 50% (i.e., by 1443 sec), but by no more than **80% each**. This leads to $TP = 24.8$ JPH, which is just 0.2 JPH below that of Scenario 9. Since this scenario seems to be more "implementable" than the other two, it is illustrated, along with the corresponding improvement project, in Figure 7.13.



Scenario 7: AS-constrained

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Maximize TP

Action Space

Decrease downtime of at most 5 machines by no more than 50.0% each

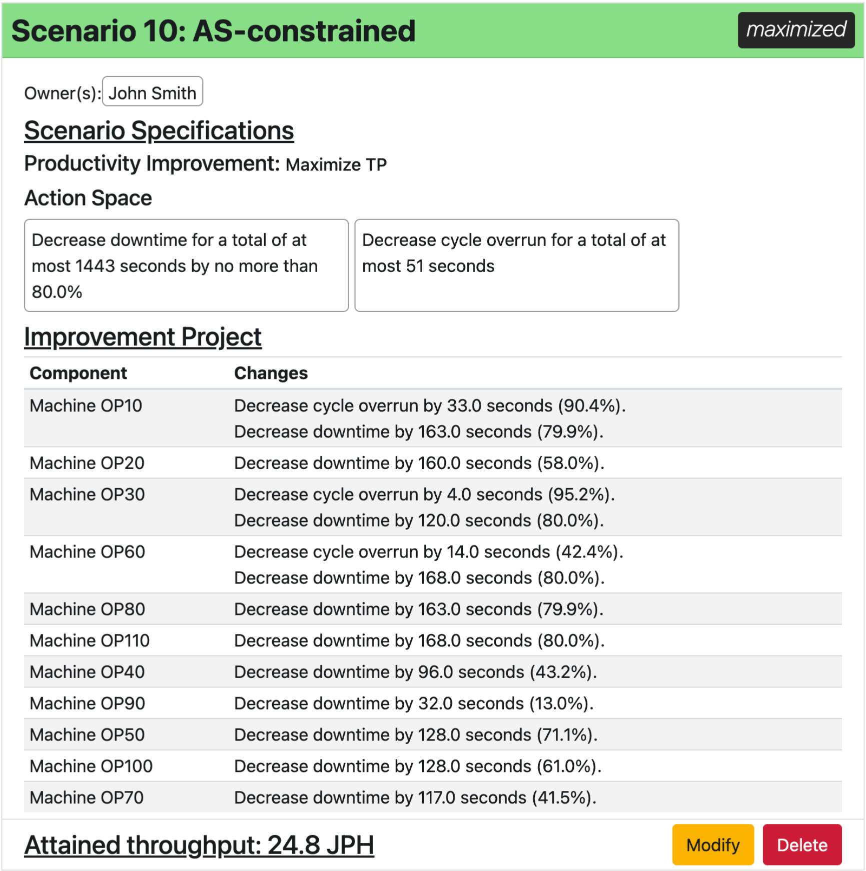
Decrease cycle overrun for a total of at most 51 seconds

Improvement Project

Component	Changes
Machine OP10	Decrease cycle overrun by 33.0 seconds (90.4%). Decrease downtime by 102.0 seconds (50.0%).
Machine OP20	Decrease downtime by 138.0 seconds (50.0%).
Machine OP30	Decrease cycle overrun by 4.0 seconds (95.2%). Decrease downtime by 75.0 seconds (50.0%).
Machine OP60	Decrease cycle overrun by 14.0 seconds (42.4%). Decrease downtime by 105.0 seconds (50.0%).
Machine OP40	Decrease downtime by 111.0 seconds (50.0%).

Attained throughput: 20.1 JPH

Figure 7.12: TCM line Scenario 7 and resulting improvement project



Scenario 10: AS-constrained

Owner(s): John Smith

Scenario Specifications

Productivity Improvement: Maximize TP

Action Space

Decrease downtime for a total of at most 1443 seconds by no more than 80.0%

Decrease cycle overrun for a total of at most 51 seconds

Improvement Project

Component	Changes
Machine OP10	Decrease cycle overrun by 33.0 seconds (90.4%). Decrease downtime by 163.0 seconds (79.9%).
Machine OP20	Decrease downtime by 160.0 seconds (58.0%).
Machine OP30	Decrease cycle overrun by 4.0 seconds (95.2%). Decrease downtime by 120.0 seconds (80.0%).
Machine OP60	Decrease cycle overrun by 14.0 seconds (42.4%). Decrease downtime by 168.0 seconds (80.0%).
Machine OP80	Decrease downtime by 163.0 seconds (79.9%).
Machine OP110	Decrease downtime by 168.0 seconds (80.0%).
Machine OP40	Decrease downtime by 96.0 seconds (43.2%).
Machine OP90	Decrease downtime by 32.0 seconds (13.0%).
Machine OP50	Decrease downtime by 128.0 seconds (71.1%).
Machine OP100	Decrease downtime by 128.0 seconds (61.0%).
Machine OP70	Decrease downtime by 117.0 seconds (41.5%).

Attained throughput: 24.8 JPH

Figure 7.13: TCM line Scenario 10 and resulting improvement project

Based on the above analysis, we conclude that:

> Reducing **total** *MTTR* and **total** cycle overrun of all machines by at most 50% results in the *TP*, which is quite close to the nominal one.

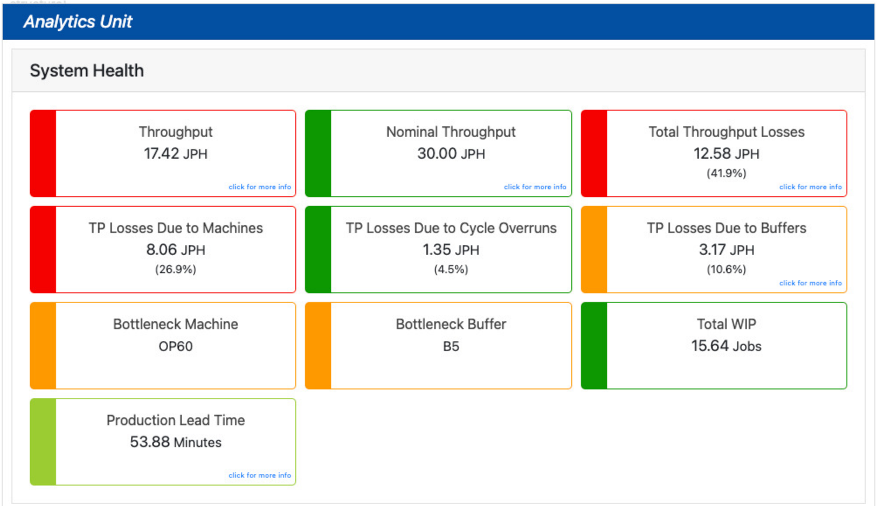
7.5 Facilitating Managerial Approval: Summary of the Designed Improvement Projects

This section is intended to comparatively summarize the designed above continuous improvement projects satisfying the desired PI and regarded as potentially most likely to receive managerial approval. This is accomplished by presenting the selected systems' health, along with a reminder of their PI, AS, improvement projects activities, as well as a few explanatory remarks.

Demand-limited market

Scenario 4: PI = {increase TP by 20%}; AS = {$MTTR$ reduction of at most two machines by no more than 50% each}.
Improvement project = {reduce $MTTR$ of OP10 and OP20 by 50%}.

The improved system's health is quantified in Figure 7.14.



Throughput 17.42 JPH
Nominal Throughput 30.00 JPH
Total Throughput Losses 12.58 JPH (41.9%)
TP Losses Due to Machines 8.06 JPH (26.9%)
TP Losses Due to Cycle Overruns 1.35 JPH (4.5%)
TP Losses Due to Buffers 3.17 JPH (10.6%)
Bottleneck Machine OP60
Bottleneck Buffer B5
Total WIP 15.64 Jobs
Production Lead Time 53.88 Minutes

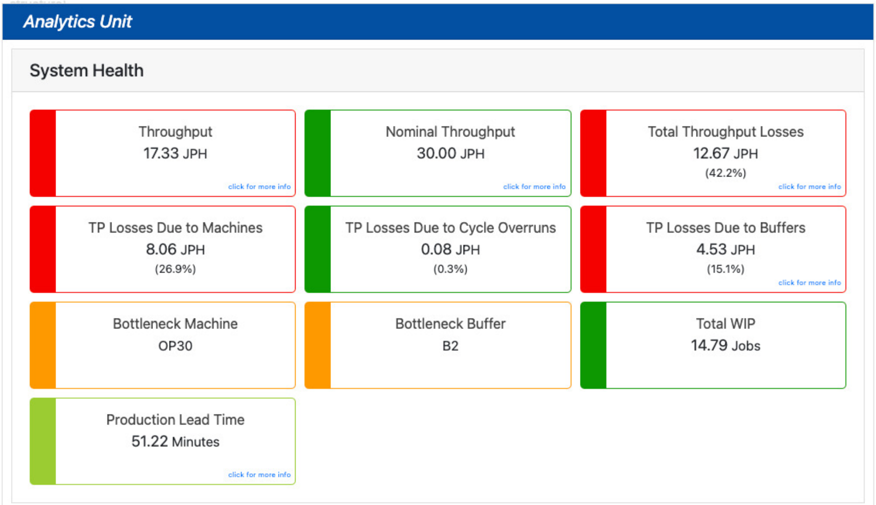
Figure 7.14: System Health of TCM line improved according to Scenario 4

The advantage of this improvement project is that it requires performance modifications of only two machines and with respect to only one parameter – their $MTTR$. In addition, it results in reduced losses due to cycle overrun and due to buffers capacity. The disadvantage is that the required $MTTR$ reductions by 50%

may be viewed as relatively large. Finally, we note that under this scenario the bottlenecks shift from OP10 and B1 to OP60 and B5.

Scenario 5: PI = {increase TP by 20%}; AS = {*MTTR* reduction of one machine by no more than 30% and total cycle overrun reduction by 80%}.
Improvement project = {reduce *MTTR* of OP20 by 30% and eliminate overruns of OP10, OP30, and OP60}.

The resulting system's health is illustrated in Figure 7.15.



Analytics Unit

System Health

🟥 Throughput 17.33 JPH (click for more info)

🟩 Nominal Throughput 30.00 JPH (click for more info)

🟥 Total Throughput Losses 12.67 JPH (42.2%) (click for more info)

🟥 TP Losses Due to Machines 8.06 JPH (26.9%)

🟩 TP Losses Due to Cycle Overruns 0.08 JPH (0.3%)

🟥 TP Losses Due to Buffers 4.53 JPH (15.1%) (click for more info)

🟧 Bottleneck Machine OP30

🟧 Bottleneck Buffer B2

🟩 Total WIP 14.79 Jobs

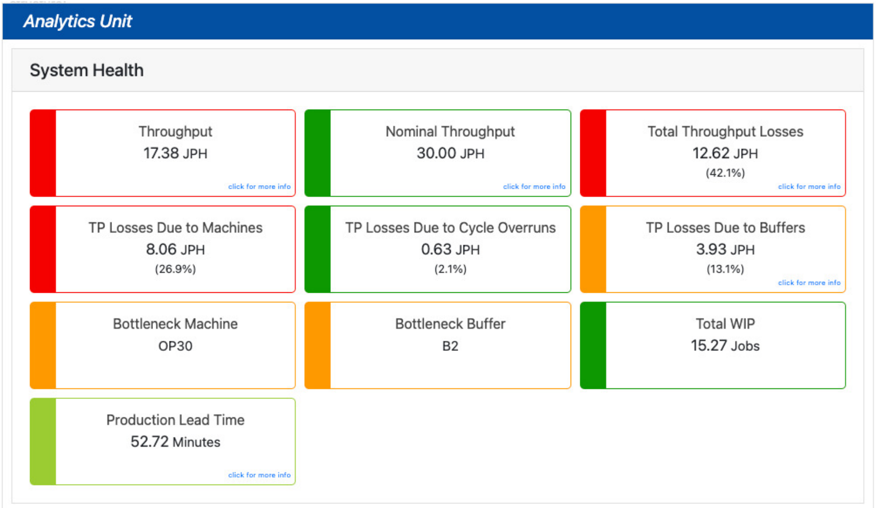
🟩 Production Lead Time 51.22 Minutes (click for more info)

Figure 7.15: System Health of TCM line improved according to Scenario 5

The advantage of the improvement project based on Scenario 5 is that it requires *MTTR* reduction of only one machine and this reduction is relatively small. Also, implementing Scenario 5 results in substantially reduced losses due to the buffers. The disadvantage is that it requires modifications of an additional parameter – cycle overrun of OP10, OP30, and OP60, and these modifications are large (almost 100%). The bottlenecks now are OP30 and B2.

Scenario 6: PI = {increase TP by 20%}; AS = {*MTTR* reduction of one machine by no more than 50% and total cycle overrun reduction by 50%}.
Improvement project = {reduce *MTTR* of OP20 by 35%, eliminate overrun of OP10 and OP30, and reduce that of OP60 by 33%}.

The resulting system's health is illustrated in Figure 7.16.



Analytics Unit

System Health

Throughput
17.38 JPH

Nominal Throughput
30.00 JPH

Total Throughput Losses
12.62 JPH
(42.1%)

TP Losses Due to Machines
8.06 JPH
(26.9%)

TP Losses Due to Cycle Overruns
0.63 JPH
(2.1%)

TP Losses Due to Buffers
3.93 JPH
(13.1%)

Bottleneck Machine
OP30

Bottleneck Buffer
B2

Total WIP
15.27 Jobs

Production Lead Time
52.72 Minutes

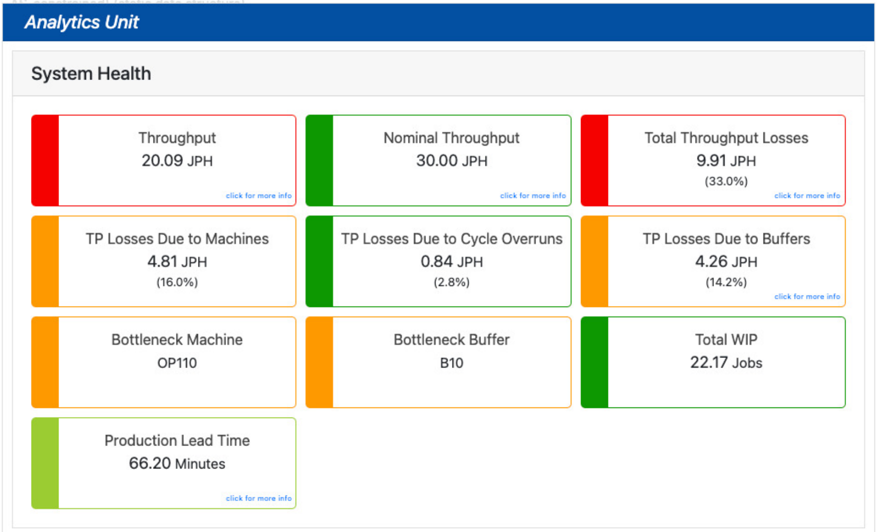
Figure 7.16: System Health of TCM line improved according to Scenario 6

The System Health under this scenario is similar to that under Scenario 5, with the only difference that $MTTR$ reduction is, as expected, larger and cycle overrun reductions are smaller.

Demand-unlimited market

Scenario 7: PI = {TP maximization}; AS = {*MTTR* reduction of at most 5 machines by no more than 50% and total cycle overrun reduction by 50%}.
Improvement project = {reduce *MTTR* of OP10-OP40 and OP60 by 50%, reduce cycle overrun of OP10, OP30, and OP60 appropriately (see Figure 7.12)}.

The resulting system's health is illustrated in Figure 7.17.



Throughput
20.09 JPH

Nominal Throughput
30.00 JPH

Total Throughput Losses
9.91 JPH
(33.0%)

TP Losses Due to Machines
4.81 JPH
(16.0%)

TP Losses Due to Cycle Overruns
0.84 JPH
(2.8%)

TP Losses Due to Buffers
4.26 JPH
(14.2%)

Bottleneck Machine
OP110

Bottleneck Buffer
B10

Total WIP
22.17 Jobs

Production Lead Time
66.20 Minutes

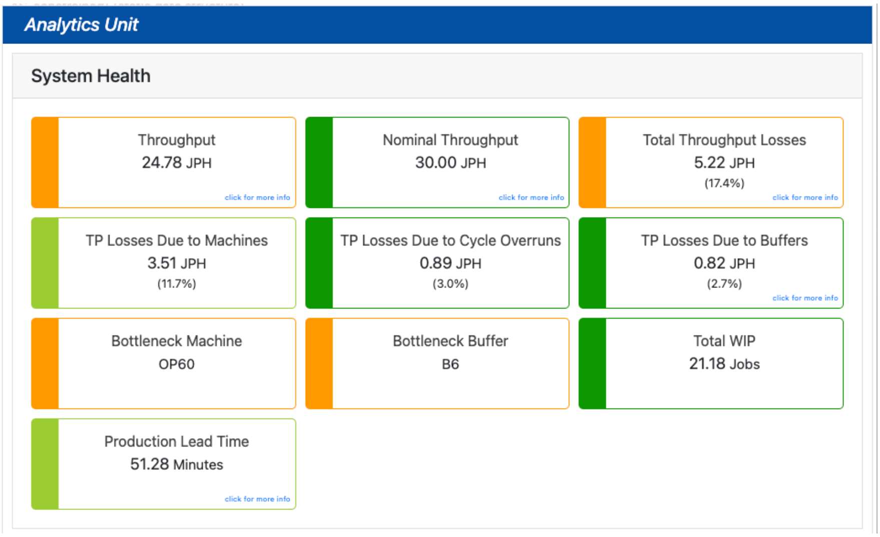
Figure 7.17: System Health of TCM line improved according to Scenario 7

The obvious advantage of this scenario is that it leads to a substantially larger TP in comparison with that provided by the demand-limited cases (20.1 JPH vs. 17.2 JPH, i.e., 16.9% improvement). The equally obvious disadvantage is that $MTTR$ of five machines must be decreased by 50% and cycle overrun of three machines must decreased dramatically, totaling, however, 51 sec. The bottlenecks now are OP110 and B10.

Scenario 10: PI = $\{TP$ maximization$\}$; AS = $\{$total $MTTR$ reduction of all machines by no more than 1443 sec and at most by 80% each, as well as total cycle overrun reduction by no more than 50%$\}$.

Improvement project = $\{$reduce $MTTR$ of all machines, with the exception of OP120, by no more than 80%; reduce the cycle overrun of OP10, OP30, and OP60 as shown in Figure 7.13$\}$.

The resulting system's health is illustrated in Figure 7.18.



Analytics Unit

System Health

Throughput
24.78 JPH

Nominal Throughput
30.00 JPH

Total Throughput Losses
5.22 JPH
(17.4%)

TP Losses Due to Machines
3.51 JPH
(11.7%)

TP Losses Due to Cycle Overruns
0.89 JPH
(3.0%)

TP Losses Due to Buffers
0.82 JPH
(2.7%)

Bottleneck Machine
OP60

Bottleneck Buffer
B6

Total WIP
21.18 Jobs

Production Lead Time
51.28 Minutes

Figure 7.18: System Health of TCM line improved according to Scenario 10

The advantage of this scenario is that the resulting *TP* is quite high. The obvious disadvantage is that all machines' *MTTR* and cycle overrun must be decreased substantially.

> The information presented in this section should allow the Operations Manager to select an improvement project, consistent with the market conditions and other engineering and business considerations.

7.6 Chapter 7 Takeaway

- ✓ This chapter illustrates the process of continuous improvement projects design in the framework of PMA-based smart serial line with unreliable machines, finite buffers, and cycle overrun.
- ✓ Since for each scenario considered, the corresponding impro-

vement project is calculated by PMA practically instantaneously, numerous possibilities have been explored, leading to a set of potential improvements, offered to the Operations Manager (OM) for selection and approval.

- ✓ Both demand-limited and demand-unlimited have been considered.
- ✓ In the demand-limited case, the specific questions investigated are:
  - ○ Can or cannot the desired by management productivity be obtained by eliminating cycle overruns entirely?
  - ○ Can or cannot the desired by management productivity be obtained by eliminating *MTTR* of any one machine entirely?
  - ○ Can or cannot the desired by management productivity be obtained by decreasing *MTTR* of two appropriately selected machines to a certain degree?
- ✓ As it turns out, for the system at hand and the desired productivity improvement, the answers to the first two questions are in the negative and to the last one in the positive.
- ✓ Based on these results, a series of improvement scenarios using simultaneous reduction of both *MTTR* and cycle overrun (in the PI&AS-constrained mode) has been investigated for the demand-limited case, and the resulting continuous improvement offered to OM.
- ✓ Another series of scenarios has been explored in the demand-unlimited case (in AS-constrained mode), where it was shown that reducing total *MTTR* and total cycle time of all machines by 50% results in *TP*, which is quite close to the system's nominal throughput.