CHAPTER 1

Introduction

Goal: The goal of this chapter is to introduce the concept of Smart Production Systems (SPS) and its software tool – Programmable Manufacturing Advisor (PMA). Also, this chapter describes the goals, contents, and the intended audience of this book, as well as the relationship between SPS and Industry 4.0. Finally, it offers a preview of the PMA-based SPS operation.

1.1 Smart Production Systems and Programmable Manufacturing Advisor

Production Systems are machines, buffers, material handling devices, and associated workforce arranged so as to produce a desired product.

Smart Production Systems (SPS) are production systems capable of self-diagnosis and autonomous design of continuous improvement projects, leading to the desired by management productivity improvement, with minimal system modifications and guaranteed results.

In this definition, the term *self-diagnosis* is used to indicate that the system has the capability of analyzing its performance, performance losses, and their causes. The term *autonomous design* is used to imply that the system has the capability of calculating actions for losses alleviation. The term *minimal* indicates that these actions can be carried out by the means within the purview of the Operations Manager (OM), i.e., without capital investments. Finally, the term *guaranteed* is used to indicate that the improvement project will indeed result in the analytically predicted system behavior.

To illustrate this definition, consider an example: The underbody assembly department of an automotive assembly plant is designed to produce nominally (i.e., when no equipment failures, cycle overruns, or quality problems occur) 60 Jobs-Per-Hour (JPH), but produces, on average, only 50 JPH. OM wishes to increase the throughput by 10%. This leads to two questions:

- What are the major causes of throughput losses?
- How can a 10% throughput increase be achieved in an optimal manner, i.e., with minimal system modifications?

If the answers to these questions are provided by the production system itself (rather than a human), according to the above definition, this system is smart.

To make a production system smart, it has to be equipped with a "brain" capable of diagnosing its performance and calculating improvement actions. Such a "brain," or an artificial intelligence (AI) device, has been developed in Smart Production Systems LLC and referred to as *Programmable Manufacturing Advisor* (PMA) (S.M. Meerkov, P. Alavian, and L. Zhang, U.S. Patent 11,861,739, Jan. 2, 2024). Programming and installing PMA at any production system makes it smart (*PMA-based SPS*). No similar technology is available on the market today.

The only requirement for PMA utilization on the factory floor is the availability of manual or automated equipment status measurements (mainly, machines' up- and downtime, cycle time, cycle overrun, and quality characteristics).

Conceptually, PMA is similar to PLC (Programmable Logic Controller). The difference is that PLC automates manufacturing equipment, while PMA automates decision-making in manufacturing environment.

The calculations carried out by PMA are based on analytics, with no simulations involved (with one exception mentioned in the remark of Section 4.8).

PMA can be deployed on the cloud or on-premises. In the latter case, PMA is deployed either within the plant's IT system or, in manufacturing organizations with no extensive IT, as a standalone device consisting of an interactive display and a server that receives machines' performance data continuously (e.g., automatically) or intermittently (e.g., manually).

The analytics embedded in PMA are based on the research on Production Systems Engineering (PSE) carried out at the University of Michigan starting from 1985. The main results of this research and its practical applications are summarized in the textbook [1] and subsequent publications (for instance, [2] -[11]).

To enable applications of the PSE results, a software tool, referred to as *PSE Toolbox*, has been developed. It has been used by teams of PSE-trained personnel and manufacturing practitioners for "manual" design of continuous improvement projects at dozens of plants at large, mid-size, and small manufacturing organizations (e.g., GM, Ford, Chrysler, Toyota, Visteon, Kroger, Kraft, Generac, etc.). The term "manual" is used here to indicate that in these applications, the intelligence has been provided by PSE-trained and manufacturing personnel, while the calculations have been carried out by PSE Toolbox. Consistently, substantial productivity improvements have been obtained, often leading to 10%-30% increase of the systems throughput.

PMA automates this process, making it AI-enabled. It provides the possibility of designing optimal continuous improvement projects by managerial/engineering personnel without training in PSE or analytics in general. PSE-trained personnel would be required only for PMA programming and deployment (similar to control engineers required for programming and deploying PLC and PID controllers).

It should be pointed out that PMA is not intended to displace managerial or engineering personnel. Its intention is to make the managerial decision-making more effective by providing optimal advice for achieving the desired by management productivity improvement.

For the readers' convenience, demos of PSE Toolbox and PMA are available at https://www.smartproductionsystems.com under the *Products* tab.

1.2 Goals and Contents of the Book

The goals of this book are:

- Offer the reader a brief introduction to the main concepts, analytics, and software tools of SPS.
- Introduce the reader to the fundamentals of PSE.
- Provide the reader with working knowledge of PSE Toolbox, PMA, and PMA-based SPS.

- Enable the reader to assist PMA programmers by providing information necessary for design and deployment of PMA-based SPS on the factory floor.
- Most importantly, enable the reader to utilize PMA-based SPS for operations management and design of continuous improvement projects with rigorously predicted results.

This is the only book on smart production systems published to-date.

The contents of this book are:

Chapter 2 introduces the production systems' concepts and terminology used in the rest of this book. In particular, it describes the types of production systems, the parameters of manufacturing equipment, and the performance metrics quantifying production systems' behavior. In addition, this chapter presents methods for calculating the minimal number of factory floor measurements necessary to evaluate machines' parameters and systems' performance metrics with desired accuracy.

Chapter 3 addresses the issue of production systems mathematical modeling. Specifically, the process of mathematical modeling is described and illustrated by six production systems (four of which are revisited in Chapters 7-10 to demonstrate the smart production systems operation).

Chapter 4 presents the fundamentals of PSE necessary for production system management and for understanding and utilization of PSE Toolbox, PMA, and PMA-based SPS.

Chapters 5 and 6 describe the operation and utilization of PSE Toolbox and PMA, respectively. Namely, Chapter 5 illustrates the "manual," i.e., PSE Toolbox-assisted, method of continuous improvement projects design, while Chapter 6 illustrates the automated, i.e., AI-enabled, method for such projects design.

Chapters 7-10 are intended to demonstrate the process of continuous improvement projects design in PMA-based SPS environment. The demonstrations presented here are based on four production systems described in Chapter 3:

- smart automotive transmission case machining line
- smart electronic board production line
- smart automotive ignition control module assembly system
- smart automotive underbody assembly system.

The additional two systems,

- smart hot-dip galvanization plant
- smart automotive paint shop system,

are demonstrated at https://www.smartproductionsystems.com/ under the *Resources* tab.

The Epilogue, References, lists of Acronyms and Notations, and Index are included at the end of the book.

In addition, a set of exercises to help the readers acquire hands-on experience with the concepts and methods included in this book is posted at the above-mentioned website, also under the *Resources* tab.

Throughout this book, the conclusions, explanatory remarks, qualitative properties, identification procedures, and definitions are color-coded: Specifically, conclusions and explanatory remarks are given in green and gray boxes, respectively; qualitative properties and identification procedures are printed on yellow and on light blue background; and definitions are printed in red font.

1.3 Intended Audience and Prerequisites

The intended audience of this book consists of:

- Managerial and engineering personnel at large, mid-size, and small manufacturing organizations interested in learning about smart production systems and, potentially, in deploying PMA-based SPS technology.
- Software developers in the area of smart manufacturing systems and AI-based technology for decision-making automation in manufacturing environment.
- Undergraduate and graduate students contemplating careers in

production systems and/or product design, with emphasis on Smart Manufacturing.

For each of these categories of audience, this book can be used either for self-study or as a textbook for industrial short courses on Smart Manufacturing and for undergraduate/graduate courses in engineering and business schools.

For the purposes of self-study, the following are recommendations for using this book by various groups of readership:

A QUICK LOOK (for those interested to learn what SPS is all about):

- Read Chapter 1 (to have an idea of what SPS and PMA are).
- Read Sections 4.3-4.11 of Chapter 4 (to learn about the main PSE concepts and their utilization on the factory floor).
- Read one or more of Chapters 7-10 (to learn about AI-enabled continuous improvement projects design in smart production systems environment).

A LONGER LOOK (for those interested to manage PMA-based SPS operations):

In addition to the material listed above,

- Read Sections 2.1, 2.2, and 2.4 of Chapter 2 (devoted to standard terminology describing production systems, as well as the machines' and buffers' parameters and performance metrics).
- Read Section 5.1 of Chapter 5 (an introduction to PSE Toolbox-assisted "manual" design of continuous improvement projects).
- Read Section 6.1 of Chapter 6 (an introduction to PMA-enabled automated design of continuous improvement projects).

AN EXTENSIVE LOOK (for those interested in participating in the design and management of PMA-based SPS):

In addition to the material listed for the above two categories of readers,

- Read Section 2.3 of Chapter 2 (to learn about the methods for evaluating machines parameters on the factory floor).

- Read Sections 5.2 and 5.3 of Chapter 5 (to learn about PSE Toolbox and PSE Toolbox-assisted continuous improvement projects design).
- Read Sections 6.2-6.5 of Chapter 6 (to learn about PMA and PMA-enabled continuous improvement projects design).

A COMPLETE LOOK (for those interested in becoming champions of SPS technology in their respective organizations and, perhaps, in offering short courses on SPS):

- Read the entire book.

As far as specific prerequisites for reading this book are concerned, actually none is necessary. A college degree and some industrial experience would be desirable, but not obligatory.

We hope that this book will be useful for both seasoned practitioners and beginners in the field of manufacturing, as well as for college students contemplating entering this field. We hope also that it will provide a new framework for automated performance analysis and design of continuous improvement projects with analytically predicted results.

Consulting, development, deployment, and training services related to PSE, PSE Toolbox, PMA, and PMA-based SPS are offered by Smart Production Systems LLC. More details can be found at https://www.smartproductionsystems.com/ under *Services*.

1.4 Relationship of PMA-based SPS with Industry 4.0

Industry 4.0 is a popular term in the current manufacturing practice. It has been introduced in report [12] to denote the onset of a new industrial revolution.

According to the authors of this report, each industrial revolution has been enabled by a new technological development:

- The first – by new power sources, leading to power-assisted labor-intensive operations.
- The second – by the division of labor leading to the assembly line and mass production.
- The third – by automation of manufacturing equipment based on sensing and computer technology as well as robotics.
- The fourth – by cyber-physical systems (CPS), i.e., systems with manufacturing equipment being integrated with sensing, computing, and communication devices in order to ensure efficient production.

Accordingly, a popular icon, representing Industry 4.0, is as shown in Figure 1.1.

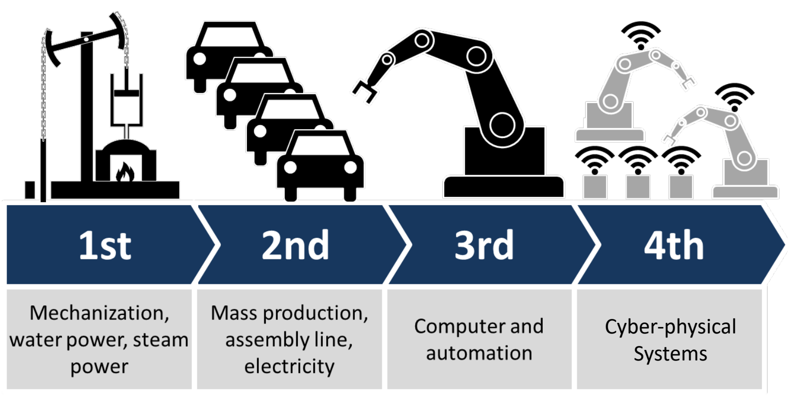


Figure 1.1: Industry 4.0 icon (image by Christoph Roser)

It can be surmised that the goal of CPS in Industry 4.0 is to revolutionize automation of decision-making in manufacturing environment in order to maximize managerial efficacy and, thus, the system productivity. To accomplish this, it is indeed desirable that a manufacturing system be infused with networked sensors, computers, and communication devices. However, in our opinion, this technology, by itself, may not be sufficient to obtain the desired productivity improvement: The system must include analytics and software for utilizing the "big data" collected/produced by this technology in order to autonomously diagnose the production system's health and calculate optimal improvement steps to be offered as advice to the manager.

This leads to a connection of PMA-based SPS with Industry 4.0: By utilizing Industry 4.0 sensing/computing/communication devices (or even without this technology per-se, but having some information of manufacturing equipment status), SPS contributes to one of the main goals of the fourth revolution – automation of decision-making in manufacturing environment based on appropriate analytics and software. Thus:

SPS contributes to one of the four main emphases of Industry 4.0 referred to as Smart Factory/Smart Manufacturing.

In view of the above, the last two revolutions could be renamed as "Equipment automation" and "Decision-making automation," respectively. This leads to a modified Industry 4.0 icon shown in Figure 1.2, where the fourth revolution is symbolized by Auguste Rodin's sculpture "The Thinker," augmented by inserting a laptop – for receiving information from the factory floor and calculating optimal decisions for productivity improvement, thereby serving as the production system's "brain."

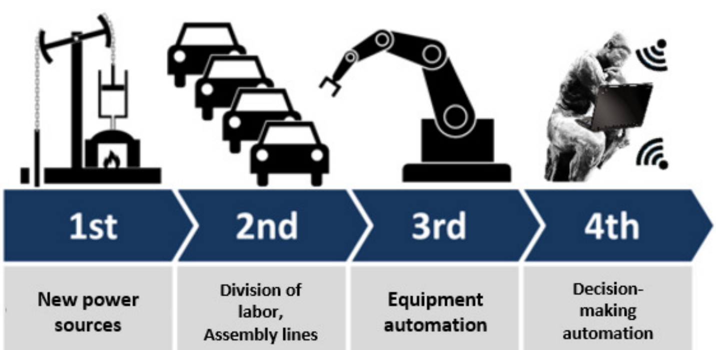


Figure 1.2: Modified Industry 4.0 icon

1.5 Preview: A Brief Demonstration of PMA-based SPS Operation

PMA-based SPS can operate in two regimes: *intermittent* or *continuous*. In the former, PMA operation is triggered by OM, who provides information on the desired productivity improvement and available means for equipment modification. In response, PMA uses the mathematical model of the production system at hand and calculates a continuous improvement project leading to the desired improvement. In the latter, PMA operation is triggered by the production system itself. It occurs when the system throughput (TP), being continuously monitored on the factory floor, drops below its desired value, for instance, by 5%. In response, PMA autonomously identifies the cause of throughput losses and designs a continuous improvement project for returning the system to the desired TP. Since illustrating the continuous regime requires numerous details of SPS operation (to be covered in Chapter 6), only the intermittent one is demonstrated below. Also, since the reader is not familiar yet with PMA terminology and concepts, some SPS features cannot be fully demonstrated here. Nevertheless, it is expected that the reader would benefit from this exposure – by knowing where this book is heading.

1.5.1 Mathematical model

The *mathematical model* (MM) of a production system is a diagram, which represents the parts flow across the system and the parameters of its machines and buffers.

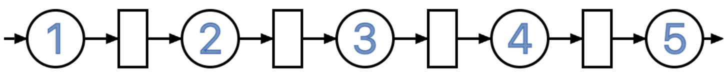
Accordingly, MM consists of a structural model, representing the former, and a parametric model, representing the latter.

Constructing an MM and uploading it into PMA, as well as establishing a process of updating the machines' and buffers' parameters, make a production system smart.

Figure 1.3 presents a screenshot of the MM of a production system uploaded in PMA and referred to throughout this book as the *Preview example*. Its structural model is comprised of machines (circles) and buffers (rectangles). Its parametric model is represented by six rows of numbers under each machine and buffer. These parameters are: machines cycle time (τ); two parameters defining machines reliability, namely, *Mean Time Between Failures* (*MTBF*) and *Mean Time To Repair* (*MTTR*); buffer capacity (N); and two additional parameters (calculated using τ, *MTBF*, and *MTTR*), i.e., machines' efficiency (e) and stand-alone throughput (SAT).

Information Unit

Mathematical model



Name	OP10	B1	OP20	B2	OP30	B3	OP40	B4	OP50
Cycle Time (s)	48		43		45		42		48
MTBF (s)	345		350		390		310		400
MTTR (s)	50		43		53		49		42
Buffer Size		2		1		1		2	
Efficiency	0.87		0.89		0.88		0.86		0.90
SAT (JPH)	65.51		74.56		70.43		74.02		67.87

Figure 1.3: Mathematical model of the Preview example

Obviously, the system at hand is a serial line with five unreliable machines and four finite buffers. In the case of other system-types described in Chapter 2 (e.g., assembly systems, serial lines with inspection stations and rework, and closed lines) additional parameters may be present (e.g., machine quality characteristics, number of carriers in the system, cycle overrun, etc.). The information necessary for developing such mathematical models is obtained either from real-time factory floor measurements, or from historical data of system's performance, or both. Chapter 2 defines in detail the system parameters mentioned above and Chapter 3 describes the process of mathematical modeling.

The mathematical model provides an initial characterization of the system at hand. In the case of Figure 1.3, it shows that:

- the slowest machines are OP10 and OP50 ($\tau = 48$ sec);
- the machine with the smallest efficiency is OP40 ($e = 0.86$);
- the machine with the smallest SAT is OP10 ($SAT = 65.51$ JPH);
- the buffers with the smallest capacity are B2 and B3.

This implies, in particular, that nominally (i.e., when all machines are fully reliable) the system can produce $\frac{3600 \text{ sec}}{48 \text{ sec}} = 75$ JPH, however, actually it cannot produce more than 65.51 JPH (since it is the smallest SAT among all machines), i.e., throughout losses are, at least, 12.7%.

1.5.2 System health

System Health is a set of systems' performance characteristics, calculated analytically by PMA, based on its mathematical model.

For the Preview example, System Health is shown by a PMA screenshot in Figure 1.4. As one can see, it indicates that:

- The system throughput is 58.26 JPH, i.e., the *actual* throughout losses are 22.3%.
- While these losses are due to both unreliable machines and finite buffers,
  - the losses due to machines are 9.49 JPH
  - the losses due to buffers are 7.25 JPH.

> ❖ This implies that both machines and buffers can be used for throughput improvement, depending on what is more feasible – decreasing machines' downtime (which is always preferable), or increasing buffers' capacity (which is less desirable), or both.

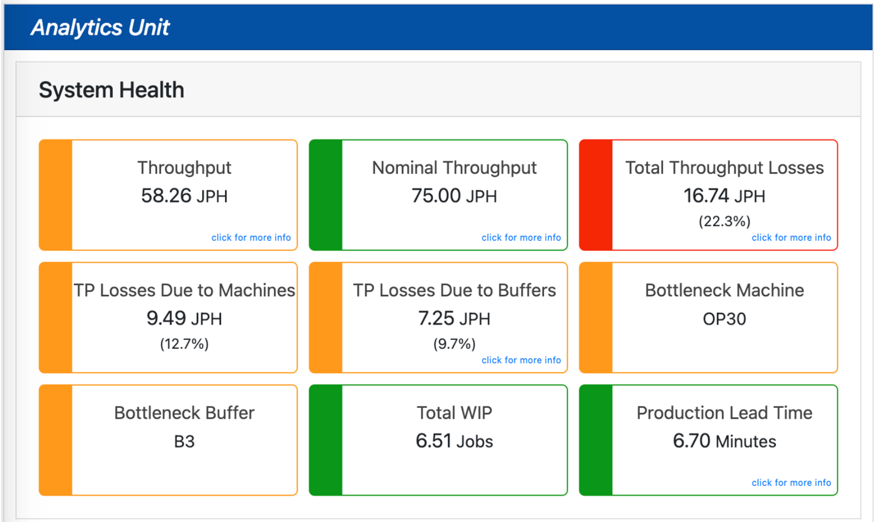


Figure 1.4: System Health of the Preview example

- The bottleneck machine (BN) (defined in Chapter 4 as the machine that affects the system throughput in the strongest manner) is OP30. Note that it is not the worst machine in the system (from any point of view – τ, e, or SAT). This is because BN, as discussed in Chapter 4, is defined not only by the parameters of individual machines, but also by:
  - machines' position in the system and
  - buffers capacity around each machine.
- The bottleneck buffer (BN-b) (defined in Chapter 4 as the buffer that affects the system throughput in the strongest manner) is B3, which is one of the two smallest buffers in the system.

❖ This implies that the design of a continuous improvement project should be centered initially not on the worst machine, but on the BN. Only when it is improved and no longer the BN, improvements should be centered on another machine – the new BN, and so on until the desired performance is achieved, if at all possible.

- In addition to the above, System Health shows the total work-in-process in the system and production lead time. (Note that the total *WIP*, shown in Figure 1.4, is larger than the total buffer capacity; this is because the total *WIP* includes not only the average number of parts stored in the buffers, but also the average number of parts being processed by the machines.)

> ❖ These two performance metrics can also be a goal of continuous improvement, e.g., to improve the system's leanness, or production lead time, or the level of customer demand satisfaction.

In cases of systems with additional causes of productivity losses (e.g., cycle overrun, or quality issues, or part carriers problem), System Health quantifies the performance degradation due to each of these causes as well.

The color-coding of the tiles in Figure 1.4 is intended to provide the user with visual guidance on the health of each performance metric: green – performance metric is within the desirable range; orange – performance metric is borderline acceptable; and red – performance metric is outside the acceptable range. These ranges are preset in PMA, and may be modified by the user, if necessary.

1.5.3 Improvement scenarios and resulting continuous improvement projects

Improvement scenario is a set of instructions provided by the Operations Manager to PMA, which defines the system's performance metric(s) to be improved and the extent of the improvement, along with (in some cases) the means for equipment modifications available for achieving the desired improvement.

Continuous improvement project is a set of equipment modifications, analytically calculated by PMA, which lead to the desired system improvement in an optimal manner.

Based on System Health, OM provides PMA with one or more improvement scenarios. These scenarios can be, roughly speaking (more details are given in Chapter 6), in two modes: *user-constrained* and *user-unconstrained*. In the user-constrained mode, OM defines not only the desired *productivity improvement* (PI) (e.g., 10% TP improvement), but also specifies the admissible *action space* (AS) to obtain the desired PI (e.g., decreasing $MTTR$ of at most three machines by no more than 40% or decreasing cycle time of at most two machines by no more than 5%, or increasing capacity of at most three buffers by no more than two units each). In the user-unconstrained mode, OM provides PMA only with the name of the performance metrics to be improved, and PMA uses the *internal constraints* (programmed into PMA by SPS designers) to calculate steps of an appropriate continuous improvement project. PMA screenshots in Figures 1.5-1.9 and Figure 1.11 illustrate each of these modes, along with the resulting continuous improvement projects calculated by PMA. It should be emphasized that, in most cases, these continuous improvement projects are calculated practically instantaneously (since PMA calculations are based on analytical formulas, rather than on computer simulations).

<u>User-constrained mode</u>

Below are five scenarios of TP improvement using this mode. The first two call for a 10% TP increase based on machines improvement only; the third – based on buffers only; the fourth – based on both machines and buffers; and the fifth calls for TP maximization based on machines' and buffers' modifications.

- **Scenario 1**: As shown at the top of Figure 1.5, this scenario calls for TP increase by 10%, with the action space defined by decreasing $MTTR$ of at most three machines by no more than 30% each. The resulting optimal continuous improvement project is shown at the bottom of Figure 1.5. It indicates that under this action space, the required TP cannot be achieved.

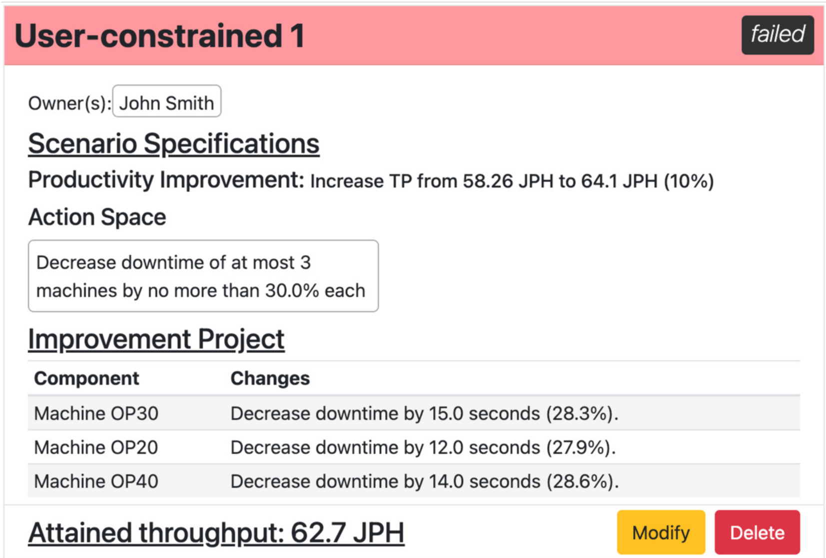


Figure 1.5: User-constrained Scenario 1 and resulting improvement project

- **Scenario 2**: Therefore, the next scenario calls for the same PI, but under AS consisting of decreasing $MTTR$ of at most three machines by no more than 30% each and, in addition, reducing the cycle time of at most two machines by no more than 10% each. Figure 1.6 shows this scenario and indicates that it is achieved by decreasing the cycle time and *MTTR* of system bottleneck OP30, cycle time of OP10 and *MTTR* of OP40 and OP20.

The above scenario calls for downtime and cycle time reduction. The former can be attained by skilled trades priority assignments or preventive maintenance improvement; the latter is enabled by increasing the operation's processing speed, which is typically possible in the range of up to 10%.

- **Scenario 3**: As shown in Figure 1.7, it also calls for the same PI, but with AS consisting of increasing the capacity of buffers by at most five units in total. Figure 1.7 shows that this throughput improvement cannot be attained.

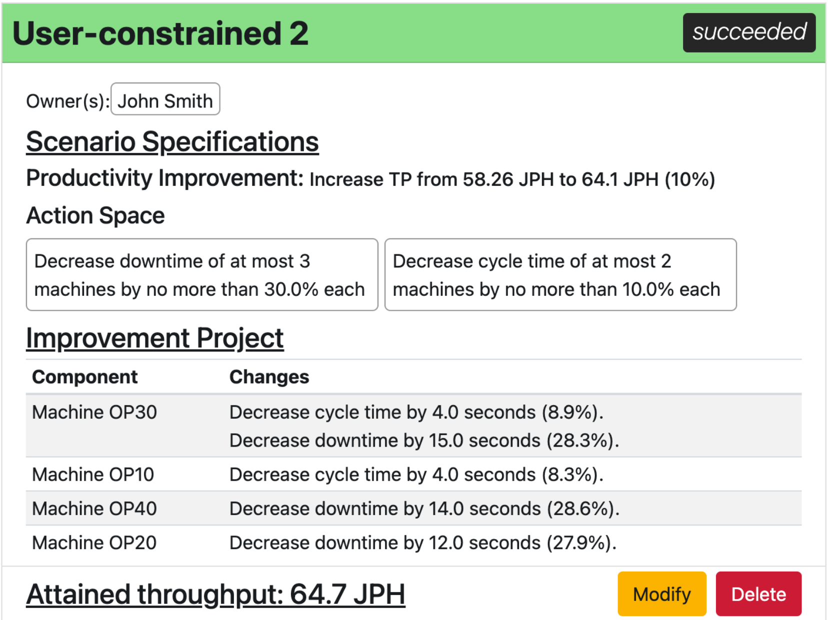


Figure 1.6: User-constrained Scenario 2 and resulting improvement project

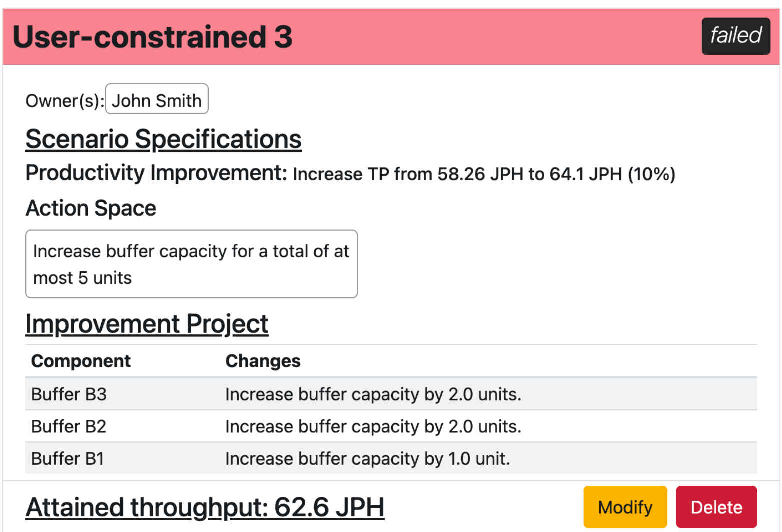


Figure 1.7: User-constrained Scenario 3 and resulting improvement project

- **Scenario 4**: In this scenario, PI is still the same, but under the AS consisting of modifying machines' $MTTR$ and buffers' capacity simultaneously in the ranges specified in Scenarios 1 and 3, respectively (see Figure 1.8). The resulting continuous improvement project leads to the desired improvement, as shown in Figure 1.8. Note that both bottleneck machine and bottleneck buffer are improved, and only three units of buffers capacity increase are required.

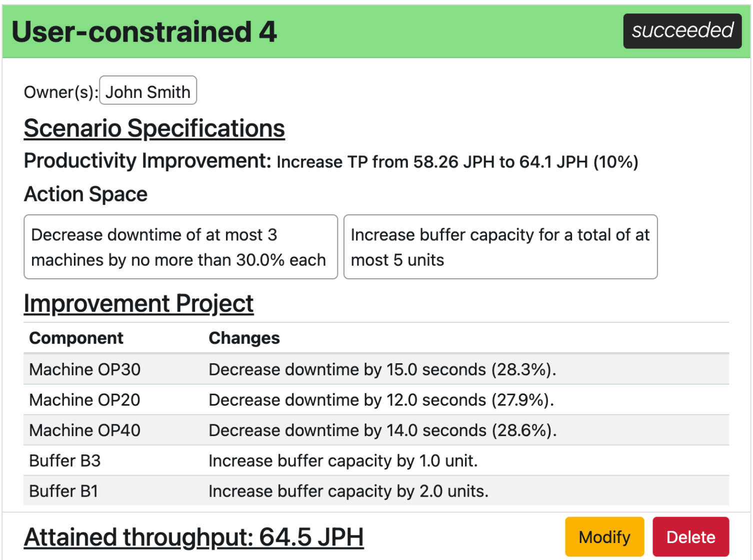


Figure 1.8: User-constrained Scenario 4 and resulting improvement project

- **Scenario 5**: Finally, the PI in Scenario 5 calls not for a specific value of TP improvement, but for TP maximization under the AS comprised of machines' $MTTR$ and cycle time modifications as in Scenario 2 and buffers' capacity increase as in Scenario 3. The resulting improvement project, as shown in Figure 1.9, leads to $TP = 67.4$ JPH, i.e., almost 3 JPH larger than in the previous scenarios.

Given the above results, OM can select one of them for implementation. Assuming that Scenario 5 has been selected, the performance of the improved system is calculated by PMA populated

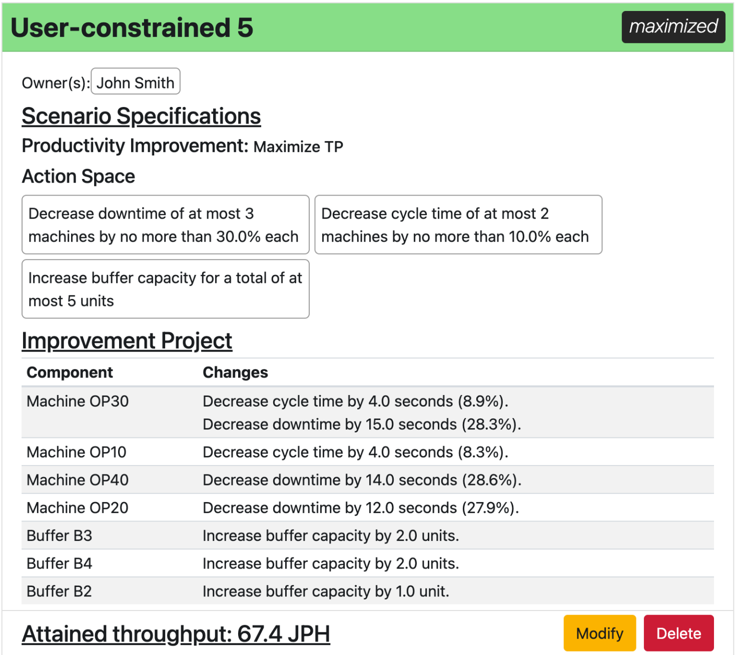


Figure 1.9: User-constrained Scenario 5 and resulting improvement project

with the parameters defined by those in Figure 1.9. The resulting System Health of the Preview example improved according to Scenario 5 is shown in Figure 1.10. As one can see, the total throughput losses in the improved system are more than twice smaller than in the original one, and the losses due to buffers are more than ten times smaller. Also, the new BN is OP50, which is now the worst machine in the system as far as its SAT is concerned. This is because the improved machines lead to a lesser demand on the buffers in their downtime attenuation capabilities.

❖ Similar results would take place in practice if the continuous improvement project of Figure 1.9 were implemented on the factory floor, provided that the mathematical model of Figure 1.3 is sufficiently precise.

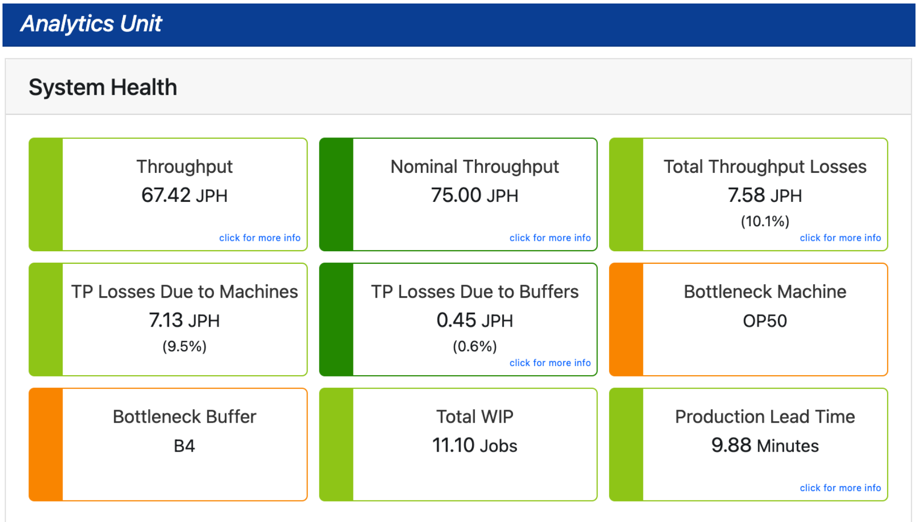


Figure 1.10: System Health of the Preview example improved according to User-constrained Scenario 5

<u>User-unconstrained mode</u>

A scenario in this mode is considered below calling for maximizing TP without defining an action space (i.e., under the internal PMA-defined constraints; in the current PMA version, these constraints allow for each machine's $MTTR$ and cycle time reduction by 50% and 10%, respectively, and total buffer capacity increase by 50%). The resulting continuous improvement project is shown in Figure 1.11. As one can see, it leads to $TP = 76.3$ JPH, which is larger than the nominal throughput of the original system (75 JPH). This happens because in the improved system, the largest machine cycle time is 44 seconds, and therefore, the nominal throughput becomes $\frac{3600 \text{ sec}}{44 \text{ sec}} = 81.8$ JPH.

It should be pointed out that the suggested equipment modifications in all of the above scenarios do not have to be exactly the same as those calculated by PMA. To be sure, to obtain the predicted performance, they may not be smaller than those indicated, but they may be larger than them. The reason is that many production systems (including serial lines as in Figure 1.3) possess the property of *monotonicity* (see [1, Chapter 4, Subsection 4.3.3]), which implies that decreasing $MTTR$ and τ or increasing N always lead to TP improvement (however insignificant it may be). So, decreasing $MTTR$ and τ below and increasing N above the indicated values will not lead to a TP reduction.

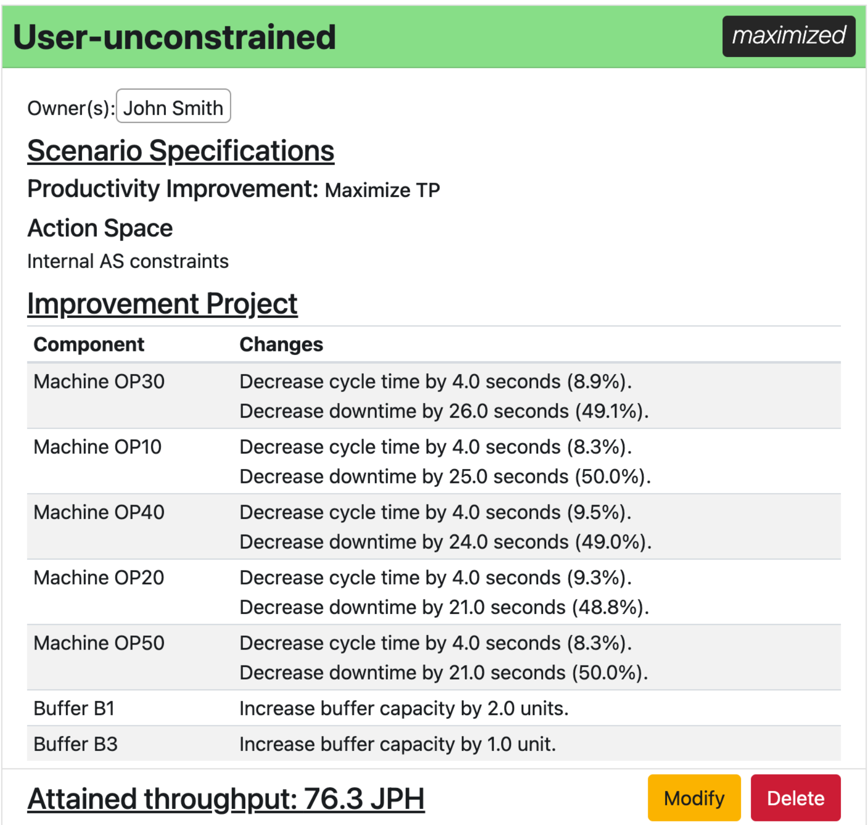


Figure 1.11: User-unconstrained Scenario and resulting improvement project

❖ While the above-considered scenarios involve parameters modification of the *existing* machines and buffers, PMA can be used for evaluating efficacy of installing *new* machines or *restructuring* overall buffering. To accomplish this, the original mathematical model should be modified by entering new machines' and buffers' parameters and, using PMA, evaluating System Health and quantifying the effects of the new equipment on the overall system performance. However, purchasing new equipment typically requires substantial capital investments, often beyond the purview of the factory floor management personnel. Since this book is intended mostly for this personnel, it does not center on the issues specific to capital investments.

To conclude this chapter, we re-iterate that:

The overall goal of this book is to provide managerial and engineering personnel, as well as the inspired students, with knowledge and ability to participate in the design and deployment of PMA-based SPS and, most importantly, to operate production systems in the SPS-based environment.

1.6 Chapter 1 Takeaway

✓ Smart Production System (SPS) is a production system capable of self-diagnosing and autonomously designing continuous improvement projects leading to the desired by management productivity improvement, with minimal system modifications and guaranteed results.

✓ Programmable Manufacturing Advisor (PMA) is an AI device that can be programmed to make any production system smart (PMA-based SPS).

✓ PMA analytics are based on the theory of Production Systems Engineering (PSE), which provides analytical methods for production system design, analysis, and improvement.

✓ PSE methods have been applied "manually" by PSE-trained personnel (using the PSE Toolbox-assisted approach) for development of continuous improvement projects at dozens of small, mid-size, and large manufacturing organizations, consistently leading to a substantial productivity improvement.

✓ PMA automates this process (using the AI-enabled approach) and offers a possibility of designing continuous improvement projects by managerial/engineering personnel without training in PSE or analytics in general.

✓ PMA-based SPS can be viewed as a part of the Industry 4.0 movement by contributing to one of its four major emphases – Smart Factory/Smart Manufacturing.