Exercises for the Smart Production Systems book

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Exercises for Chapter 1

*In all exercises formulated below, use your common sense to provide and **justify** your answers. In Chapter 4, you will be asked to consider these exercises again and either change or maintain your answers, based on the quantitative methods described in that chapter.*

Exercise 1.1. Consider a serial production line with ten identical machines and no buffers. Where should a single buffer be placed so that the throughput of the system is maximized?

Exercise 1.2. Consider a serial production line with eleven identical machines and ten identical buffers. Assume that one of the machines can be replaced by a more efficient one. Which machine should be replaced so that the throughput is maximized?

Exercise 1.3. Assume that two types of machines are available: those with short up- and downtime and those with long up- and downtime, but with identical Stand-Alone Throughput,

$$SAT = ce = \frac{cT_{up}}{T_{up} + T_{down}} = \frac{c}{1 + \frac{T_{down}}{T_{up}}},$$

where c is machine's capacity, e its efficiency, and T_{up} and T_{down} are its up- and downtime, respectively. Note that, according to the last of these expressions, SAT depends on the ratio of down- and uptimes and, thus, remains the same in either case – long or short up- and downtimes. It turns out that this is not the case for the throughput of production systems with two or more machines and finite buffers. Which type of the machines would you prefer to use – those with short or with long up- and downtimes – so that the system throughput is maximized?

Exercise 1.4. If the efficiency, e, of a machine in a serial production line can be improved, is it better to increase its uptime by a factor of α or decrease its downtime by the same factor α, so that the system throughput is maximized?

Exercise 1.5. In a serial production line with identical machines and identical buffers, which machine is the bottleneck?

Exercise 1.6. In an assembly system with identical machines and identical buffers, which machine is the bottleneck?

Exercise 1.7. Is the machine with the smallest SAT necessarily the bottleneck machine of a production line? Is the smallest capacity buffer necessarily the bottleneck buffer of a production line?

Exercise 1.8. Is the buffer of capacity $N = 3$ necessarily lean? Is the buffer of capacity $N = 300$ necessarily not lean?

Exercise 1.9. Is the machine producing the largest fraction of defective parts necessarily the quality bottleneck of a serial line?

Exercise 1.10. In a production line with parts transported on carriers, will the throughput necessarily increase if the number of carriers is increased?

Exercises for Chapter 2

Exercise 2.1. Consider a production system comprised of unreliable machines, each characterized by its up- and downtime, T_{up} and T_{down}. Most methods for analysis and design of such systems are based on sufficiently precise estimates, $\widehat{T}_{up}$ and $\widehat{T}_{down}$, i.e., on (α, β)-precise estimates of T_{up} and T_{down} for each stand-alone machine. To obtain such estimates, a critical number of up- and downtime measurements must be obtained and used in (2.12) for calculating $\widehat{T}_{up}$ and $\widehat{T}_{down}$. Provide and **justify** your answers to the following questions, which arise in this regard:

- Are the critical numbers of measurements for calculating $\widehat{T}_{up}$ and $\widehat{T}_{down}$ identical or not?

- Assuming that the realizations of up- and downtime are distributed exponentially, what are the critical number of up- and downtime measurements to obtain $(\alpha = 0.1, \beta = 0.9)$-precise estimates of T_{up} and T_{down}?

- Can this number be used even if these distributions are not exponential?

Exercise 2.2. In the scenario of Exercise 2.1, assume that a machine produces a quality part with probability q and a defective part with probability $1 - q$. Will the critical number of up- and downtime measurements for evaluating its $\widehat{T}_{up}$ and $\widehat{T}_{down}$ work for evaluating $(\alpha = 0.1, \beta = 0.9)$-precise estimate $\widehat{q}$ as well?

Exercise 2.3. Consider an unreliable machine described in Exercise 2.1. Assume that an (α_e, β_e)-precise estimate of its efficiency, $\hat{e}$, is evaluated using factory floor measurements of its up- and downtime. What is the critical number of T_{up} and T_{up} measurements required to obtain $(\alpha_e = 0.1, \beta_e = 0.9)$-precise estimate $\widehat{e}$?

Exercise 2.4. Consider a production system consisting of unreliable machines as those in Exercise 2.1. Assume that its throughput, TP, is evaluated using factory floor measurements of machines' up- and downtime. What is the critical number of T_{up} and T_{down} measurements to obtain ($\alpha_{TP} = 0.1, \beta_{TP} = 0.9$)-precise estimates of TP?

Exercises for Chapter 3

Exercise 3.1. A production system manufactures products A and B. Each product consists of two parts: A1 and A2 for product A and B1 and B2 for product B. The processing of A and B require several technological steps. The departments where these steps are carried out are shown in Figure 3.13. The number of each department indicates its order in the technological process. The material handling among the departments is carried out by carts, which are pushed by machine operators from one department to another.

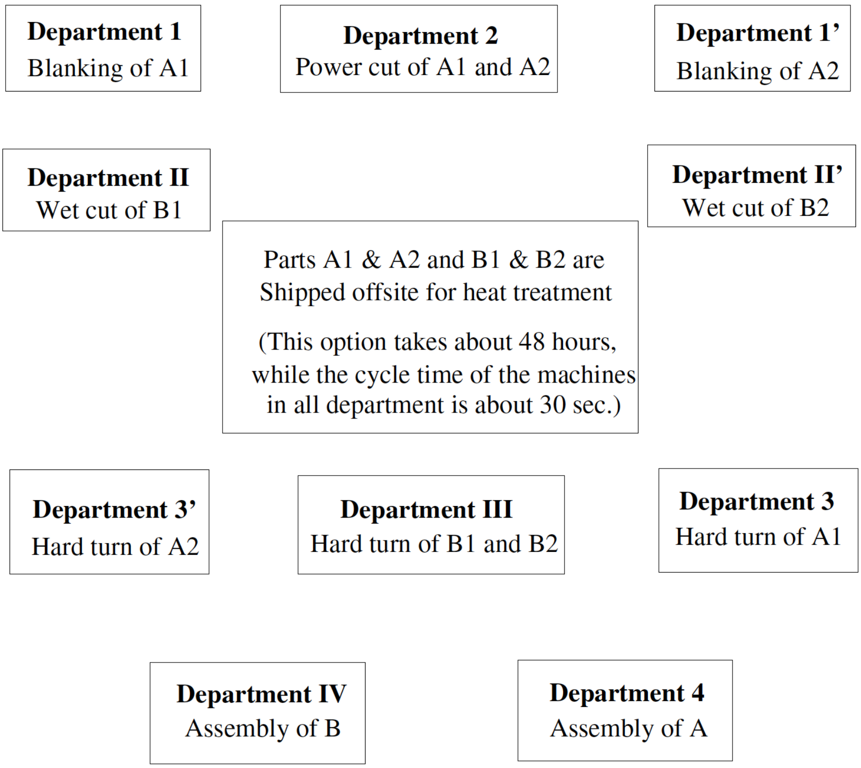

Figure 3.13: Products A and B manufacturing system layout

(a) Construct a structural model of this production system.
(b) Describe the data that have to be collected to identify this model.
(c) Describe which steps must be taken to collect these data.
(d) Describe which steps must be taken to validate this model.

Exercise 3.2. The layout of a production system for an automotive ignition device is shown in Figure 3.14. It consists of 15 operations, separated by buffer-conveyors. Construct a structural model for this system and simplify it to a serial line.

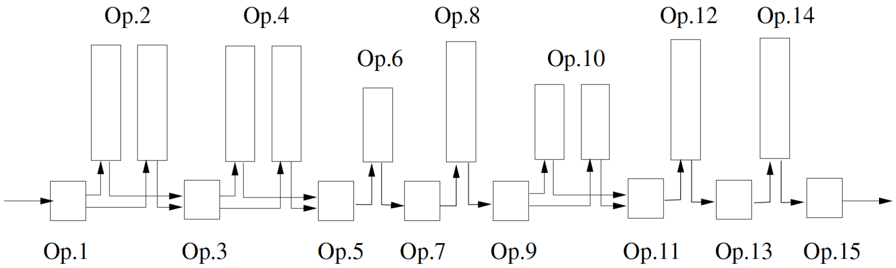

Figure 3.14: Automotive ignition device production system layout

Exercise 3.3. The layout of a production system for an automotive fuel injector assembly is shown in Figure 3.15. It consists of four main operations: Housing Subassembly, Valve Body Assembly, Injector Subassembly, and Injector Final Assembly. In addition, the system contains Shell Assembly, three Welding operations (L.H.W., U.H.W., and Weld), two Overmold operations (O.M.1 and O.M.2), two Set Stroke operations (Stroke 1 and Stroke 2), one Leak Test operation (L.T.) and one High Potential operation (Hi Pot). Finally, the system includes five buffers positioned as shown in Figure 3.15 and conveyor buffering among all other operations.

Construct a structural model for this system and simplify it to a serial line.

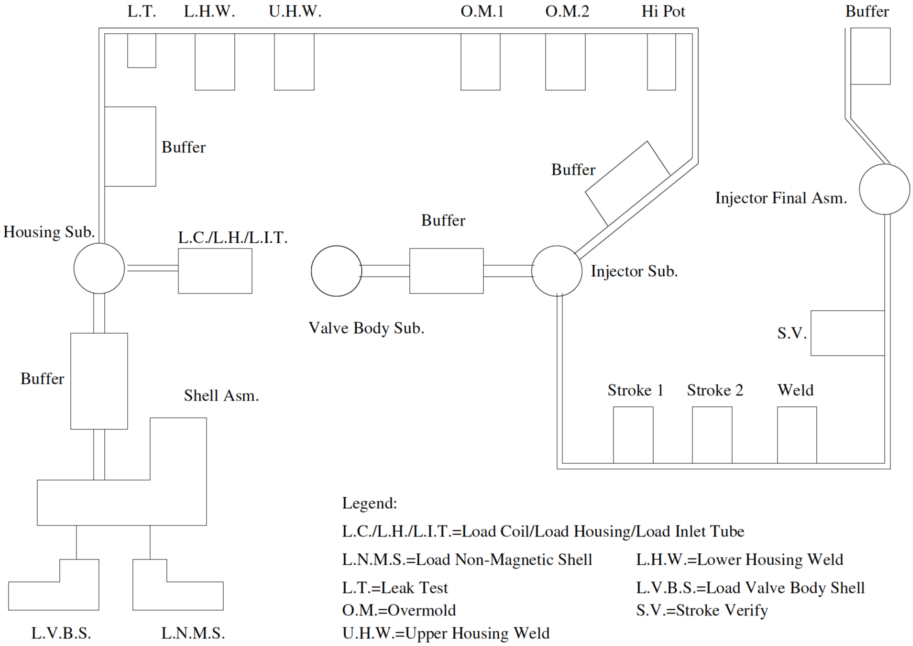

Figure 3.15: Fuel injector assembly system layout

Exercises for Chapter 4

Consider again Exercises 1.1-1.10 introduced in Chapter 1 and repeated below as Exercises 4.1-4.10 for the readers' convenience. Use the quantitative methods of Chapter 4 to provide and ***rigorously justify*** *your answers. If necessary, also use PSE Toolbox and/or PMA.*

Assuming that all answers you will provide here are correct, denote as X *the number of answers different from those provided in Chapter 1. Then the number* $Y = 10 - X$ *can be viewed as the "level of common sense trustworthiness" in the area of production systems engineering. (Don't be surprised if your* Y *turns out to be quite small: in our experience, common sense does not work too well in the area of production systems.)*

Exercise 4.1. Consider a serial production line with ten identical machines and no buffers. Where should a single buffer be placed so that the throughput of the system is maximized?

Exercise 4.2. Consider a serial production line with eleven identical machines and ten identical buffers. Assume that one of the machines can be replaced by a more efficient one. Which machine should be replaced so that the throughput is maximized?

Exercise 4.3. Assume that two types of machines are available: those with short up- and downtime and those with long up- and downtime, but with identical Stand-Alone Throughput,

$$SAT = ce = \frac{cT_{up}}{T_{up} + T_{down}} = \frac{c}{1 + \frac{T_{down}}{T_{up}}},$$

where c is machine's capacity, e its efficiency, and T_{up} and T_{down} are its up- and downtime, respectively. Note that, according to the last of these expressions, SAT depends on the ratio of down- and uptimes and, thus, remains the same in either case – long or short up- and downtimes. It turns out that this is not the case for the throughput of production systems with two or more machines and finite buffers. Which type of the machines would you prefer to use – those with short or with long up- and downtimes – so that the system throughput is maximized?

Exercise 4.4. If the efficiency, e, of a machine in a serial production line can be improved, is it better to increase its uptime by a factor of α or decrease its downtime by the same factor α, so that the system throughput is maximized?

Exercise 4.5. In a serial production line with identical machines and identical buffers, which machine is the bottleneck?

Exercise 4.6. In an assembly system with identical machines and identical buffers, which machine is the bottleneck?

Exercise 4.7. Is the machine with the smallest SAT necessarily the bottleneck machine of a production line? Is the smallest capacity buffer necessarily the bottleneck buffer of a production line?

Exercise 4.8. Is the buffer of capacity $N = 3$ necessarily lean? Is the buffer of capacity $N = 300$ necessarily not lean?

Exercise 4.9. Is the machine producing the largest fraction of defective parts necessarily the quality bottleneck of a serial line?

Exercise 4.10. In a production line with parts transported on carriers, will the throughput necessarily increase if the number of carriers is increased?

Exercises for Chapter 5

These exercises are intended to provide the users with hands-on experience for designing continuous improvement projects using PSE Toolbox. In Chapter 6 these exercises will be used for designing continuous improvement projects in the PMA-based SPS environment.

Exercise 5.1. *This exercise is motivated by a term project carried out by Craig Herring, Shengfa Lin, and Rusheikesh Ved as a part of the University of Michigan course titled "Production Systems Engineering" under the supervision of Professor Meerkov.*

This exercise addresses the issue of performance improvement of an automotive fuel tank production system. Its simplified structural model is a serial line consisting of 12 automated (mostly, welding) machines and one manual operation (inspection station). The parametric model of all 13 operations (which are assumed to be exponential) and 12 buffers is given in Table 5.1.

Table 5.1: Parametric model of fuel tank production system

	Name	τ **(sec)**	T_{up} **(min)**	T_{down} **(min)**	e	SAT **(JPH)**	N
OP10	Rings	59	4148	12.5	0.997	60.8	1
OP20	Baffle Weld 2	52	5195	3.7	0.999	69.2	2
OP30	Baffle & Hose	61	6926	6.0	0.999	59.0	2
OP40	Track Welding	50	5195	4.3	0.999	71.9	2
OP50	Circular Welder	83	3450	18.8	0.995	43.1	2
OP60	Leak Test 1	61	4153	6.5	0.998	58.9	1
OP70	Cap	48	10395	2.0	0.999	75.0	6
OP80	Air Dryer	54	20789	0.1	0.999	66.7	1
OP90	Oven	60	10395	2.0	0.999	60.0	1
OP100	Inspection Manual	51	20780	10.0	0.999	70.6	12
OP110	Remove cap	53	3457	9.6	0.997	67.7	1
OP120	Inspection Cam	60	20789	0.1	0.999	60.0	1
OP130	Leak Test 2	53	3456	10.8	0.997	67.7	

Given this parametric model, the goal of this exercise is to analyze this system's health and design an improvement project that leads to the desired performance improvement. To accomplish this:

- Carry out Steps 2-8 of the *Procedure of PSE Toolbox-assisted Design of Continuous Improvement Projects* described in Section 5.3 of SPS book.
- At Step 7, assume that the desired Performance Improvement (PI) is increasing TP by 10% and the available Action Space (AS) consists of:
    - cycle times of at most three machines cannot be reduced by more than 7%
    - downtimes of at most five machines cannot be reduced by more than 35%
    - capacity of at most two buffers cannot be increased by more than 3 units each.

Exercise 5.2. *This exercise is motivated by a term project carried out by Ravinder Grewal and Russ Conte as a part of the University of Michigan course titled "Production Systems Engineering" under the supervision of Dr. Alavian and Professor Meerkov.*

This exercise addresses the issue of performance evaluation and improvement of a production system manufacturing Endoscopic Ultrasound (EUS) access catheter, which is a small probe for examining patients' gastrointestinal tract and nearby organs.

A simplified structural model of this system consists of three components: Line 1 for producing the Cannula assembly, Line 2 for producing the Handle assembly, and an offline 8-hour Silicone Coating air-dry facility, separating the two lines (see Figure 5.26)

As one can see, Line 1 consists of OP10-OP50 and Line 2 of OP60-OP80, and the air-dry facility is modeled as buffer B5. Since this buffer is of a large capacity, it makes the two lines essentially independent.

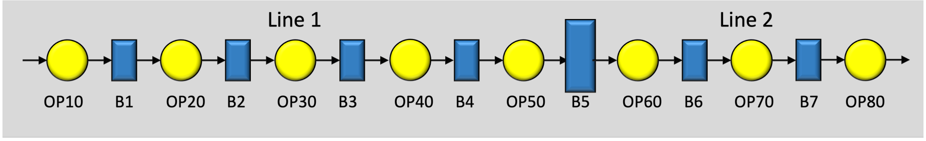

Figure 5.26: Structural model of EUS catheters production system

All the operations of Line 1 and Line 2 are carried out manually by two operators, which are cross-trained to carry out all the tasks involved. They have one 7-hour shift per day and work jointly either in Line 1 or Line 2.

This system is a pilot facility to be extended to a larger throughput. It operates as follows: Both operators work in Line 1 until the fixtures in the air-dry facility are filled by 30 silicone-coated subassemblies. Next day, the operators work in Line 2 until all 30 jobs are complete and then switch to working in Line 1 again. Then the process is repeated anew. Obviously, this system produces no more than 30 units daily, and the plan is to extend this facility to producing 100 units per day.

The goal of this exercise is to analyze the pilot system behavior and extend it to a 100 units per day production. This is to be accomplished based on the parametric model given in Table 5.2 .

Table 5.2: Parametric model of the EUS catheters production system

	τ (sec)	T_{up} (min)	T_{down} (min)	e	SAT (JPH)	N
OP10	150	2.50	0.260	0.906	21.7	2
OP20	129	2.15	0.286	0.882	24.6	2
OP30	10	0.17	0.357	0.319	114.7	2
OP40	48	0.80	0.280	0.741	55.6	2
OP50	11	0.18	0.104	0.638	208.6	30
OP60	98	1.63	0.265	0.860	31.6	2
OP70	27	0.45	0.227	0.665	88.6	2
OP80	47	0.78	0.277	0.739	56.6	

Specific problems to be addressed are the following:

- Investigate the pilot system's performance. Specifically:
    - Evaluate the throughput of stand-alone Line 1 and Line 2.
    - Determine the average time necessary to fill the air-dry facility by Line 1 and the time to empty it by Line 2.
    - Make a conclusion about the total number of hours the operators are engaged in production per their 7-hours daily shift.
- Develop an improvement project to reach 100 JPH production. Specifically:
    - Assuming that the capacity of the air-dry facility is infinite, calculate the number of parts, X, that the system must produce per day, so that the operators are fully occupied during their 7-hour shifts.
    - If $X < 100$, recommend the pilot system modifications (i.e., improvement of Line 1, Line 2, and B5), which would lead to $X = 100$ JPH.
    - Summarize the steps of the designed continuous improvement project.

Exercise 5.3. *This exercise is motivated by a term project carried out by Pooya Alavian, William Breznau and Blake Fecteau as a part of the University of Michigan course titled "Production Systems Engineering" under the supervision of Professor Meerkov.*

This exercise is devoted to analysis and improvement of an assembly line manufacturing stackers for an electric vehicle battery. A stacker consists of 30 interior lithium-ion battery cells, along with the first and the last cells, which form one of the battery's modules. While its throughput was considered to be sufficient to meet

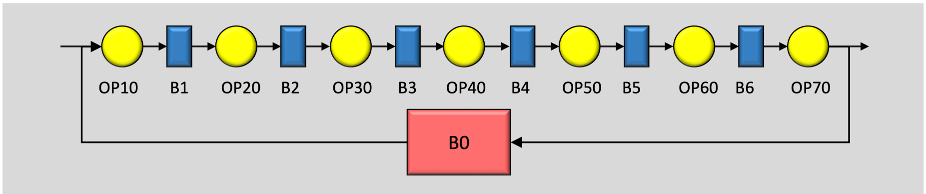

Figure 5.27: Structural model of stacker assembly line

the customers demand, the company plans called for its improvement by 10%. The goal of this exercise is to investigate the system performance and design a continuous improvement project leading to the desired performance.

The structural and parametric models of this line are shown in Figure 5.27 and Table 5.3.

Table 5.3: Parametric model of stacker assembly line

	τ (sec)	T_{up} (min)	T_{down} (min)	e	SAT (JPH)	N
OP10	9.7	23.8	0.912	0.963	358.3	4
OP20	9.5	31.3	0.829	0.974	368.2	5
OP30	9.7	17.2	0.594	0.967	359.6	4
OP40	9.5	32.3	0.636	0.981	370.7	4
OP50	9.2	20.4	0.736	0.965	376.4	4
OP60	10.2	125	0.854	0.993	351.6	9
OP70	8.8	4.8	1.153	0.805	328.4	

$$N_0 = 30, \quad S = 22, \quad S_{nec} = 7$$

- Given this mathematical model, carry out Steps 2-8 of the Procedure of PSE Toolbox-assisted Design of Continuous Improvement Projects described in Section 5.3 of SPS book.

- At Step 7 assume that the desired Performance Improvement (PI) is 10% of TP increase and the available Action Space (AS) is defined by

- number of carriers can be increased by no more than 8;
- downtimes of at most five machines can be reduced by no more than 30%;

Exercises for Chapter 6

Address Exercises 5.1-5.3 of Chapter 5 using the Procedure of PMA-enabled Design of Continuous Improvement Projects described in Section 6.5 of SPS book.