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Solid as Steel: Production Planning at thyssenkrupp

On Monday, March 31, 2014, production manager Markus Schulze received a call from Reinhard Täger, senior vice president of thyssenkrupp Steel Europe's production operations in Bochum, Germany. Täger was preparing to meet with the company's chief operating officer and was eager to learn the reasons why the current figures of one of Bochum's main production lines were far behind schedule. Schulze explained that the line had had three major breakdowns in early March and therefore would miss the planned utilization rate for that month. Consequently, the scheduled production volume could not be carried out. Schulze knew that a lack of production capacity utilization would lead to unfulfilled orders at the end of the planning period. In a rough steel market with fierce competition, however, delivery performance was an important differentiation factor for thyssenkrupp.

Täger wanted a chance to review the historic data, so he and Schulze agreed to meet later that week to continue their discussion.

After looking over the production figures from the past ten years, Täger was shocked. When he met with Schulze later that week, he expressed his frustration. "Look at the historic data!" Täger said. "All but one of the annual deviations from planned production are negative. We never achieved the production volumes we promised in the planning meetings. We need to change that!"

"I agree," Schulze replied. "Our capacity planning is based on forecast figures that are not met in reality, which means we can't fulfill all customers' orders in time. And the product cost calculations are affected, too."

"You're right," Täger said. "We need appropriate planning figures to meet the agreed delivery time in the contracts with our customers. What do you think would be necessary for that?"

"Hm, I guess we need a broad analysis of data to identify the root causes." Schulze answered. "It'll take some time to build queries for the databases and aggregate data. And—"

"Stop!" Täger interrupted him. "We need data for the next planning period. The planning meeting for May is in two weeks."

thyssenkrupp Steel Europe

A major European steel company, thyssenkrupp Steel Europe was formed in a 1999 merger between historic German steel makers Thyssen and Krupp, both of which had been founded in the nineteenth century. thyssenkrupp Steel Europe annually produced up to 12 million metric tons of steel with its 27,600 employees. In fiscal year 2014–2015, the company accounted for €8.7 billion of sales, roughly a quarter of the group sales of its parent company, thyssenkrupp AG, which traded on the DAX 30 (an index of the top thirty blue-chip German companies). Its main drivers of success were customer orientation and reliability in terms of product quality and delivery time.

Bochum Production Lines

The production lines at thyssenkrupp Steel's Bochum site were supplied with interim products delivered from the steel mills in Duisburg, 40 kilometers west of Bochum. Usually, slabs[1] were brought to Bochum by train and then processed in the hot rolling mill (see **Figure 1**). The outcome of this production step was coiled hot strip[2] (see **Figure 2**) with mill scale[3] on its surface. Whether the steel would undergo further processing in the cold rolling mill or would be sold directly as "pickled hot strip," the mill scale needed to be removed from the surface.

Figure 1.
Source: thyssenkrupp AG, http://www.thyssenkrupp.com/en/presse/bilder.html&photo_id=898.

The production line in which Täger and Schulze were interested, a so-called push pickling line (PPL), was designed to remove mill scale from the upstream hot rolling process. To remove the scale, the hot strip was uncoiled in the line and the head of the strip was pushed through the line. The processing part of the line held pickling containers filled with hot hydrochloric acid, which removed the scale from the surface. Following this pickling, the strip was pushed through a rinsing section to remove any residual acid from the surface. After oiling for corrosion protection, the strip was coiled again. The product of this step, pickled hot strip, could be sold to B2B customers, mainly in the automotive industry.

Figure 2.
Source: thyssenkrupp AG, http://www.thyssenkrupp.com/en/presse/bilder.html&photo_id=891.

Other types of pickling lines were operated as continuous lines, in which the head of a new strip was welded to the tail of the one that preceded it. The differentiating factor of a PPL was its batching process, which involved pushing in each strip individually. Production downtimes due to push-in problems did not occur at continuous lines, but with PPLs this remained a concern. Nevertheless, thyssenkrupp chose to build a PPL in 2000 because

[1] Slabs are solid blocks of steel formed in a continuous casting process and then cut into lengths of about 20 meters.

[2] A coiled hot strip is an intermediate product in steel production. Slabs are rolled at temperatures above 1,000°C. As they thin out they become longer; the result is a flat strip that needs to be coiled.

[3] Mill scale is an iron oxide layer on the hot strip's surface that is created just after hot rolling, when the steel is exposed to air (which contains oxygen). Mill scale protects the steel to a certain extent, but it is unwanted in further processes such as stamping or cold rolling.

increasing demand for high-strength steel made it profitable to invest in such a production line. At that time, high-strength steel grades could not be welded to one another with existing machines, and the dimensions (at a thickness of more than 7.0 millimeters) could not be processed in continuous lines.

The material produced on the PPL was not simply a commodity called steel. Rather, it was a portfolio of different steel grades—that is, different metallurgical compositions with specific mechanical properties. (For purposes of this case, the top five steel grades in terms of annual production volume have been randomly assigned numbers from 1 to 5.) Within these top five grades were two high-strength steel grades. These high-strength grades were rapidly cooled after the hot rolling process—from around 1,000°C down to below 100°C. Removing the mill scale generated during this rapid cooling process required a different process speed in the pickling line. Only one of the five grades could be processed without limitations in speed and without expected downtimes.

Performance Indicators

At thyssenkrupp, managers responsible for production lines needed to report regularly on the performance of the lines and the fulfillment of individual objectives. The output, or throughput, of the production lines had always been an important metric. Even today, coping with overcapacities and customers' increasing demands concerning product quality, the line throughput was part of the set of key performance indicators. These indicators were taken into account for internal benchmarking against comparable production lines at other sites. The line-specific variable production cost was calculated as cost over throughput and was expressed in euros per metric ton. Capacity planning was based on these figures, eventually resulting in delivery time performance. In the steel industry, production reports contained performance indicators at different levels of aggregation. A very important metric was *throughput* (tons[4] produced) per time unit[5]; the performance indicator *run time ratio*[6] (RTR) was the portion of time used for production (run time) compared to the operating time of a production line.

Operating time = Calendar time – (legal holidays, shortages,[7] all scheduled maintenance)

Run Time = Operating time – (breakdowns, exceeding downtime for maintenance, set-up time)

Both figures were reported not only on a daily basis (i.e., a 24-hour production period) but also monthly and per fiscal year. Deviations from planned figures were typically noted in automated reports containing database queries. Thus, every plant manager received an overview of past periods. Comparable production lines of different sites were benchmarked internally.

[4] Throughout this case, the term "ton" refers to a metric ton.

[5] *Tons produced* are usually reported by shift (eight hours), by month, and eventually by fiscal year.

[6] The metric *run time ratio* is calculated as run time over operating time (e.g., 8 hours of operating time, or 480 minutes, with 48 minutes of downtime yields a RTR of 90%).

[7] Shortages can refer to material shortages, lack of orders, labor disputes, or energy/fuel shortages (external).

Deviation from Planned Throughput

Steel production lines had typical characteristics and an average performance calculated based on an average production portfolio, mostly determined empirically using historic figures. For planning purposes, a fixed number was usually used to place order volumes on the production lines and in this way "fill capacities." On a monthly basis, real orders then were placed to a certain amount, which was capped by the line capacity. Each month's production figures had three possible outcomes.

The first possibility was that the planned throughput would be reached and at the end of the month there would be extra capacity. In this case, the extra capacity would be filled with orders from the next month if the intermediate product already were available for processing. Otherwise, the line would stand still without fulfilling orders. This mode was very expensive because idle capacity would be wasted, and fixed costs occurred anyway.

The second possibility was that the planned throughput would *not* be reached. This would mean that at the end of the month, orders would be left that could not be fulfilled. This mode was also very expensive because the planned capacity could not be used, and real production costs were higher than pre-calculated. Product calculation would result in prices that were too low, so contribution margins would be much lower than expected—or even negative.

In the third scenario, the exact planned throughput would be met (+/- 100 tons per month, or +/- 1,200 tons per year, was set as accurate). This was the ideal case, but this had occurred only once in the first ten years of line history (see the annual figures in **Table 1**).

Table 1: Annual Deviation from Planned Production in the First Ten Years of Line Operation

Year of Operation	Annual Deviation from Planned Production (tons)
1	- 23,254
2	- 22,691
3	+ 1,115
4	- 22,774
5	- 2,807
6	- 20,363
7	(financial crisis) - 66,810
8	- 21,081
9	- 4,972
10	- 9,486

Each month, production management had to explain the deviation from planned figures. Many reasonable explanations had been given in the past. Major breakdowns were a common explanation because downtimes directly influenced the RTR. The RTR theory—the lower the run time ratio, the higher the negative deviation from the plan—was often mentioned as the dominating force behind the PPL not achieving the planned throughput.

The production engineers' gut feeling was that a straightforward reason would explain patterns that showed peaks "against the RTR theory," namely the material structure: The resulting throughput can be explained on the basis of whether the material structure is favorable or unfavorable. A specific metric of the structure was the ratio *meters per ton* (MPT), a dimension indicator. The MPT theory reflected the fact that material with a low thickness and/or a low width carried a lower weight per meter. In other words, it took longer to put one ton of material through the production line if the process speed remained constant. According to the MPT theory, negative deviations in months with average or above-average RTR could be explained by this metric.

Data

Schulze realized he had to compile data carefully in order to have any hope of finding possible explanations for the deviations from planned throughput. He decided to define aggregate clusters for material dimensions such as the width and the thickness of the strips.

The technical data of the Bochum PPL relevant to the data collection were:

Width:	800 to 1,650 mm
Thickness:	1.5 to 12.5 mm
Maximum throughput:	80,000 tons per month

Then Schulze reviewed available past production data, beginning with the night shift on October 1, 2013, up until the early shift on April 4, 2014. Unfortunately, he had to omit a few shifts during this six-month period because of missing or obviously erroneous data. Schulze's data set accompanies this case in a spreadsheet.

The explanation of the variables in the data set is as follows:

Shift:	The day and time at the beginning of a shift.
Shift type:	The production line operated 24/7 with three eight-hour shifts; the early shift ("E") started at 6 a.m., the late (or Midday) shift ("M") started at 2 p.m., and the night shift ("N") started at 10 p.m.
Shift number:	thyssenkrupp Steel used a continuous rolling shift system with five different shift groups (shift group 1, shift group 2, etc.). The binary variables indicate whether the shift group *i* worked a particular shift.
Weekday:	The line operated Monday through Sunday, but engineers usually worked Monday to Friday on a dayshift basis (usually starting at 7 a.m.).
Throughput:	The throughput (in tons) during a shift.
Delta throughput:	The deviation (in tons) of actual throughput from planned throughput.

MPT:	A dimension indicator (meters per ton).
Thickness clusters:	Each cluster represented a certain scope of material thickness in millimeters within the technical feasible range of the production line. Strips fell into one of three clusters. The variables "thickness 1," "thickness 2," and "thickness 3" denote the number of strips from the first, second, and third thickness clusters, respectively, that were processed during a shift.
Width clusters:	Each cluster represented a certain scope of material width in millimeters within the technically feasible range of the production line. Strips fell into one of three width clusters. The variables "width 1," "width 2," and "width 3" denote the number of strips from the first, second, and third width clusters, respectively, that were processed during a shift.
Steel grades:	Strips of many different steel grades were processed on the line. The steel grades 1 to 5 are the grades with the largest portion by volume. The variables "grade 1," "grade 2," "grade 3," "grade 4," and "grade 5" denote the proportion (in %) of steel of that grade that was processed during a given shift. The remaining strips were of other steel grades; their proportion is given by "grade rest."
RTR:	The run time ratio (in %), which is calculated as run time divided by operating time.

Schulze quickly realized he had data on more variables than he could employ for his analysis. Obviously, the total number of strips in the three width clusters had to be the same as the total number of strips in the three thickness clusters. Similarly, the proportions of the six different steel grades always added up to 100%. Schulze also decided to omit the dimension indicator (MPT) for his own analysis, as he now had much more detailed and reliable information about the size of the strips.

After the analysis of the aggregated and clustered data, Schulze looked at his prediction model for delta throughput. From his experience, he knew he had found the key drivers for deviations from the planned production volume. "Look at this equation," he said to the production engineer in charge of the PPL. "The model coefficients determine the outcome, which is the deviation from planning. If we had the forecast figures for May, I could predict the deviation based on this model. Please get the numbers of coils from the different clusters and the proportions of the different steel grades. For the RTR, I'm guessing 86% is an appropriate figure."

Assignment Questions

PART A: INITIAL ANALYSIS

First, obtain an initial overview of the data. Next, plan to examine the two theories proposed by the production engineers.

Questions:

1. Perform a univariate analysis and answer the following questions:
    a. What is the average number of strips per shift?
    b. Strips of which thickness cluster are the most common, and strips of which thickness cluster are the least common?
    c. What are the minimum, average, and maximum values of delta throughput and RTR?
    d. Are there shifts during which the PPL processes strips of only steel grade 1, or of only steel grade 2, etc.?
2. Can the RTR theory adequately explain the deviations from the planned production figures? Explain why or why not.
3. Is the MPT theory sufficient to explain the deviations? Explain why or why not.

PART B: SCHULZE'S MODEL

Now interpret Schulze's model.

Questions:

4. Develop a sound regression model that can be used to predict delta throughput based on the characteristics of the strips scheduled for production and Schulze's estimated RTR. Include only explanatory variables that have a coefficient with a 10% level of significance.
5. Interpret the coefficient of RTR for the PPL and provide a 90% confidence interval for the value of the coefficient (in the population).
6. A strip of thickness 1 and width 1 is replaced by a strip of thickness 3 and width 3. This change does not affect any other aspect of the production. Provide an estimate for the change in delta throughput.

PART C: PREDICTION OF MAY THROUGHPUT

Two weeks after the first phone call about the deviations of production figures from planned volumes, Schulze was happy to have a sound prediction model on hand. Now he was looking forward to applying the model for future planning periods. The planning meeting for May was scheduled for the next day, and the production engineers have provided the requested material-structure data that would serve as input for the model.

"Let's see what the prediction tells us," Schulze said to Täger. As usual, the initial plan included an average capacity of 750 tons per shift. "I'm pretty sure the initial estimate will yield a useful first benchmark, but we also need to look at the uncertainty in the forecast," Schulze continued, and he entered the data.

"All right," Täger replied. "I can see the predicted deviation from planned production for the next month in the model. We should show this in the planning meeting tomorrow and adjust the line capacity for May."

The next day, the predicted outcome was included in the monthly planning for the very first time. A new era of production planning at thyssenkrupp Steel Europe had begun.

Next, determine Schulze's forecast.

Questions:

7. The table below shows the data provided by the production engineers. Because of major upcoming maintenance on the PPL, only 84 shifts were planned for the month of May. Provide an estimate for the average delta throughput per shift in May based on these estimated figures. (The actual figures are, of course, still unknown.)

Table 2: Forecasts for the Month of May

Characteristic	Forecast
Thickness 1	996
Thickness 2	1,884
Thickness 3	434
Width 1	1,242
Width 2	1,191
Grade 1	109
Grade 2	709
Grade 3	167
Grade 4	243
Grade 5	121

8. Provide a 90% confidence interval for the average delta throughput per shift in May.

9. An RTR of 86% for a production facility such as the Bochum PPL is considered a good value. A value of 90% would be considered world class. The effort to increase production performance measured in RTR by just one percentage point, from 86% to 87%, is assumed to be very costly. In light of your model, would you expect such a performance improvement to pay for itself?

PART D: ADDITIONAL ANALYSIS

Schulze's prediction model led to an intensive discussion in the production-planning meeting that provided him with much food for thought. As a result, he decided to analyze whether the inclusion of some human or timing factors potentially could enhance his prediction model.

In the final part of the analysis, consider some enhancements to your model.

Questions:

10. Determine whether, for given production quantities, the performance of the PPL depends on the group working each shift. Can you detect any significantly over- or under-performing shift groups?

11. Tests and rework are regularly scheduled on early shifts during the week (but not on weekends). Both involve interruptions and slow process speed, which are not indicated as downtimes and are not included in the RTR. As a result, all else being equal, early shifts during the week should process less steel than the other shifts. Can you show the presence of this effect?

12. Provide a final critical evaluation of your prediction model. What are the key insights with respect to production planning at the Bochum PPL? What are the weaknesses of your model?