The past few years have seen an increase in the demand for sheet steel coated for purposes of environmental protection and also to protect the steel against corrosion. The reasons for this increase of demand are as follows: With the changes of the environment, there are more sources of corrosion attack, and the intensity of corrosion has also increased. Therefore, hot-dip galvanizing is used widely to protect steel products against corrosion. Galvanized steel products are used in almost every industry, but the highest quantities are used in two fields. One of them is the construction industry, where galvanized steel is used everywhere from building structures to eaves, gutters, joinings, assemblies and permanent shuttering. Formed sheet steel is used for light-steel solutions in the construction industry for the production of elements and cover. Due to its numerous advantages, it is used widely in the construction industry. Besides significant weight benefits, it is also easy to transport and assemble, and it is also characterized by a high resistance against corrosion. The other main area of the use of galvanized sheet steel is transport. Large quantities are used in modern car manufacturing globally. Railway carriages, bridges and the power line towers are also made from galvanized steel, and it is also an important material in shipbuilding and seaside constructions due to the highly corroding effect of sea climate. In order to ensure efficiency in development, our company’s management found it necessary to use Value Analysis within the framework of a project. What lends special interest to the development is that after the value analysis of the product, the value analysis of the technology also became necessary. Our research has found that the ideal solution is a simultaneous value analysis of the product and the technology.

Value analysis of hot-dip galvanizing

The purposes of the project

Resulting from the fact that our products have to meet ever strictening requirements, and also from the fact that technologies are changing at an ever accelerating pace, the importance of a permanent analysis of technological processes has become highly important.
The purposes of the value analysis of hot-dip galvanizing are the following:
- to meet the requirements of users and producers
- to eliminate quality problems resulting from the production process
- to reduce the costs of the processes
- to reduce the use of material and energy
- to improve the utilization of capacity of the main production process and of the technology
- to improve efficiency
- to eliminate hard human physical labor
- to improve work safety, health protection and environmental protection.

The subject of the project

The subject of our value analysis is the process of hot-dip galvanizing. The hot-dip galvanizing of cold-rolled broad sheet by way of the Sendzimir technology takes place using state-of-the-art, automatic machines. As a result of the process, a high-value diffuse coating is formed on the steel surface. The process of hot-dip galvanizing involves the dipping of the properly cleaned sheet iron into zinc. While the steel is dipped into the zinc, due to the high temperature, the zinc diffuses into the surface of the base metal, alloys with it and forms a coating.

The technology has three main sections:
- entry section
- technological treatment
- exit section.

In the first section of the development, the value analysis of the product is necessary because it is the product that will be used directly by the user. The customer is the source of product requirement, while the source of technology requirement is the product. The steel strip, which is not yet heat-treated, is delivered into the coil conveyor by a hydraulic cart. Here, the coil end is unwound, and the material is taken to the straightener unit with the help of trundles. The straightener smoothens out any surface irregularity caused by the previous winding up of the coil so that the surface can be cut by the crop shears. The shears crop the unusable coil ends of the material, and they also remove the badly welded sutures. The cold-rolled strip is spliced on an automatic welding machine. During splicing, continuous galvanizing is ensured by a strip storage unit with a holding capacity of 160m. The storage unit is hung above a heat-treating furnace, and it is filled 100% during the process. The thermal preparation and tenderizing of the surface of the steel strip about to be galvanized is done in a 50-metre-long natural gas-operated furnace, which is also equipped with supplementary electronic heating. During the tenderizing heat treatment, all pollution is burned off the surface of the sheet (oil and fat products, oxides), as the required coating will only form on a clean metal surface. This is followed by the cooling of the material in a way which ensures that the 120 tons of zinc in the galvanizing kettle remains at the required galvanizing temperature even with the added heat coming from the metal strip.

After the entry section, the material is conveyed into the galvanizing kettle in the technological treatment section. The galvanizing kettle contains 120 tons of zinc, alloyed with aluminium and lead. The exact content of the kettle is: 99.6 – 99.8% Zn; 0.08 – 0.12 % Pb; 0.16 – 0.24% Al. while in the kettle, the zinc saturates the surface
of the basic metal due to the high temperature (450-470 °C). The zinc is then alloyed with the metal and creates a coating on the surface. To ensure the required coating thickness, the unnecessary liquid zinc is blown back into the kettle with the help of special blowers. The sheet leaves the kettle at a temperature of 450-470 °C, and it is cooled down to 100-120 °C with the help of air fans after a trip of 30 metres. The sheet is further cooled under 60 °C in a water cooler tank. In order to remove any harmful metallurgic phenomena and to ensure the required flatness of the galvanized strip, the material is led through a skin pass mill, where it receives a permanent shape change of 0.8-0.15 %. Depending on climatic conditions, the surface of the galvanized metal may receive white rust during storage and transport. To prevent this, the sheet is chromatized in post-treatment. Another task of the exit technological section is to ensure continuous operation of the machinery even during the removal of the finished coil. The exit looper coils up the galvanized strip. When the required amount or diameter is coiled up on the exit looper, the crop shears cut the material. The welding sutures and test-piece is also cut off here. The coil is pushed by a hydraulic shield onto the transport vehicle, where the material is measured, packed and transported to be used or further processed.

**Information Concerning the Technological Process**

The phases and equipment of the cold-rolled strip galvanizing process are summarized in the following table:

<table>
<thead>
<tr>
<th>Equipments of entry section</th>
<th>Equipment of technological treatment</th>
<th>Equipments of exit section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>Equipment</td>
<td>Equipment</td>
</tr>
<tr>
<td>Coil conveyor</td>
<td>Galvanizing kettle</td>
<td>Straightening machine</td>
</tr>
<tr>
<td>Straightener</td>
<td>Control equip. of zinc coating’s thickness</td>
<td>Chromatizing kettle</td>
</tr>
<tr>
<td>Welding machine</td>
<td>Blower</td>
<td>Dryer</td>
</tr>
<tr>
<td>Heat-Treating furnace</td>
<td>Measuring device of zinc coating’s thickness</td>
<td>Exit looper</td>
</tr>
<tr>
<td>Downcoiler</td>
<td>Water cooler</td>
<td>Crop shears</td>
</tr>
<tr>
<td>Thickness measuring device</td>
<td>Skin pass mill</td>
<td>Coil conveyor</td>
</tr>
<tr>
<td>Entry looper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phases</th>
<th>Phases</th>
<th>Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 deliver to plant</td>
<td>P9 galvanizing</td>
<td>P13 straighten by stretching</td>
</tr>
<tr>
<td>P2 picking up</td>
<td>P10 regulation of zinc coating</td>
<td>P14 chromatizing</td>
</tr>
<tr>
<td>P3 unwinding</td>
<td>P11 cooling of strip</td>
<td>P15 cooling the strip</td>
</tr>
<tr>
<td>P4 straightening</td>
<td>P12 measuring of zinc coating</td>
<td>P16 looping/storage of strip</td>
</tr>
<tr>
<td>P5 cropping of coilends</td>
<td></td>
<td>P17 cropping of strip</td>
</tr>
<tr>
<td>P6 welding</td>
<td></td>
<td>P18 winding</td>
</tr>
<tr>
<td>P7 looping of strip</td>
<td></td>
<td>P19 packaging</td>
</tr>
<tr>
<td>P8 annealing</td>
<td></td>
<td>P20 storage</td>
</tr>
</tbody>
</table>

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PRODUCT REQUIREMENT ANALYSIS
For the value analysis of the technological process it is important to identify the product requirements as well, and to analyze the process in consideration of these requirements.
User requirements regarding hot-dip sheet iron:
I_1 Usability in construction industry
I_2 Excellent processing properties
I_3 Excellent formability
I_4 Homogeneous zinc coating
I_5 Optimal layer thickness
I_6 Excellent layer without surface defects and cracks
I_7 High degree of corrosion protection
I_8 Excellent temperature resistance
I_9 High ageing resistance
I_10 Cathode protection against corrosion
I_11 Good cohesive behavior of zinc coating
I_12 Aesthetic surface

PRODUCT FUNCTION ANALYSIS
The functions of the product are defined based on consumer / user requirements.
Product functions (hot-dip galvanized sheet steel) are to:
F_0 Allow additional processes
F_1 Ensure formability
  F_11 Ensure dimensional accuracy
  F_12 Meet the elasticity requirements
F_2 Allow mechanical processes
  F_21 Ensure dimensional accuracy
  F_22 Meet the elasticity requirements
F_3 Ensure applying further coatings
  F_31 Ensure homogeneous surface
  F_32 Ensure adhesion
F_4 Allow additional assembly
F_5 Meet durability requirements
  F_51 Resist against mechanical attack
  F_52 Resist against corrosion attack
    F_521 Resist against atmospheric attack
    F_522 Resist against other corrosion attack
F_6 Meet the medical regulations
  F_61 Resist against micro-organism
  F_62 Allow cleaning
F_7 Meet aesthetical requirements

The second phase of the analysis is that of technology requirements. What and how the technology has to do to meet the product requirements fully. The technology has to meet the following requirements:
I_1 To produce protective coating
I_2 Clean the strip
I_3 Ensure the cohesion of coating
I_4 Continuous galvanizing of strip
I_5 Continuous adjustment of process
I_6 The maintenance of plant can be calculated
I_7 Continuous quality-control
I_8 Protect the environment
I₉ Eliminate of harmful metallurgical effects  
I₁₀ Prevent white rust forming  
I₁₁ Ensure the correct bath composition and temperature  
I₁₂ Make the product ready for distribution  
I₁₃ Easy operation  

The functions of the technology are to:  
F₀ Produce protective coating  
F₁ Ensure material  
F₁₁ Transport the material  
F₁₂ Pick up the material  
F₁₃ Make endless strip  
F₂ Pretreat the surface  
F₂₁ Clean the surface  
F₂₂ Ensure the adhesion  
F₃ Apply the coating material  
F₃₁ Ensure the coating material  
F₃₂ Ensure the correct temperature  
F₃₃ Ensure the layer application  
F₄ Post-treat the surface  
F₄₁ Improve the mechanical properties  
F₄₂ Prevent white rust forming  
F₄₃ Cool the strip  
F₅ Make product ready for distribution  
F₅₁ Ensure quantity  
F₅₂ Protect from damage  
F₅₃ Allow the identification  
F₅₄ Allow the delivery  
F₆ Regulate the process  
F₆₁ Indicate defects  
F₆₂ Eliminate defects  
F₇ Allow correction  
F₇₁ Control quality  
F₇₂ Allow continuity  
F₈ Coordination  
F₈₁ Handling of material and product  
F₈₂ Protect the environment  
F₈₃ Allow switching  
F₉ Ensure maintenance

For an easier overview and assessment of functions, we have prepared a function-parameter-equipment matrix, with parameters and equipment assigned to the functions (Figure 1.). The definition of the function parameters also helps define and install most adequate machinery. Figure 2. contains FAST Diagram of hot-dip galvanized steel.
Figure 1. Function-parameter-equipment matrix. Source: Authors’ edition

<table>
<thead>
<tr>
<th>Function</th>
<th>Parameters</th>
<th>Value</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>F11</td>
<td>coilweight</td>
<td>max 15 mt</td>
<td>coil conveyor</td>
</tr>
<tr>
<td></td>
<td>outside diameter of coil</td>
<td>800 - 1650 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inside diameter of coil</td>
<td>500 or 610 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>line speed</td>
<td>max 8 m/min</td>
<td></td>
</tr>
<tr>
<td>F12</td>
<td>coilweight</td>
<td>max 15 t</td>
<td>coil conveyor</td>
</tr>
<tr>
<td></td>
<td>outside diameter of coil</td>
<td>800 - 1650 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inside diameter of coil</td>
<td>500 or 610 mm</td>
<td></td>
</tr>
<tr>
<td>F13</td>
<td>frequency</td>
<td>acc. to parameters of coils</td>
<td></td>
</tr>
<tr>
<td></td>
<td>current intensity / amperage</td>
<td></td>
<td>end scrapping welding machine</td>
</tr>
<tr>
<td>F21</td>
<td>line speed</td>
<td>30 m/min</td>
<td>heat treating furnace</td>
</tr>
<tr>
<td></td>
<td>furnace tempreature</td>
<td>nominal 750 C⁰</td>
<td></td>
</tr>
<tr>
<td></td>
<td>tempreature of strip heat treated</td>
<td>430 - 480 C⁰</td>
<td></td>
</tr>
<tr>
<td>F22</td>
<td>line speed</td>
<td>30 m/min</td>
<td>heat treating furnace</td>
</tr>
<tr>
<td></td>
<td>protective gas composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>protective gas pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F31</td>
<td>bath composition</td>
<td>Zn 99,6 - 99,8%</td>
<td>galvanizing kettle</td>
</tr>
<tr>
<td></td>
<td>Pb 0,08 - 0,12%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Al 0,16 - 0,24%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F33</td>
<td>layerthickness</td>
<td>acc. to standaard</td>
<td>control equip. of zinc coating’s thickness</td>
</tr>
<tr>
<td></td>
<td>air tempreature</td>
<td>40 - 70 C⁰</td>
<td></td>
</tr>
<tr>
<td></td>
<td>coatingmaterial consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F41</td>
<td>tensil force</td>
<td>max 6820 N</td>
<td>straightening machine</td>
</tr>
<tr>
<td></td>
<td>permanent deformation</td>
<td>0,8 - 1,5 %</td>
<td></td>
</tr>
<tr>
<td>F42</td>
<td>tempreature</td>
<td>50 C⁰</td>
<td>thermostat chromatizing kettle</td>
</tr>
<tr>
<td></td>
<td>concentration of bath</td>
<td>35%</td>
<td></td>
</tr>
<tr>
<td>F43</td>
<td>dryer capacity</td>
<td>8400 m³ / hour</td>
<td>dryer</td>
</tr>
<tr>
<td></td>
<td>tempreature</td>
<td>100 - 120 C⁰</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 C⁰</td>
<td>water cooler</td>
<td></td>
</tr>
<tr>
<td>F51</td>
<td>coilweight</td>
<td>max 10 t</td>
<td>coiler</td>
</tr>
<tr>
<td>F71</td>
<td>coatingthickness</td>
<td>100 - 350 g/m²</td>
<td>layerthickness measuring device with isotope</td>
</tr>
<tr>
<td></td>
<td>measurement range</td>
<td>0 - 400 g/m²</td>
<td></td>
</tr>
<tr>
<td>F72</td>
<td>looper capacity</td>
<td>max 160 m</td>
<td>entry looper</td>
</tr>
<tr>
<td></td>
<td>max 72 m</td>
<td>exit looper</td>
<td></td>
</tr>
<tr>
<td>F81</td>
<td>line speed</td>
<td>6 - 34 m/min</td>
<td>roller</td>
</tr>
</tbody>
</table>
Figure 2. FAST Diagram of hot-dip galvanized steel Source: Authors’ edition
Figure 3. Fast Diagram of the Technology Source: Authors’ edition
**Proposed technology innovations (examples)**

To increase the cooler capacity of the heat treating furnace, to control function F2 "to pretreat the surface". This would be necessary because otherwise the excess heat of the sheet may overheat the heat treating furnace and the 450°C exit temperature cannot be kept, and low cooling intensity may reduce the production line’s capacity. The cooling capacity can be increased in the following ways: increase the number of cooling cartridges. However, for this, the structure of the furnace needs to be changed, which is costly.

The next possibility is to increase the capacity of the cooling fan, not only by increasing its rotation and pressure but also by providing a larger quantity of cooling air. The cheapest solution is to increase the cooling surface. A possible method to do that is to weld longitudinal cooling flanges on the existing cooling cartridges.

**Results**

Function analysis and the assessment of function costs have made it possible for the team to identify the points of intervention that the proposed innovations target. Although in our case, we used the value analysis for the development of an existing product, the results can definitely be regarded as innovations. According to experts’, these potential innovations could not have been identified without value analysis. We can conclude that function and cost analysis, and team work almost inevitably leads to the launch of the innovation process (Kaufman et al., 2006).

**Summary**

For many decades, value analysis used to focus on cost reduction. However, Hungarian and international experts have called attention to the fact that value analysis has become one of the most effective tools of the innovation process (Bytheway & Charles, 2007; Iványi et al., 2002; Sato et al., 2005).

Marketing research has directed attention to the fact that the fast technological changes “eliminate” from the market the machines and equipment that are still in a good technical condition and were considered modern not long ago. For example, reducing the price of floppy disks would not boost sales because floppy drives are not installed in new computers anymore. In countries where value analysis is used widely (the USA, Japan, South Korea, etc) it is part of the innovation process already, which makes it possible to accelerate the product’s market entry and to avoid unnecessary costs. Value analysis is not used widely in the Hungarian national economy. This deserves even harder criticism in light of the fact that the Society of Hungarian Value Analyst (SHVA) has been a member of SAVE International since 1996, and has contributed to the most recent achievements in value analysis. It is important to note here also that, with SHVA’s support, value analysis is currently included in the curriculum of 11 institutions of higher education in Hungary. Students who meet the qualification criteria can obtain the first level of SAVE International’s international certification (AVS: Associated Value Specialist).

The College of Dunaújváros is also among the educational institutions where is value analysis is taught as a subject. Our college has made it possible for hundreds of Hungarian and international (Ukrainian, Chinese, Turkish, etc) students to obtain
the AVS certificate. Another important aspect of the present project is that we have turned it into a Case study, and we have used it successfully in the curricula of Hungarian and international students. We hope that value analysis will become part of business practice soon, and will thus contribute to the recovery from the crisis.

Acknowledgements

We express heartfelt gratitude to SHVA for many years of cooperation that has made it possible to adapt a state-of-the-art innovation methodology at the College of Dunaújváros. We also thank the experts of SAVE International for the fact that their honored us with their visits, and for the cooperation that has contributed significantly to the successful adaptation of value analysis at our college. And last but not least, we thank the present and former leaders of the Institute of Social Science and of the College of Dunaújváros for their steady support of our educational and research activities in the field of value analysis.

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