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THE LEAN INDUSTRY 4.0 APPROACH ON THE EXAMPLE OF AN AUTOMATED LINE FOR DOSING LOOSE RAW MATERIALS

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Purpose: The target of the hereby paper is to conduct the analysis of the disruptions in the area of processes happening in the field of dosing loose raw materials and depict the system which aims at eliminating sources of waste and which enables controlling and monitoring the whole value-adding process by means of the line automating and adopting the operator panel (HMI) including the SCADA application being installed.
Design/methodology/approach: The scope of the paper covers the lean industry 4.0 approach and is based on the case study method.
Findings: Changes on the global scale occurring in the mechanism of sources creation in terms of competitiveness are pushing firms to become opened to the benefit of the potential arising from the fourth industrial revolution. The urgency of taking into consideration the efficiency requirements is triggering companies to look for competitive advantages in the field of the basic products packaging within the scope of the fourth industrial revolution.
Practical implications: The target of the hereby paper is to depict the system which aims at eliminating sources of waste and which enables controlling and monitoring the whole value-adding process.
Originality/value: Considering the complementarity of Lean Management and Industry 4.0, there is presented the example of how I4.0 technology can support particular waste reduction management techniques.

Keywords: Lean Industry 4.0, waste reduction, material flow management, dosing loose raw materials.

Category of the paper: Case study.

1. Introduction

For a number of decades producers have been using the lean principles and tools in order to reduce waste and improve productivity (Lucantoni et al., 2022, pp. 83-93). The lean concept offers the basis for operational excellence by means of standardizing processes, creating and implementing the culture of ongoing improvement as well as empowering factory floor workers (Bicheno, Holweg, 2016, pp. 4-24).

Lean Management approach limits also the complexity, costs and total lead time involving all operations in the value chain (Boston Consulting Group, 2017). It introduces techniques designed to engage all the staff in continuous reviewing and enhancing the efficiency as well as improving the value of products and services provided (Ejsmont et al., 2020). This assumption is based on such management methods as reducing waste, planning takt time and standardizing processes (Boston Consulting Group, 2017). The entire array of versatile tools are used in order to achieve the lean objectives such as: Value Stream Mapping, 5S, Total Productive Maintenance, Single Minutes Exchange of Die, Kanban, Poka-Yoke, Just-in-time, Takt time, Jidoka, Heijunka, among others (Lean Enterprise Institute Polska).

Nevertheless, taking into account the increasing complexity level of operations, numerous enterprises have discovered that lean management approach by itself is not sufficient enough for meeting their operational requirements (Lewandowska-Ciszek, 2022, pp. 3-14). Recently, the entire combination of advanced digital technologies referred to as Industry 4.0 has emerged for the purpose of providing novel approaches for tackling complexity scope and enhancing productivity levels (Agostinho, Baldo, 2021). By means of deploying the appropriate set of technologies, producers are able to boost such factors as speed, efficiency, and coordination as well as facilitate additionally the self-managing factory activities (Boston Consulting Group, 2017).

2. Industry 4.0

The German National Academy of Science and Engineering published the industry 4.0 manifesto in 2013 (Kagermann et al., 2013). The theoretical background was for the first time introduced by Kagermann, Wahlster and Lukas in 2011 (German Research Centre for Artificial Intelligence, 2021) and since this year there have been developed the further research and there have been proceeded the continuation of the hereby idea by the variety of numerous stakeholders and researchers (Nai Yeen Gavin Lai et al., 2019).

At the same time it became the initiative of the German government on the strategic level and was incorporated into the “High-Tech Strategy 2020 Action Plan” (MacDougall, 2014).

Producers are enabled nowadays to attain new levels of operational performance in terms of excellence. It can be achieved by handling complexity and capacity in order to improve flexibility and innovation (Lucantoni et al., 2022, pp. 83-93). There is an enhanced number of Industry 4.0 solutions applied for reducing Waste (Ejsmont et al., 2020). The fourth step in the development of technological advancement in manufacturing is triggered by nine fundamental technologies such as: additive manufacturing, advanced robotics, augmented reality, big data and analytics, cloud computing, cyber security, horizontal and vertical system integration, the industrial internet, and simulation. Sensors, machines, work pieces, and IT systems are combined along a value chain which extends beyond the scope of a single company. These connected entities can be involved in the joint interaction and the analysis of the data for such purposes as predicting failure, reconfiguring themselves, and adapting to undergo the alteration (Boston Consulting Group, 2017). The idea of Industry 4.0 seems to be perceived as a strategy for achieving the competitive edge in the foreseeable future (Banaszyk, 2022, pp. 2-9). It is concentrated on the target of optimizing the value chains due to autonomously controlled production which is also dynamic (Mrugalska, Wyrwicka, 2016). Industry 4.0 as well enables enterprises to share the benefits of automation technology processes more broadly within the organization by, for instance, equipping and training factory floor workers who can in this way receive and apply real-time information regarding their machinery. By achieving the target of transparency increase and predictability improvement and by eventually allowing self-controlled systems to develop, Industry 4.0 is promoting quicker, more adaptable, and more effective activities. Producers can take the advantage of these benefits to attain their broader objectives such as producing higher-quality goods and reducing costs (Boston Consulting Group, 2017).

The process of production is becoming highly flexible, which connected with automation enables mass customization and increased productivity of the product array. However, it needs a different method of management from the previous one as the company environment within this scope of activities is frequently difficult to define. It happens because the leading concepts used here involve cooperation, integration, networks, collaboration, sharing, synergy, etcetera while geopolitical factors have a decidedly faint impact. I4.0 is not a single action of a particular enterprise company, but an entire strategy that allows the development of the economy, society and the companies operating in it. These processes are based on the possibility of creating dynamic, self-organizing, inter-organizational networks which can be optimized according to chosen criteria which represent, in essence, the combination of the work of individuals with information systems (Mączyńska, Okoń-Horodyńska, 2020).

Both lean management and Industry 4.0 support the objectives of operational excellence.

Considering the above-mentioned complementarity of Lean Management and I4.0, there is presented below the example of how I4.0 technology can support particular waste reduction management techniques.

3. Target of the study and method

The target of the hereby paper is to conduct the analysis of the disruptions in the area of processes happening in the field of dosing loose raw materials and depict the system which aims at eliminating sources of waste and which enables controlling and monitoring the whole value-adding process by means of the line automating and adopting the operator panel (HMI) including the SCADA application being installed.

The scope of the paper covers the issue of Lean Management Waste and the possibilities of eliminating it by using Industry 4.0 tools and is based on the case study method.

4. Process analysis and results

4.1. Process description prior to improvement

The dosing of raw materials is performed on the basis of the selected recipe, without SCADA system support. The dosing process of loose raw materials is initiated in the ingredient dosing area of S1. If the mobile process tank S1.T is on the weight transmitter S1.WT and the operator starts dosing using the START button located on the control cassette, the dosing system S2 is activated. It is the operator's responsibility to control the dosing of the correct product according to the recipe. The operator is informed of the weight of the raw material in the S2 dosing system. Raw materials flow from area S2 to S1 (Figure 1) proceeds in the following order:

- opening of the valve under the screw conveyor by the operator after pressing the START button,
- start of screw conveyor,
- simultaneous start of hammer sequence operation,
- stopping the screw conveyor and closing of valve under screw conveyor by operator after pressing STOP button.

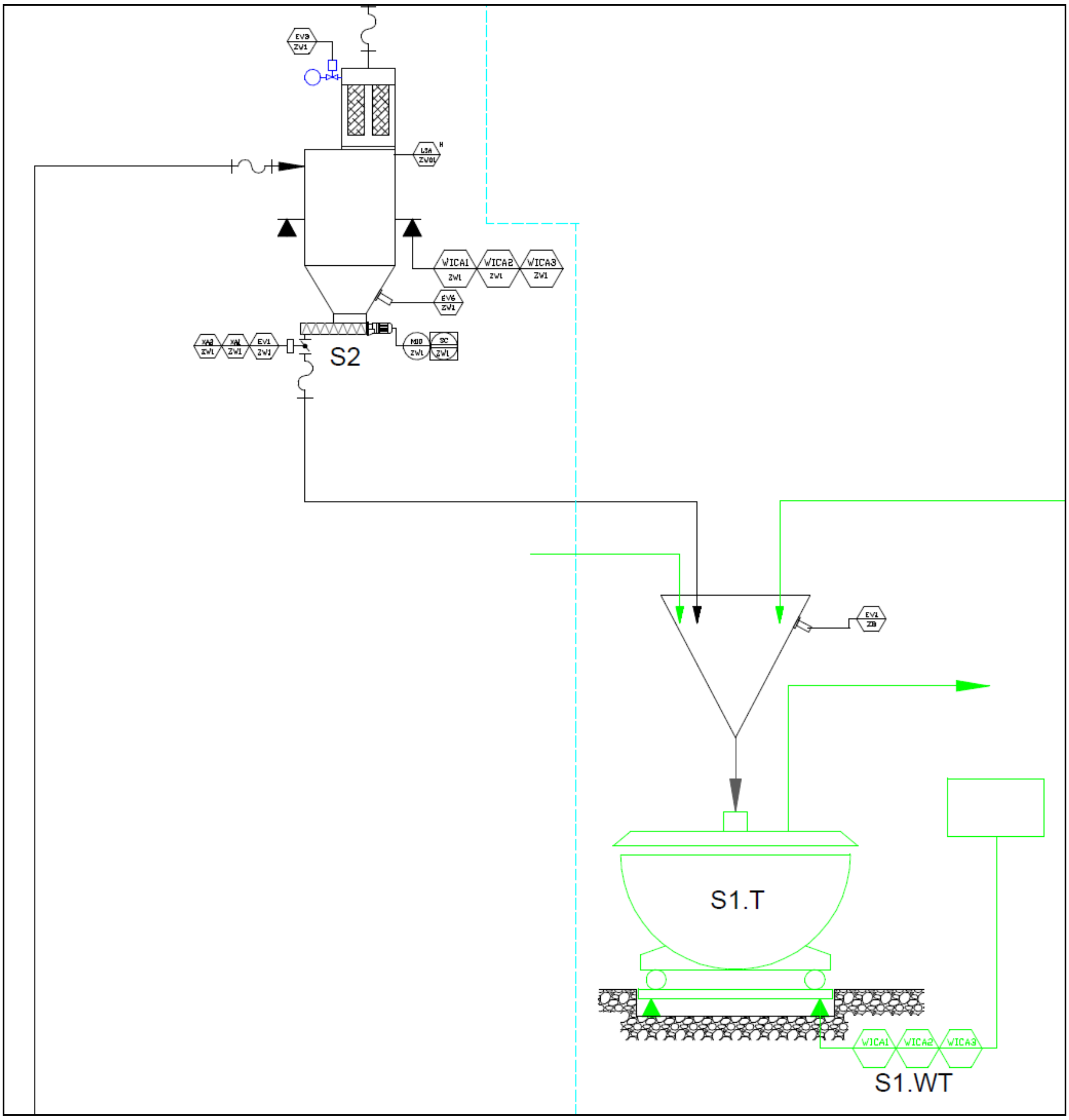

Figure 1. Raw materials flow from area S2 to S1.

Source: Own study based on the company's source materials.

Raw materials are transported to the S2 dosing tank from big bag station S4 using a vacuum transport system S3 (Figure 3).

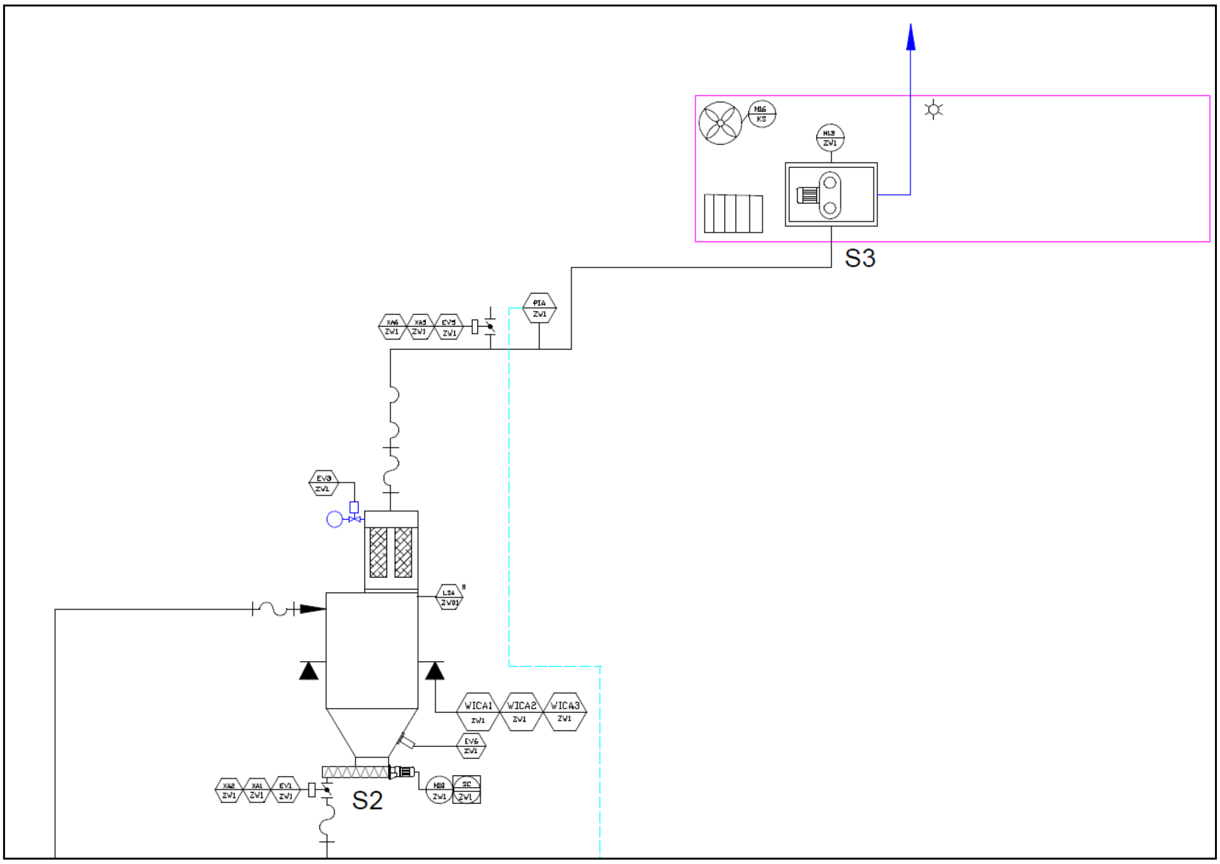

Figure 2. Raw materials flow to the S2 dosing tank from big bag station S4 using a vacuum transport system S3.

Source: Own study based on the company's source materials.

The transport system is activated by the operator, who decides when and in what quantity to apply the product. Information on the weight of the raw material in the S2 weighting system is read by the operator from a local screen. The operator also monitors the pressure indicator in the pipes of the conveying system. If he or she notices that the pressure has reached the required value to start transporting raw material, he or she activates the START button on the control cassette to dose raw material from big bag S4 to zone S2 (Figure 3).

The sequence for starting the transport system is as follows:

- valve actuation by the operator by pressing the START button,
- start of the vacuum pump,
- waiting by operator until the set pressure is reached in the conveying system,
- starting of the product feeding sequence from big bag station S4 after pressing the START FEED button by the operator,
- sending request for product feeding to big bag station S4.

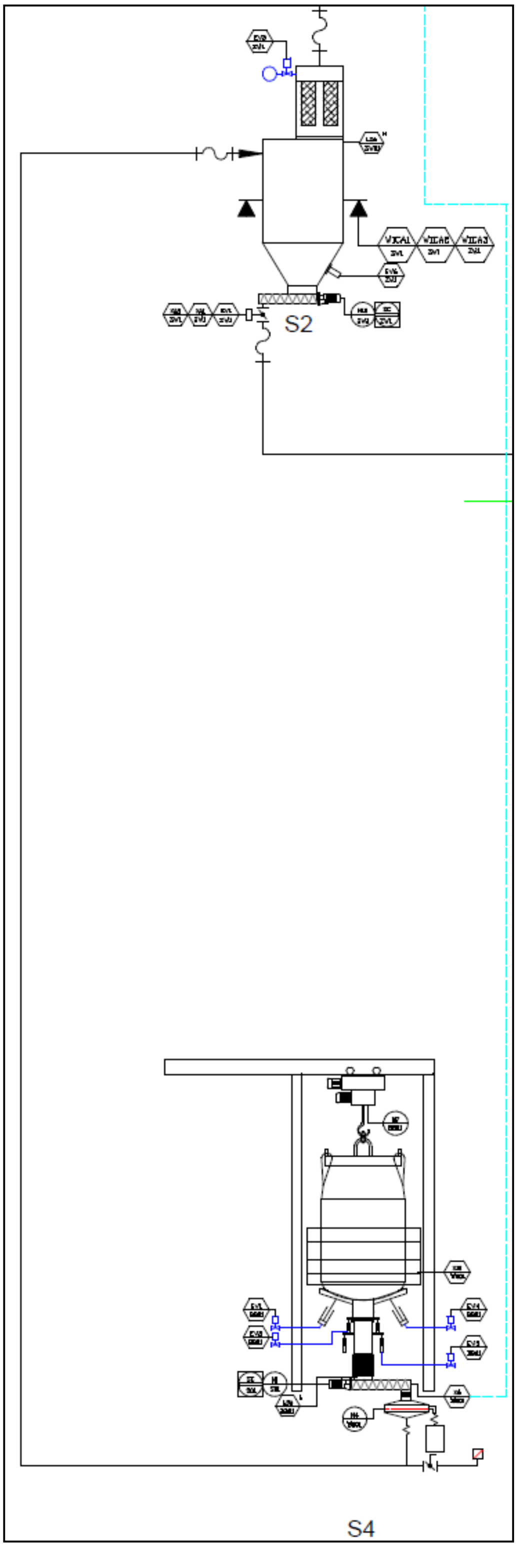

Figure 3. Dosing raw material from big bag S4 to zone S2.

Source: Own study based on the company's source materials.

Raw materials are fed into the production system via the big bag station S4.

When the valve under the screw conveyor is closed and the product sensor above the screw detects the product, a sequence is activated by pressing the START FEED button:

- starting of sieve,
- opening of the valve below the screw conveyor,
- starting of screw conveyor,
- sequential operation of massagers to smooth the feeding of raw material.

Big bag change is carried out using control cassettes. If a bag needs to be changed during operation of the conveying system, the operator switches off the massagers, sieve and screw conveyor, while the vacuum pump of the conveying system continues to operate.

Five types of Waste were diagnosed in the ingredient dosing area of S1 (Table 1). The operator does not have real-time information about the raw material in the process tank in weighting area S2. Some operators record this information in the form of handwritten notes. The biggest problem occurs at the shift changeover, as often this information is not passed between shifts. The consequence of the above is the occurrence of Waste in the form of over-processing, waiting, defects, motion, transport. If the wrong raw material or the desired raw material, but in the wrong quantity, is dosed into tank S1, defects, motion can occur.

Table 1.
Seven types of Waste occurring within defined zones

Names of the zones	Seven types of waste						
	overproduction	inventory	motion	transport	waiting	over-processing	defects
the ingredient dosing area of S1			˅	˅	˅	˅	˅
the dosing system S2	˅	˅	˅	˅	˅	˅	˅
vacuum transport system S3					˅		
big bag station S4	˅	˅	˅	˅	˅	˅	˅

Source: own study.

In the S2 weighting area, 7 types of Waste were diagnosed (Table 1). The predominant type of Waste in this area is motion, resulting from the low accuracy and system inertia of the weighting system, which is due to the distance between weighting station S2 and big bag station S4. The length of the transport pipelines between S2 and S4 affects the low accuracy of the weighting process. The operator is not able to determine clearly which mass of raw materials is currently in the transport system. This hinders the accuracy of ingredient transfer, which translates into problems in achieving the desired weight of the intermediate product in tank S2. When the operator finds that there is less than the desired amount of raw material in tank S2, the operator has to restart the system to make up the shortfall of raw materials. If there is more raw material in tank S2 than required by the recipe, the operator decides on the disposition of the overflow. If there is a possibility, the excess is managed for the next weighting in tank S1.T. If this is not possible, the operator directs the oversupply to the scratch bin.

In the next area of the vacuum transport system S3, Waste occurs in the form of waiting (Table 1). This occurs while waiting for the required pressure to build up in the transport system to start transporting products from area S4 to S2.

At big bag station S4, seven types of Waste were listed (Table 1). The predominant type of Waste is motion. The presence of one big bag station in a system where more than one raw material is dosed determines the frequent exchange of bags of raw material. The big bag exchange operation is time-consuming, requires a constant commitment of human resources and can cause errors when the raw material being dispensed is replaced. Each raw material has one storage area located right next to the big bag station. When changing the dosed component, the currently used bag should be put back in its dedicated place. If the raw material stock at the big bag station is exhausted while it is being dispensed, the operator goes to the storage area to replenish the missing raw material, which generates motion and waiting. If the stock of raw material runs out during the dosing process, but the dosed quantity was sufficient for the process, the operator assembles another big bag with a different raw material. He or she then goes to the raw material warehouse to refill the empty storage area. This can generate defects, as the operator may put the big bag in the wrong storage area.

4.2. Process description after improvement

The control of the product dosing zones was implemented using an operator panel with an installed SCADA application. Graphic symbols were embedded on it to allow control of the line and to visualize the current status of the production process. The purpose of the visualization is to minimize the level of Waste in the process, to make it easier for the operator to control production and to quickly diagnose faults and problems occurring during line operation in real time.

The dosing of raw materials takes place on the basis of a recipe previously selected in the SCADA system. The process of dosing loose raw materials starts in the ingredients dosing area S1. If the mobile process tank S1.T is on the weight transmitter S1.WT and the operator starts the dosing via the SCADA system, the S1 area sends the requests for dosing the respective raw materials in a predefined order to the weighting area S2, respectively to the weighting tanks S2.1, S2.2, S2.3. Once the request to dispense the appropriate amount of product has been sent to the S2 weighting zone, to the respective S2.1, S2.2, S2.3 weighting tanks, the sequence of dispensing product from this zone follows, assuming the tanks have sufficient product.

Raw materials flow from area S2 to S1 (Figure 4) proceeds in the following order:

- opening the valve below the screw conveyor,
- starting screw conveyor,
- simultaneous starting of hammer sequence operation,
- slowing down of the screw conveyor at the end of product dosing,
- stopping of screw conveyor,
- closing the valve below the screw conveyor.

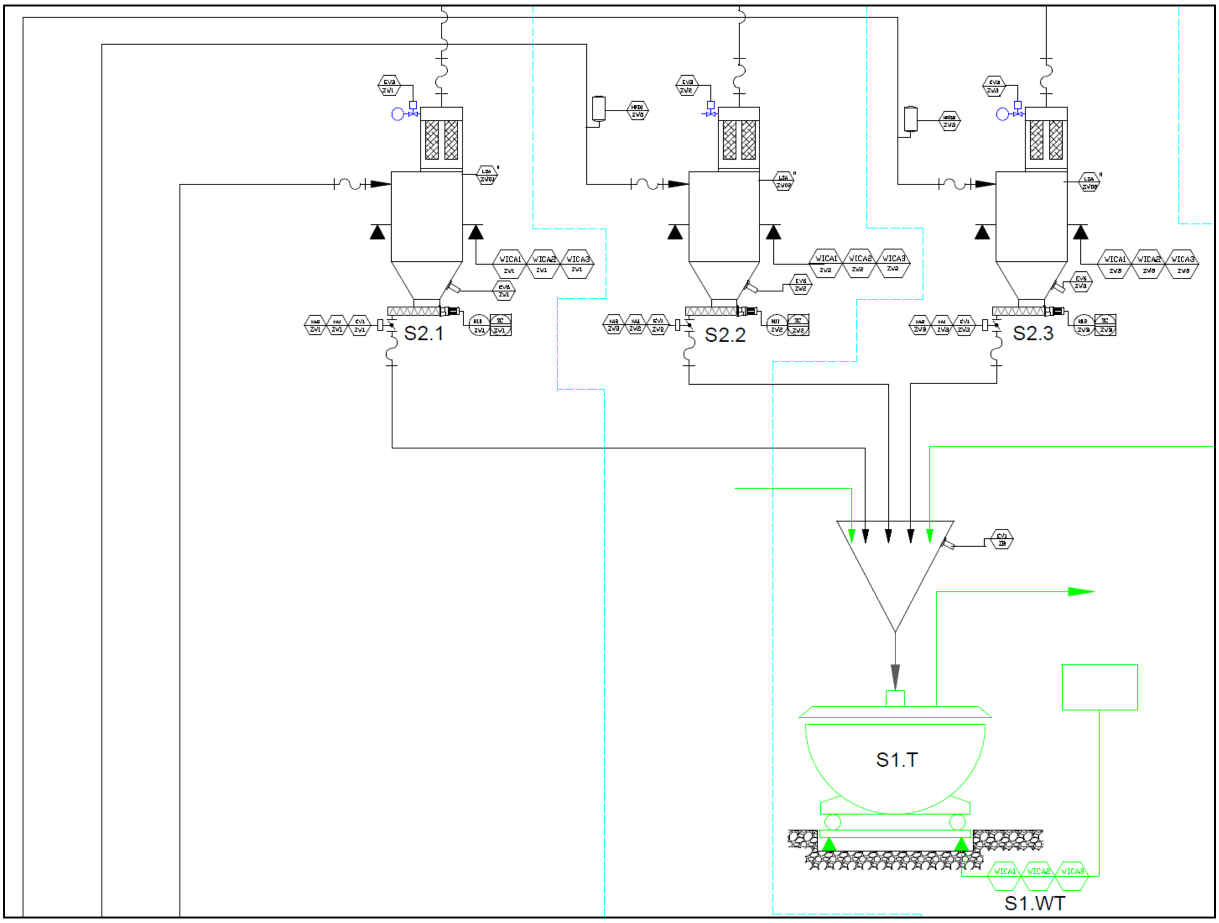

Figure 4. Raw materials flow from area S2 to S1.

Source: Own study based on the company's source materials.

Raw materials are transported to the weighting tanks located in weighting area S2 from big bag station S4, respectively from S4.1, S4.2, S4.3 by means of a vacuum transport system S3 (respectively vacuum pump: S3.1, S3.2, S3.3) (Figure 5). The transport system is activated upon receipt of a request from the S2.1, S2.2, S2.3 weighting tanks, in situations when the product level in these tanks reaches a minimum level defined in the SCADA system.

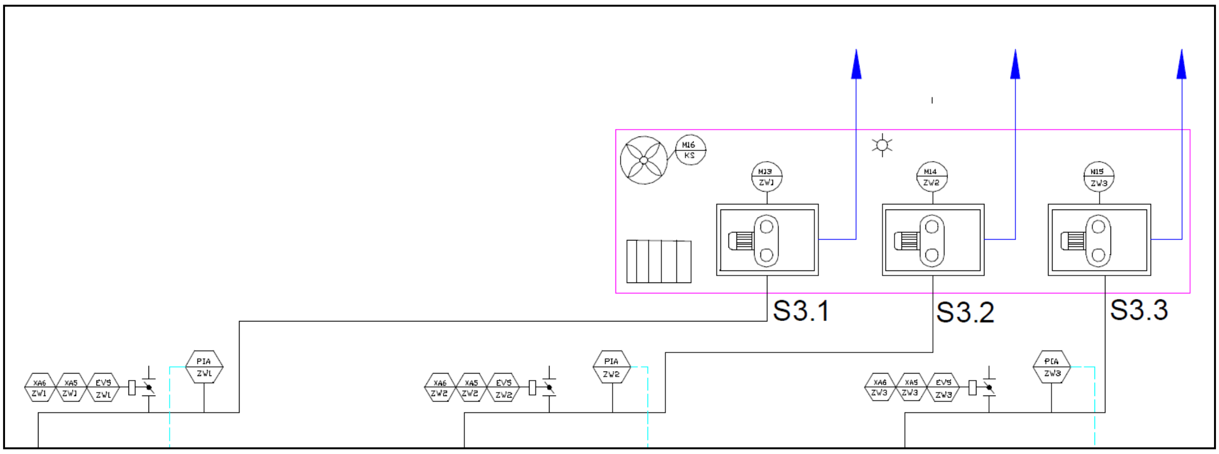

Figure 5. Vacuum transport system S3.

Source: Own study based on the company's source materials.

When the required pressure is reached in the pipelines of the transport system, it will send a request to feed the product to the big bag station S4 (Figure 6).

The start-up sequence of the transport system is as follows:

- product replenishment requests in the weighting area,
- operating valves in the transport area,
- starting the vacuum pump,
- waiting until the set pressure is reached in the conveying system,
- sending request for product feeding to big bag station S4.

Raw materials are fed into the production system via the big bag station.

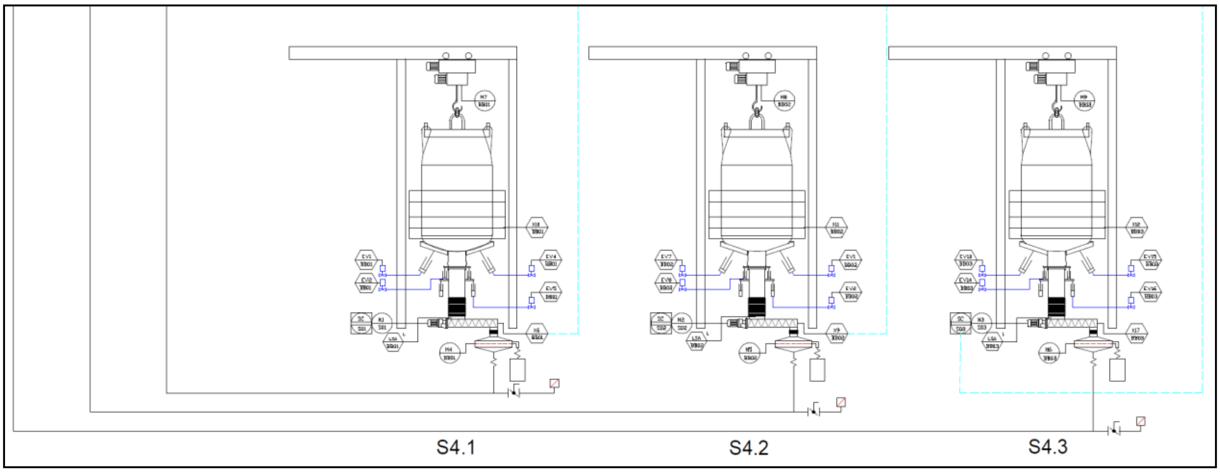

Figure 6. S4 area.

Source: Own study based on the company's source materials.

When the valve under the screw conveyor is closed and the product sensor above the screw detects the product, a sequence is switched on when a request is received from the conveying system:

- starting of sieve,
- opening of the valve below the screw conveyor,
- starting of screw conveyor,
- sequential operation of massagers to smooth the feeding of raw material.

Big bag change is carried out using control cassettes. If it is necessary to change a bag while the conveying system is in operation, the massagers, screen and screw conveyor are switched off, while the vacuum pump of the conveying system continues to operate.

5. Summary

The extension of the control system to include two additional big bag stations, two additional weighting stations, as well as the expansion of the under-pressure conveying system has eliminated sources of Waste in the S2 weighting zone. After the line upgrade, the need to divert excess raw material to the scratch bin has been eliminated, as each raw material tank is independent and acts as a buffer. In this variant, there is also no underdosing in the S1 area, as the PLC controls the dosing and is responsible for dosing the correct amount of product according to the recipe.

The S2 dosing area, which is equipped with three containers, also acts as a buffer for the individual raw materials. This makes it possible to change big bags in the big bag station area without stopping the entire process.

The use of three big bag stations has eliminated the problem of storing individual raw materials in the wrong storage field. After streamlining the system, each big bag station is assigned one specific raw material, which is fed into the system from that station. Next to each station, there is one storage area necessary for the replenishment of raw materials. The storage area together with the big bag station forms a 2-bin system, on the basis of which raw material replenishment is carried out.

The expansion of the entire system did not increase the number of employees operating the system, but significantly increased the efficiency of the system by reducing sources of Waste.

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