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A MODEL FOR THE SYSTEMATIC IDENTIFICATION OF INNOVATION OPPORTUNITIES IN A INDUSTRIAL PRODUCTION PROCESS

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Abstract
An industrial production process is a technical system that generates value by turning available resources in products to be sold. When the process is not able to exploit all the available resources in terms of market demand, raw materials, etc. the value generated by the system decreases due to a lack of functionality or performance. In this paper the authors present a road-map, based on the integration of different methods and tools, able to support the analysis of an industrial production process in order to identify business opportunities that are not exploited to their maximum extent. The identification of the functional needs is the key step to define innovation tasks at aimed removing the business limits. An application of the road-map to improve the solid biofuels production process is also presented as case study in order to clarify and to validate the proposed approach.

Keywords: multidisciplinary process optimization, systematic process innovation, process modeling.

1. Introduction

An industrial production process can be considered as a technical system able to generate value by manufacturing products under well known boundary conditions such as market demand, raw material availability, product quality requirements, etc. When the process is not able to exploit the available resources according to their potentialities, the value generated by the system decreases dramatically due to the lack of functionality. The identification of these functional needs becomes a crucial issue in order to remove the "bottlenecks" that limit the productivity. As highlighted in [1], the implementation of suitable technical solutions able to cover these lacks of performance is a difficult task since it involves the knowledge dispersed across many disciplines including: process engineering, resources management, information technology and marketing. During the last three decades different methods have been proposed in order to perform a systematic analysis and optimization of a production process with the aim to find out its lacks and improve its efficiency.

In [2] an integration of two complementary metrics, the Overall Equipment Effectiveness and the Overall Throughput Effectiveness is suggested in order to perform a quantitative measurement of the productivity of the system and to make a systematic benchmarking between different kinds of production process of several factories.

A model to generate productivity improvement in a group of manufacturing companies is presented in [3]. The methodology consists of three steps: Productivity Needs Analysis (PNA) which gives an overview of the current manufacturing condition of the company, identifies the key productivity measures for the plant and forms the basis for a detailed study of production efficiency. The plant processes and problems are defined and are associated with the appropriate tools and metrics in a Manufacturing Needs Analysis (MNA), which generates an initial 1-year improvement plan for a particular manufacturing unit. The output from the procedure is obtained as a numerical ranking. In order to ensure that the tools which are found to be effective are fully embedded within the company, the PNA and MNA are combined with a Training Needs Analysis (TNA).

In [4] the efficiency of different approaches to improve a container-filling production process is estimated by means of three types of actions: reducing setup cost, reducing the arrival rate of the out-control-state and reducing the process variance. Different models have been adopted in order to determine the optimal process improvement and production parameters through numerical simulations.

An integrated multidimensional process improvement methodology is presented in [5] to address the yield management, process control and cost management problems for a production process. Here the Total Quality Management (TQM) is used to manage the cost of the system according to the quality requirements and a discrete event simulation is used to perform process reengineering (Business Process Reengineering) and process improvement.

All the above mentioned models are useful tools in order to optimize a production process with respect to the product requirements and the production costs, but they are not suitable to suggest any specific improvement of the system according to the potential that it has to generate value. In such a context the authors have developed a road-map to support the analysis of a production process from both functional and economical point of view in order to identify still not exploited business opportunities. Moreover, a systematic approach to link the analysis of the system with the identification of the technical solutions able to overcome these functional needs is also proposed. Section 2 reports the proposed road-map, the selected tools and a detailed description of their integration. In Section 3 the application of the road-map to improve the production process of solid biofuel in the region of the Appennino Tosco-Emiliano is described. Eventually, in Section 4 the proposed approach is discussed and some opportunities of further implementation are presented.

2. Tools and Method

In order to fulfill the objectives presented in the previous section, a roadmap based on the integration of complementary techniques supporting process analysis and development here is presented.

This road-map is able to support the analysis of an industrial production process in order to identify business opportunities that are not exploited due to poor performance and/or lacks of functionality of the system. The identification of the functional needs is the key step to define innovation tasks aimed removing the business limits. The road-map and the related tools are shown in figure 1.

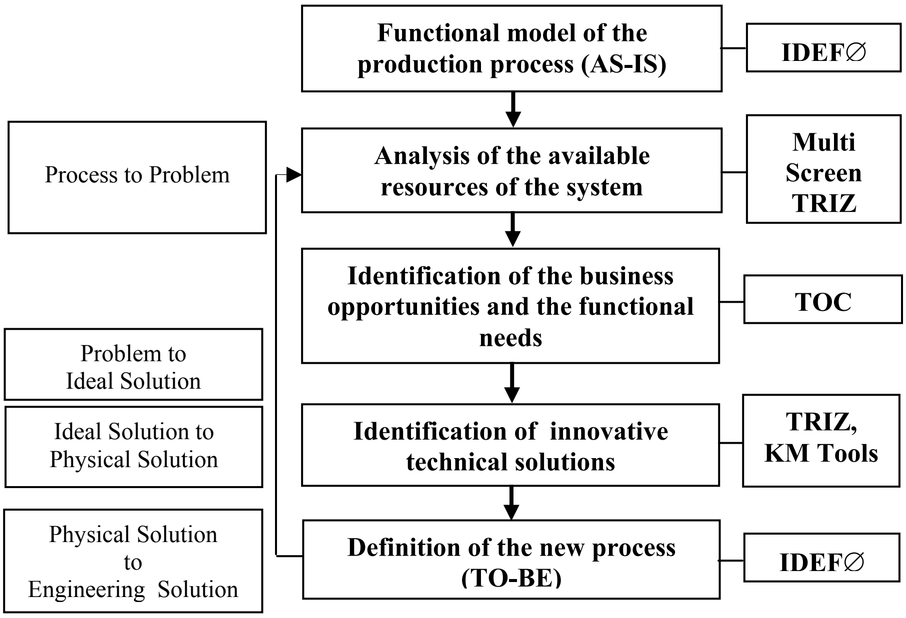

Figure 1: proposed roadmap for identification of technology innovation opportunities in an industrial process and related tools.

<u>*Functional model of the production process*</u>: the first step of the procedure requires to define the functional model of the process (AS-IS model) in order to characterize each phase according to the functions that it performs. The flows of materials, information and energy in input and output to each phase are represented. The functional parameters such as the efficiency in terms of energy consumption and the input/output physical parameters (such as temperature, pressure, etc.) of the materials involved in the process are also detailed for each phase. The IDEF∅ technique is adopted to perform the functional analysis of the process in order to represent a process according to the E.M.S. (Energy, Material and Signal) flows, by specifying control mechanisms and tools.

<u>*Analysis of the available resources of the system*</u>: once each phase of the process has been described in terms of the functions that should be performed and the physical

input and output parameters have been identified, the analysis of the available resources is performed. According to the TRIZ concept of "resources", each substance, field, interaction, characteristic, property, time/space availability within the system not used at its maximum potentialities is an opportunity to improve the system itself. This step has the following tasks:

- To analyze each phase of the process and its flows in order to discover if there are resources inside the system that are not exploited. These resources may be used in order to improve the overall efficiency of the system (i.e. the energy lost due to the friction in a phase may be used as thermal heating for other phases of the process, etc.).
- To identify the availability of external achievable resources in terms of market opportunities and available materials;

An useful tool to support this task is the so-called (by the TRIZ community) Multi-Screen approach, consisting in a multi-scale analysis to be focused on each time-step/phase of the process and on the cause-effect relationships existing between its functional interactions.

Identification of the business opportunities and the functional needs: once the system has been characterized in terms of functional parameters, the analysis of the requests the process is able to satisfy is made according to the results of the previous step. As a consequence, it is possible to identify business opportunities still unexploited in the current reality due to technological and functional needs that the system is not able to supply at present.
Such a complex task requires modeling both the functional architecture of the process and the value of the flows involved within and outside it. Such a technical-economical model can be suitably built according to the tools provided by the Theory of Constraint (TOC). According to the TOC, the production process is represented as a technical system constituted by chains of operations, where each ring represents a phase. The flows taken into account in this kind of model are the monetary flows generated by the system that are defined as follows [6]:

- Troughput (T): "The rate of which the entire system generates value through sales (product or service)": this flows represents the money coming in the system.
- Inventory (I): "All the money the system invests in things it intends to sell": this is the flow of money that are spent in order to buy the raw materials.
- Operating Expenses (OE): "All the money the system spends turning Inventory into Throughput" this flow of money going out the system to buy labor, utilities, consumable supplies, energy, etc.

According to TOC principles, to improve the system the first priority is increasing T, since it has the greatest potential impact on the bottom line, while decreasing OE and/or I is secondary and in any case should not jeopardize future throughput.

The problem is to know "what to change" in the current reality of the system in order to improve its Throughput: this represents the functional need or the so called "constraint" to be removed. TOC problem-analysis tools, the Current Reality Tree (CRT) is helpful to accomplish this task. By CRT the cause-effect relationships behind the current situation can be highlighted going back from one or more tangible or not tangible undesirable effects produced by system. The root cause represents the core problem that originates all the undesirable effects: this represents the Constraint of the system to be removed in order to increase the T/OE ratio of the entire process.

Identification of innovative technical solutions: the aim of this step is to analyze the constraint in order to identify the innovation demand to remove it. Once the expected improvement in terms of performance and/or functionality related to the constraint have been identified, they are translated into new specifications of the innovative process.
Focusing the process requirements on the Constraint limits brings sometimes to unexpected specifications due to the clearer vision of the process obtained through the model of the system. It may happen that these specifications don't require any inventive step, but just the application of solutions already known by the design team.
Besides, if the previous analysis points to the necessity to overcome a trade-off due to conflicting requirements or to a physical limit of an internal resource, the "injection" can be conceived by applying TRIZ tools for the identification and solution of physical contradictions.
As a result, a conceptual solution is generated in terms of physical properties of the system that allows to improve the Throughput of the Constraint or to reduce its Operating Expenses/Inventory.
Due to the nature of the TRIZ inventive process, the conceptual solution could be derived from any field of application, thus its embodiment into an engineering solution may involve multidisciplinary competences, even external to the design team experience.
This task can be suitably supported by Knowledge Management (KM) tools, in order to retrieve and analyze relevant technical contents from patents, scientific journals etc. even with limited resources.

Definition of the new process (TO – BE): the solutions developed in the previous phase are then evaluated to establish the opportunities of implementation in the process. A simulation of the TO-BE process is performed in order to verify the impact of the proposed innovations on its functional parameters and to compare the updated Troughput/Operating Expenses with the old process. Once again IDEF∅ and TOC tools are used in this step.

The first iteration stops with the definition of the TO – BE process; of course, the latter may be further analyzed in order to check whether the Constraint of the process is still the same or another phase/function of the process has become the most critical.

According to the needs of the whole process the above described steps can be iterated: as depicted in figure 1, the new iteration starts from the analysis of the resources available for the TO - BE process, since it represents the current reality of the improved system.

3. Application of the road-map to improve the production process of solid biofuel in the Appennino Tosco-Emiliano.

Solid biofuel obtained by the sustainable exploitation of forestry resources represents a relevant complementary source of energy to oil and its derivatives. In the last two years the market demand of solid biofuel in Italy is dramatically grown and it represents a business opportunity for a lot of rural areas: one of these is the Appennino Tosco-Emiliano. Two different kinds of solid biofuel are obtained by the exploitation of the forestry resources and sawdust:

- Wood chips: pieces of wood having overall dimensions of 25 X 30 X 20 mm, maximum moisture content of 20% in weight, market price 70 €/Ton;
- Pellets: cylinders of pressed sawdust having a diameter of 6 or 8 mm, height of 35 mm, moisture content of 10% in weight, market price 220 €/Ton;

The installation of stoves for domestic usage, able to burn this kind of biofuel is grown in the last years in Italy so that the market demand of wood chips and pellets is much more than the market supply. The IDEF∅ of the process by which solid biofuel are manufactured, is shown in figure 2.

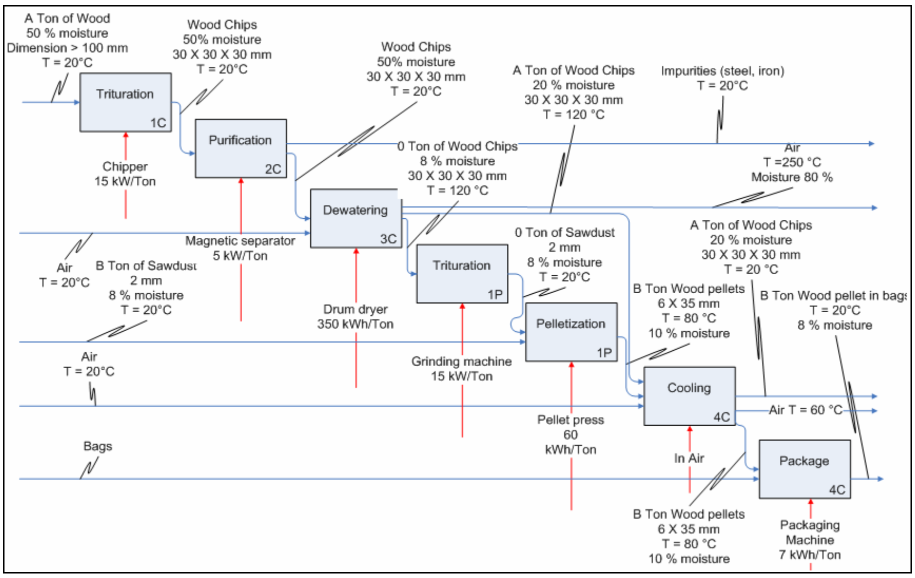

Figure 2: IDEF∅ of the solid biofuel production process (AS-IS).

According to this figure, the process used to produce the wood chips starts with the trituration (called "chipping") of the wood biomass in order to obtain chips having overall sizes of about 30 X 30 X 30 mm. The next phase is aimed at purifying the obtained wood chips by removing any kind of impurities (such as solid particles, glass, iron, etc.). In order to avoid fermentation, the moisture content is reduced to 20% in weight, a dewatering is performed using thermal heating and at the end of the process the wood chips are cooled in air. Due to moisture and dimensions requirements only sawdust is actually used to produce pellet. Besides, the pellettization of the sawdust produces a not negligible heat due to the high friction of the extrusion die, thus the pellets require to be cooled at the end of the process before the packaging.
The availability of the wood biomass resources in the Appennino Tosco-Emiliano and their costs are summarized in table 1. In table 2, the costs of each phase of the process are surveyed (the cooling phase is omitted since it does not generate costs).

Table 1: biomass resources availability

	Moisture contents %	Dimensions (mm)	Availability (Ton/Year)	Cost (€/Ton)
Sawdust	10	2	5000	5
Renewable Wood	50	>100	30000	25

Table 2: production costs (€/Ton) of solid biofuel

	Trituration	Purification	Dewatering	Pelletization	Packaging
Wood Chips	3	2	38	-	-
Pellets	-	-	-	11	1.5

As shown in the IDEF∅ diagram (figure 2) there are flows of energy discharged from some phases of the process that constitute unexploited internal resources of the system (such as the heat content discharged by the cooling phases, the heat content in the air discharged from the dewatering phase, etc.) as well as the materials extracted by the purification process and the water obtained during the dewatering phase. While the materials extracted by the purification phase may constitute market opportunities, the thermal flows discharged during the process have temperatures that don't allow their reuse for other task of the process.
According to TOC paradigm the T, I and OE flows generated by the Current Reality of the system have been evaluated. At present, while the market demand of wood chips is entirely covered by the production, the pellets demand is not satisfied at all. Under these boundary conditions the monetary flows that may be generated by the process are those reported in table 3.
The required investments for the plant assessment are also summarized and the productivity, Net Profit and ROI are evaluated for each product.
The analysis of the system performed on the basis of the ROI criterion, suggests to focus the production just on pellets from sawdust, without taking into account the

use of the wood; in other words, according to the ROI criterion, the usage of wood to produce pellets is not worthwhile.

Table 3: T, I, OE and Investment (M€) generated by the system in a year.

	Wood chips from wood	Pellets from Sawdust	Pellets from wood
T	2.10	1.10	6.60
OE	1.14	0.067	1.67
I	0.75	0.03	0.75
Investment	1.30	0.05	1.35
Productivity (T/OE)	1.84	16.50	3.95
Net Profit (T-OE-I)	0.21	1.01	4.18
ROI (NetProfit/Investment)	0.16	20.20	3.10

On the contrary, the analysis of the monetary flows according to TOC principles shows that selling one ton of pellets more (that means one ton of wood chips less, according to the available resources) produces an increment of the Throughput of the whole system. So TOC contradicts the ROI criterion since the throughput suggests to improve the pellet from wood process instead of to use only sawdust. Thus the main problem of the current reality is that while the process is able to satisfy the market demand of the wood chips, it is not able to produce more pellets to be sold. The negative effect is that the market demand of pellets cannot be satisfied.

As described in the previous section, the CRT tool allows to point to the causes of the undesired situation. As shown in figure 3, the Constraints limiting the Throughput of the system are the moisture content and the dimensions of the wood chips that does not allow their pelletization so that only sawdust is used. These constraints are related to the limited performance of the system that requires too much energy to dewater the chip and it is not able to reduce their dimensions up to those required for the pelletization phase.

Thus, the analysis of the process brings to well defined technical problems:

- how to dewater chips from 50% to 8-12% of moisture with minimum energy consumption?
- How to triturate the chips into 2.5 mm diameter particles, in order to allow the pelletization?

While the second task is somehow achievable with already well established technologies, dewatering is actually demanded to thermal dehumidification that is a high energy consumption, poor efficiency process (indeed it has the highest OE of the process).

The efficiency depends on the dimensions of the processed material: dewatering sawdust requires less energy than dewatering wood chips. So the problem is that actual technologies for trituration are not able to work properly with wet materials, while thermal dewatering is more efficient with small size materials.

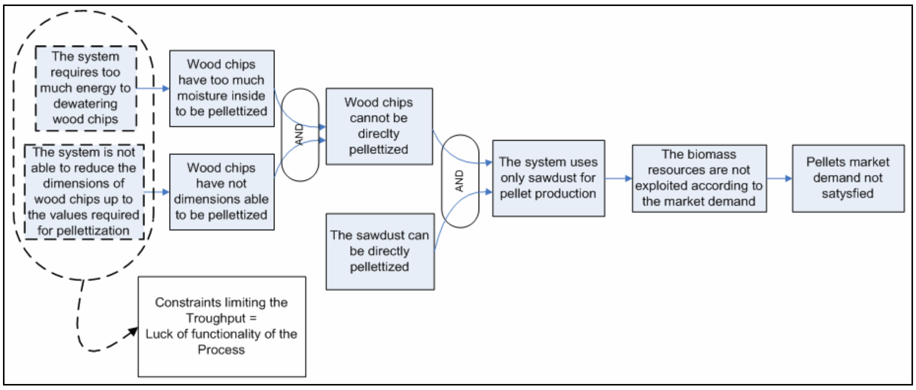

Figure 3: Current Reality Tree of the AS-IS process: from the negative effect (dx) to the core problem(s) (sx).

A deeper analysis of the problem has revealed a number of concurrent contradictions both in heat dehumidifiers and in triturating machines. Among them, the latter have a relevant evolutionary potential in terms of contributing to moisture reduction: high speed mechanical energy is a powerful resource to separate water from wood particles during the milling process. If ultrasonic waves are generated by means of high speed shocks, they can further contribute to moisture reduction as claimed also in [7, 8, 9]. A specific patent search to validate such a conceptual solution has revealed three patents [10, 11, 12] adopting the same physical principle to pulverize and dry raw material. At least one of these patents has been converted into a real product by First American Scientific Corp.: a rotor equipped with chains or knifes operates the trituration of the material, by shooting the particles towards the walls of the machine. The impact transforms the kinetic energy of the particle into impact energy that makes the particles and the water vibrate: this allows the separation of the different materials. According to the datasheet supplied by the producer, such a system is able to reduce the moisture content from 60% to 10% and the particle size up to 1 mm.

The most relevant property of this technology is the energy consumption three times less of a traditional heat based dehumidification.

A novel TO-BE process has been simulated under the assumption to integrate this technology and the IDEF∅ diagram presented in figure 4 has been developed. This process allows to exploit the available biomass resources according to the actual market demand so that the T of the system can be maximized. Moreover the OE of the dewatering/trituration phase has been strongly reduced (22 vs 38 €/Ton).

A further advantage is that the final product has a moisture content of 8 % (pellets) instead of 20 % (wood chips) compared with the old process, thus improving the heating power supplied to the customers.

Of course, due to the constraints constituted by the already granted patents, it is necessary to choose whether acquire the machine produced by First American Scientific Corp. or develop a new mechanical system implementing the same physical principle. Such a decision of course depends on several strategic,

economical, financial issues that will be evaluated by the industrial partners of the present project.
Nevertheless, the TO-BE process is still under investigation by the authors in order to check further opportunities for improvements. A new iteration according to the proposed road-map has been performed and the results shown that the pelletization will be the new critical phase limiting the performance of the system.

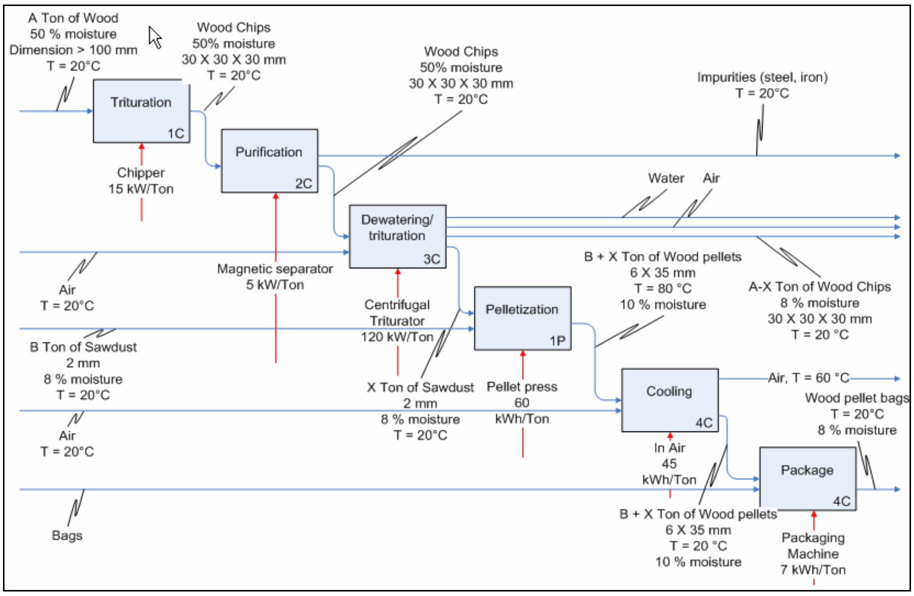

Figure 4: TO-BE process.

4. Conclusions

A road-map to support the analysis of a production process in order to find functional limits and business opportunities has been presented. The procedure is based on the integration of different methods and tools in order to perform, technical-economical analysis according to the multidisciplinary nature of the task. The main aspects of the proposed integration have been investigated and described.
The application of the road-map to the production of solid biofuel has demonstrated its validity with relevant opportunities of improvement and innovation.
The focus on the Constraint of the process, identified according to the TOC philosophy allows to manage even complex situations with affordable efforts; by improving the Throughput of the Constraint the whole process gains the maximum benefit.
Moreover by simulating the development of the Constraint performance and the shift of the Throughput bottleneck to another phase of the process, it is possible to anticipate technological and know-how needs in the field.
The research work will be further developed in order to extend the applicability of the roadmap not only to production processes, but also to other kinds of technical systems and to decision processes in general . The integration of process simulation

tools will be performed in order to speed-up the application of the procedure and in order to support the decision phases.

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