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USE OF AUGMENTED AND VIRTUAL REALITY IN INDUSTRAL ENGINEERING

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Keywords: virtual reality, augmented reality, advanced industrial engineering
Abstract: This paper describes the use of virtual and augmented reality technologies in various fields of industrial engineering. The article provides the brief description of how augmented or virtual reality contributes to the process improvement. It is also focused on the characteristic areas and the best-known areas of industrial engineering such as goods picking, design of production and logistics systems, design of assembly workplaces and visualization of procedures and ergonomics.

1 Introduction

Virtual and augmented reality as terms are well-known today and they are used in many sectors. These technologies have been used in a wide range of disciplines such as military, aviation, healthcare, but is most widely presented in the area of marketing, advertising and sales. The industry field is also not immune to progress in sophisticated information technology. Current virtual and augmented reality applications in this area get a very interesting view. The use of augmented reality in industry and manufacturing is still in the research and development phase, although the first initial projects are already underway.

2 Virtual and augmented reality within the virtual continuum

Virtual continuum is a continuous scale between a complete virtual reality and a real environment [1]. This scale includes all possible variants between the ratio of real and virtual elements. The area between these two extremes is called mixed reality. Mixed reality consists of a real environment in combination with virtual objects and interaction, according to the proportion of virtual elements in the image. Virtual Reality (VR) is an environment modelled by means of computer simulating reality. The technology of virtual reality completely pulls users into the virtual environment. The user uses a Head Mounted Display (HMD) and head-mounted device that may or may not be connected to the computer. In the virtual reality environment, the user is immersed into the virtual world, and can interact with it in a meaningful way. The virtual environment experience has a wide range of information when stimulates all the senses. Visual and sound components are the most preferred, but in more sophisticated cases the other senses, such as smell and touch, are stimulated. System that provides user´s feedback and touch interaction are called haptic system. User interaction is ensured by classic computer equipment such as keyboard and mouse, or specially tailored devices such as 3D glasses, clothing that sensing the movement and clothing that stimulates the touch, multi-channel sound, and the others. The environment created in this way can create an image of the real world [2].

3 Use of augmented and virtual reality in industrial engineering

The Department of Industrial Engineering is very intensively zealous for research in the field of using the virtual reality for industrial engineering. The main applicable areas of these new technologies include:

- **The area of goods picking, warehouse** - The proper functioning and organization of the warehouse has implications for the speed and quality of services provided to customers [3]. Picking of goods forms an irreplaceable role in the logistics chain connected with the preparation and processing of order. With increasing pressure on quality and timeliness of delivery as well as increasing diversity and number of picking items, new forms of organization are also developing and new technologies are applied to picking processes. In practice, they are starting to apply so-called free-picking systems. The advantage of these systems is mainly the replacement of the classic paper document by electronic order picking in combination with other technologies, enables to simplify, speed up and improve the process of searching and completing items into the picking order. An example of such a picking method is the so-called „pick-by“ systems [4]. The use of augmented reality in picking order (Figure 1) belongs to “pick-by-vision” system.

Figure 1 Pick-by-vision system using augmented reality

- **Design of production and logistics systems** - Designing production and logistics systems is another potential area for the application of augmented reality resources. Nowadays, computer technology and its possibilities are widely used in designing production systems. Augmented reality provides the designer with the advantage of creating a digital model of the manufacturing system and putting it into the real environment. The principle consists in placing markers in the production space and assigning virtual objects to individual markers. With head mounted display or stereoscopic 3D glasses, the designer can view the proposed layout. Digital designing of production and logistics systems does not replace the classical design concept, but extends the capabilities of the designer, what is enhancing the design quality of the resulting layout [5]. The design and visualization of a production and logistics system in a digital environment requires the preparation of 3D models for all components from which the proposed system will be assembled (production machines and equipment, transport and handling equipment, handling units, storage facilities, auxiliary equipment, etc.). The created digital 3D models are then the cornerstone of the digital design of production and logistics systems in a computer environment. 3D modelling of the production system gives us an environment that allows the designer to perceive this modelled environment very much like his real model without the need for major investments to build a real production system [6]. At the same time, it enables the designer to verify several variants of the solution in a short time, which ensures that the resulting production system will be effectively designed already in the preparation phase. For designing production systems, we can use virtual reality technology using Unity 3D programming environment and HTC Vive Pro (Figure 2).

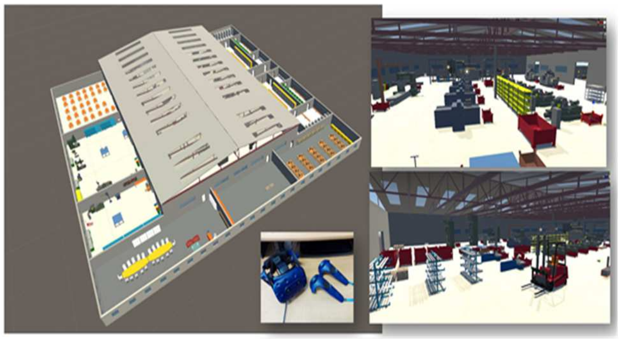

Figure 2 Design of production system in virtual reality using HTC Vive Pro and Unity 3D

For detailed design of smaller workplaces, we can use augmented reality technology and 3D objects displaying using a tablet or cell phone (Figure 3).

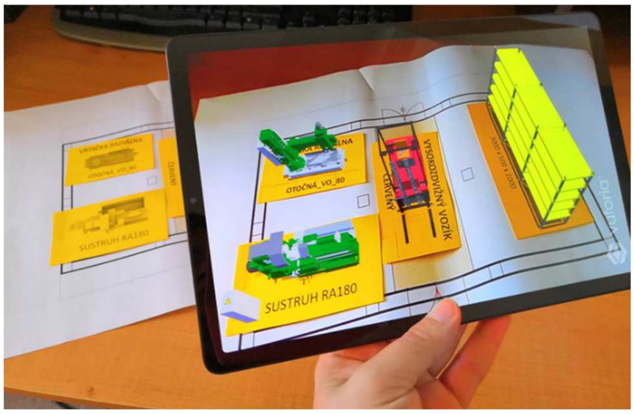

Figure 3 Design of production system using augmented reality and tablet

- **Detailed design of assembly workplaces and visualization of assembly procedures** - A related area for the design of production and logistics systems is also the area of assembly design. In the conceptual design phase, several variants of workplace design are generally created and the advantages and disadvantages of individual designs are evaluated. It is very advantageous to create variants in 3D environment because of much better imagination and possibility of complex design verification [7]. Thanks to the third dimension of the models, we are much more aware of how the individual elements of the workplace interact and limit each other. Augmented reality can work on multiple technologies to assign virtual models to the real world. In this case, it is best to use a tracking system with markers (Figure 4). This is because the easiest and the fastest to prepare and most stable to quickly place and move multiple models.

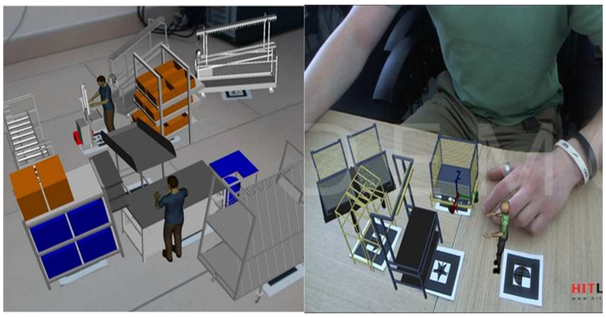

Figure 4 Detailed design of production system using augmented reality with markers [7]

Augmented reality technology can be applied in many areas. Its use is realistic especially when displaying assembly and workflows, where the main idea is to remove paper instructions and replace them with animated visualization using augmented reality. Assembly means mostly the implementation of connecting technological operations. It is characterized by high intensity of material and information flow and short operation times. The greatest time consumption is spent on the operation manipulation and on the correct positioning of the component to be assembled. Augmented reality offers a solution to reduce this time consumption by providing visual information to the worker during assembly (Figure 5).

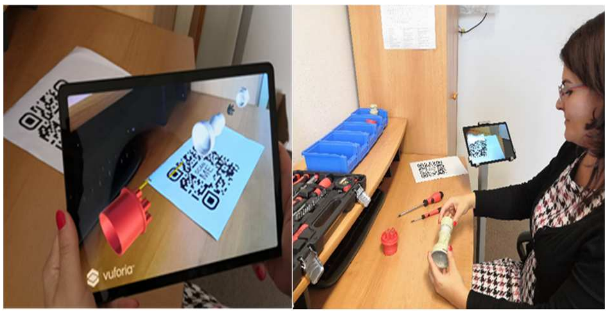

Figure 5 Assembly with augmented reality

- **Service activities and maintenance** – Use of augmented reality in maintenance and service offers a range of options, from simple visualization of disassembly (Figure 6), assembly and replacement of components to visualization of complex service activities [8].

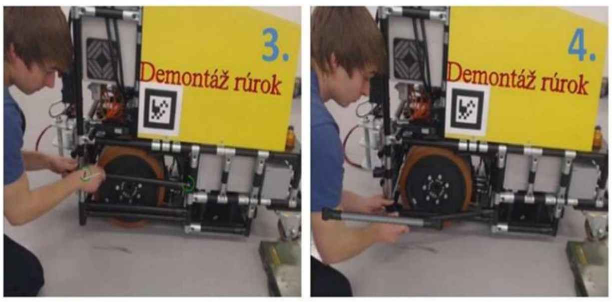

Figure 6 Service activities with augmented reality [7]

- **Ergonomics** - Ergonomics is a scientific discipline dealing with the relationships that emerge between man and the environment that surrounds him [9]. One of the mobile tools for rapid identification and risk analysis in the field of workplace design and ergonomics is CERAA (Ceit Ergonomics Analysis Application). The idea of creating a mobile application as a screening tool came with the demand of larger companies that have hundreds of workplaces and are unable to identify risks with their own resources and tools. CERAA is a mobile application for screening evaluation of workers' spatial conditions and working positions at potentially hazardous workplaces. It is created on the basis of legislation and technical standards, on its own platform, with the support of virtual and augmented reality [10-16]. One of the biggest advantages is that the user does not need to be an expert in ergonomics, basic knowledge of ergonomics and detailed design of workplaces is sufficient. In order to use the application effectively, the customer needs a tablet, an installed application, a marker and training for the applications (Figure 7). The main objective of the CERAA assessment is to determine whether the workplace is at risk from an ergonomics perspective and whether a detailed assessment of the workplace and a proposal for remedial measures by second-level instruments are necessary, or what health risks to workers.

Figure 7 CERAA augmented reality evaluation examples [10]

- **Logistics area** - Despite the fact that the area of augmented reality in logistics, as in other areas of industrial applications, is only at the beginning of its deployment, it is a great contribution to improving logistics processes. For example, augmented reality allows logistics service providers to quickly access expected information anytime. This is highly beneficial for the prospective and accurate planning and execution of tasks, such as optimizing delivery and handling, and extremely important in delivering higher-level customer service. As with the promotion of dynamic transport, augmented reality in this case serves primarily to assist the driver in navigating to the place of delivery. In this case, the augmented reality system can not only provide basic navigation but can also serve as an additional information presentation. For example, when the augmented reality device is directed to a particular building or block of buildings, the driver will be provided with additional information about the building (entrance position, unloading characteristics, unloading parking options, etc.). If no public database containing information about the location of the entrance or other local facts is available for that location, the augmented reality device can be used to position its own tags and thereby create its own independent database. When the next shipment arrives at the location, the augmented reality device makes the previously collected information available.

4 Conclusion

Virtual and augmented reality technologies currently represent a very dynamically developing area of information technology applications. Their deployment in industrial practice and at the same time in university teaching processes is becoming an everyday part. The use of new technologies in industrial engineering has its merits and brings significant process improvement.

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IMPACT ANALYSIS OF SHALE GAS EXPLOITATION

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Keywords: shale gas, fracking, directional drilling, environmental impacts, system dynamic
Abstract: Shale gas is a type of unconventional gas exploited by the fracking process that has been widely diffused in the United States of America. This example has also led several countries to equate the possibility of exploring gas in non-conventional reservoirs, following the release of the world ranking of technically recoverable reserves in 2013 from the U.S. Energy Information Administration. Fracking is the combination of two complex processes: hydraulic fracturing and horizontal drilling and it can raise important environmental and social concerns. Currently, the methodologies used to assess impacts, when choosing a new energy source, tend to deal independently with the variables that make up these impacts. However, these variables are interrelated and will interact with each other. A systemic analysis is then required to deal with these complex relations. The purpose of this paper is to demonstrate the use of a system dynamics tool to assess these impacts and by this contribute to making better energy-related choices and to support the achievement of sustainable development goals.

1 Introduction

The topic of shale gas has been the focus of several studies in different countries addressing issues such as its availability, development and potential, the politics frame its exploitation and its impacts or public acceptance. The interest on the topic is well justified, given the increasing rate of production in countries such as United States (U.S.), Canada or China [1,2]. In 2013, the U.S. Energy Information Administration [3] released a report, which presented a world ranking of countries with technically recoverable shale gas reserves, i.e. reserves of gas that could be produced with current technology, regardless of the price of natural gas and its costs of production. In this context, countries with the largest reserves would be China, followed by Argentina, Algeria, U.S., Canada, Mexico, Australia, South Africa, Russia and Brazil as tenth in this ranking.

The fracking or hydraulic fracturing technology associated with horizontal drilling has been widely diffused in the U.S. in the exploration of shale gas, supported by public policies, including significant government grants in a learning by doing process. Supposedly, because of this process, great technological advance has taken place, allowing large-scale production, in the early 2000s, transforming the industry of this sector in the U.S. [4]. Despite this unbridled race by the advance in the exploitation of shale gas, the information provided by the U.S. Environmental Protection Agency [5] shows concern with the related human and environmental health, potential effects on the quality and quantity of drinking water, the use of waste water generated by fracking and competition between water-producing activities, especially in areas of the country with low or irregular water availability [6].

The conditions of shale gas exploitation must be closely observed, since several critical factors can directly influence the economic viability of this activity, such as geographic and geological characteristics, protected areas, indigenous and traditional community lands, agribusiness activities, as well as environmental legislation. Particularly remarkable it is the issue of water stress as the lack of water availability can curtail shale development in many places and the final destination of the return water from fracking would be a sensitive point in this process [7,8]. The projection and planning for the use of water resources along with the monitoring of the characteristics and properties of the water produced could then determine its strict use and destination [9,10].

Other concerns surround this exploration, there are many doubts about the economic effects on employment and income, several reports sponsored by the gas industry may have overestimated these effects [11]. In addition to economic and environmental issues, there is great concern about the approval of local society for the shale gas exploitation. Companies realized the need to increase space for further discussion by academics, the public, regulators, and local decision-makers to build more appropriate regulations [12,13].

There is an expectation of the emergence of large shale gas production industries beyond the US territory. Due to this fact, the International Energy Agency (IEA) [14] drew up the so-called Golden Rules for the Golden Age of Gas, which was a report specially developed with shale gas as the focus. Among other relevant information, the IEA [14] stressed the importance of full transparency of measurements and monitoring of environmental impacts, as well as a commitment to local communities, highlighting society's acceptance of this exploration technology. The U.S. Department of Energy (DOE) showed that the use of the high technology of an information system, together with the management of projects, could minimize the undesirable effects of this activity [15]. A careful selection of sites to drill and more effectively identify the most productive areas, can considerably reduce exploration time and provide a lower risk of seismic or fluid displacement between geological layers [16]. The agency values the application of high standards in design, construction and integrity testing of the well, with particular concerns for the risk of leakage in aquifers.

The possibility of using shale gas is already being considered for Brazil on the energy plans for 2050 but, as the Environmental Thematic Committee (CTMA) highlighted, the extension of these plans still depends on further studies to be elaborated [17,18]. Preliminary evaluations of the National Agency for Petroleum, Natural Gas and Biofuels (ANP), coupled with information from the U.S. Energy Information Administration, created the conditions for the launch in 2013 of the Twelfth Round of Bids for Exploration, Development and Production of Oil and Natural Gas in Brazil. The bid offered 240 exploratory blocks in an auction process [3,19]. These regions present a high potential for the generation of electricity with the production from this onshore gas. The chart presents these regions on the overall Brazilian map (Figure 1).

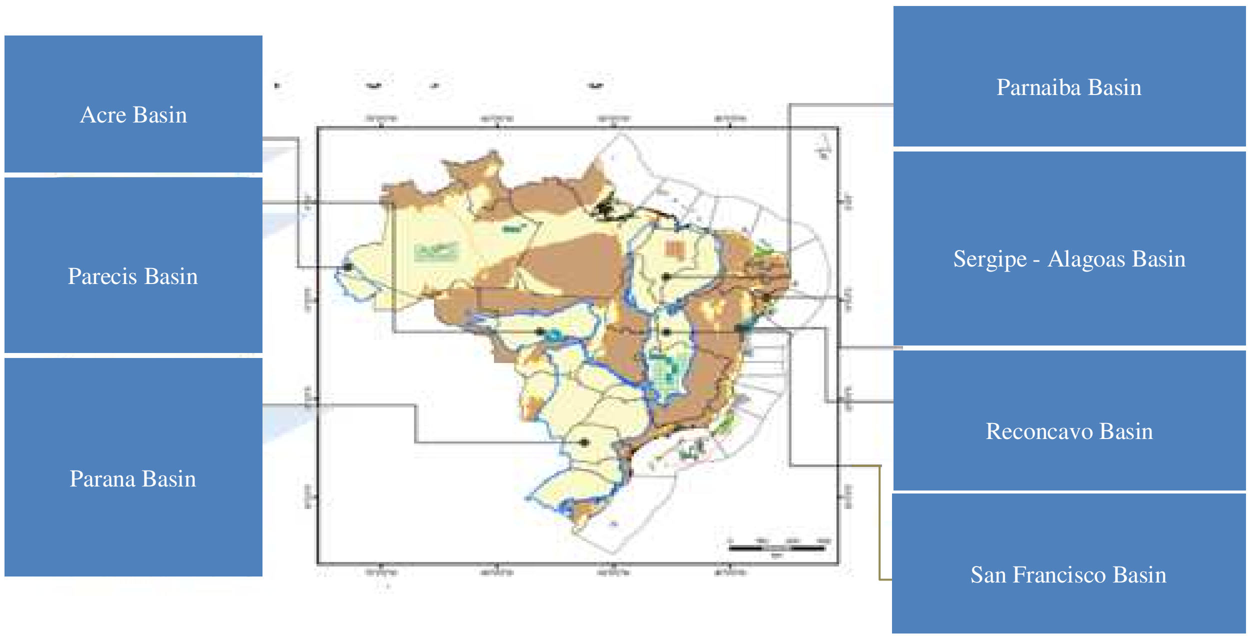

Figure 1 Basins of 12th bidding to oil, conventional and unconventional gas exploitation. Source: ANP 2013[19]

The exploitation of shale gas can be complex and requires a multidisciplinary analysis of the project integrating several dimensions, namely: environmental, economic, technological, legal, and social. If these dimensions would be analysed independently significant impacts should be expected. However, a systemic and integrated perspective for these dimensions should be envisaged to assess their interrelations and potential positive or negative synergetic effects [20]. This is precisely the focus of this study. Firstly, a methodology based on system dynamics for impact assessment of shale gas as an energy source is proposed. Secondly, the methodology will be used for the analysis of the interactions involving the potential impacts of shale gas exploitation by fracking based on the Brazilian case.

2 Methodology

J. Forrester created System Dynamics (SD) in the 1950s at the Massachusetts Institute of Technology on the assumption that the behaviour of a system is generated by the structure of that system. By understanding a system, as being a set of interconnected elements and interacting with each other, to form an organized integer, the dynamics of systems would assess how the parts of that system are related, determining the behaviour of the same, example, a manufacturing plant, an animal cell or an oil base.

In the 1960s, SD moved away from manual simulation and evolved into computational modelling, where Forrester published the classic Industrial Dynamics book [21]. A method of applying SD would be to use modelling as a tool to simulate the behaviour of cause and effect relationships between parts of this system over time [22].

For this research, a critical analysis of the literature was firstly conducted to provide the required context and scientific background for the research. The reviewed literature addressed the topic of shale gas and its impacts at world scale and for the particular case of Brazil. Figure 2 shows the methodological approach for this research.

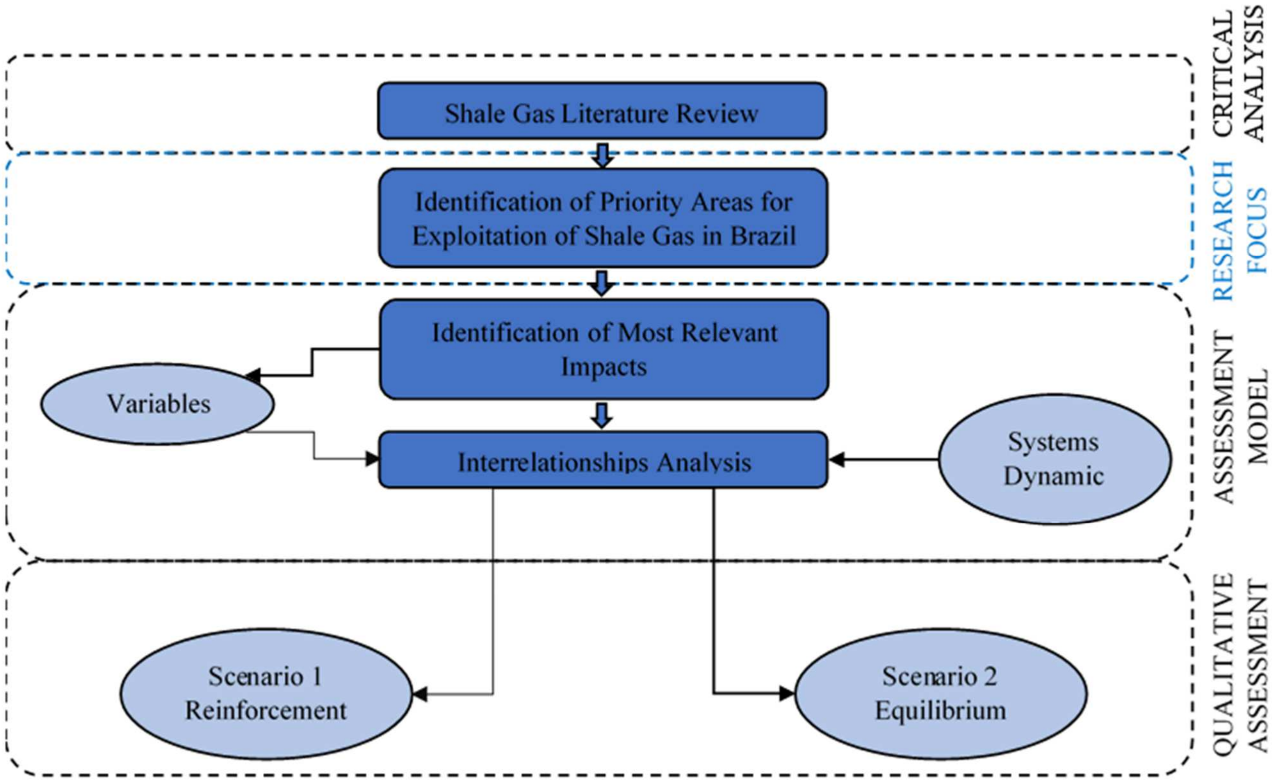

Figure 2 Methodological approach

This literature review allowed us to proceed for the following steps, namely the identification of the priority areas for the exploitation of shale gas in Brazil and the expected impacts of this activity [19]. These impacts were then translated on a list of variables, which were relevant and were considered on the analysis of interrelationships (Tables 1 to 5). The analysis of interrelationships is a key step of the process as it recognizes that the variables should not be handled independently but rather by recognizing their influences, either through positive or negative feedback. As such, the use of system dynamics modelling was considered to be the most adequate approach to analyse the potential impacts of shale gas exploitation. For simplicity and given the information scarcity, a soft or qualitative SD approach was used as the main tool was to assess which variables are affected by each other with no attempt of quantifying the extent of the impacts or flows.

As such, the analysis addressed two mains scenarios:

- Scenario 1 or reinforcement feedback, for which an increase one variable would lead to an increase in related variables and would end up leading to an increase in the initial variable. As such, each variable reinforces the direction of action of the previous variable, either increasing or decreasing output, in what can configure a snowball effect according to the SD Theory.
- Scenario 2 or equilibrium feedback for which an increase one variable would lead to a reduction on a related variable and would end up leading to a reduction in the initial variable. As such, one of the variables reverses the direction of action of the previous variable, which shows cause and effect relationships in what would configure a balancing effect according to the SD Theory.

For the particular case under analysis, a soft modelling approach was used to allow the perception of any system based on the recognition of the cause and effect relationship between variables and feedback structures. The systemic model was developed in a specific software [23] that provides a graphical modelling interface using causal link diagrams.

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Table 1 Variables by economic dimension

Sequential	Variable	Source
1	Costs for society	[24,25]
2	Taxes and royalties	[26,27]
3	Cost-benefit ratio	[25,26,28]
4	Global price of other resources	[29,30]
5	Local development	[26,28]
6	Development / growth of the country	[26,28]
7	Regional energy prices	[31,32]
8	Relative value	[27,29,30]
9	Shale energy supply	[27,33]
10	Shale gas international price	[31,34]
11	Energy demand	[27,33,35]
12	Investment in production	[24,30]
13	Production costs	[24,27,30]
14	Energy of shale	[24,36]
15	Activity gains	[24,27]

Table 2 Variables by technological dimension

Sequential	Variable	Source
16	Importation of technology	[37-39]
17	Importation of equipment	[37-39]
18	Specialized human capital	[28,27,39]
19	Patent registration	[38,39]

Table 3 Variables by environmental dimension

Sequential	Variable	Source
20	Mitigation and treatment costs	[24,25,28]
21	Risks of global contamination	
22	Risks of contamination of surface water	[16,24,33]
23	Risks of groundwater contamination	[16,24,33,40]
24	Production of greenhouse gas (GHG)	[24,33,39]
25	Risks of seismic events	[16,24,33]
26	Safe water availability	[16,28]
27	Water consumption	[16,28]
28	Conflict level by water	[16,39]

Table 4 Variables by social dimension

Sequential	Variable	Source
29	Disorganized displacement of population	[41,42]
30	Number of agreements with science and technology institutions (STI)	[20,39]
31	Number of researches	[38,39]
32	Benefits to society	[25,26]
33	Job and income	[26,38]

Table 5 Variables by legislative dimension

Sequential	Variable	Source
34	Political conflicts	[26,43]
35	Land-use zoning regulations	[41,43]
36	Water resources management	[24,28]
37	Legal conflicts	[26,36]
38	Concession for the shale gas exploration and production (E&P)	[24,27]
39	Regulations	[26,28] [35,44]

3 Results and discussion

From the literature review, the priority areas for shale gas were identified through the auction offered by the ANP, which offered 240 exploration blocks in Brazil, distributed in seven sedimentary basins. These blocks included 110 exploration blocks in New Frontier Basins, which are those whose geological knowledge or technological advancement have not reached the maturity or degree of complexity to reduce the high exploratory risk, and 130 exploratory blocks in Mature Basins, located in regions already under an advanced stage of exploitation, with well-developed infrastructure and specialized local manpower. These Mature Basins included 11 Brazilian states: Acre, Amazonas, São Paulo, Paraná, Mato Grosso, Maranhão, Bahia, Goias, Tocantins, Alagoas e Sergipe [19]. According to Brazilian Environmental Ministry (in Portuguese MMA - Ministério do Meio Ambiente) all the areas made available to shale gas exploitation are above aquifers [16]. Given that connection between the terrestrial surface and the catchment area of the gas is established through a conduction duct made of cement, the possibility of contamination through the duct cannot be excluded. Another possibility of contamination of these aquifers is the existence of natural faults and large scale fractures within or between the formations that may potentially allow flow paths outside the production zone [45,46].

Following the identification of the priority areas for shale gas exploration, the most relevant impacts were

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related to soil, earthquakes, overlapping with protected areas, water resources, the final flowback water and disposal of chemicals [47-49]. From the identification of these impacts, 39 variables were listed, spanning five dimensions: economic, legislative, technological, environmental, and social. These variables were selected from the scientific literature (Table 1 to Table 5) and distributed through soft modelling, elaborating a causal link diagram (Figure 3).

The model presented numerous formations of reinforcement feedbacks and equilibrium feedbacks, as expected by the systems dynamic's methodology. The analysis was limited to 16 of the most representative feedbacks, namely 6 of reinforcement feedbacks and 10 of equilibrium feedbacks to avoid redundancy. As detailed previously, scenario 1 consists of a set of reinforcement feedbacks called **R1, R2, R3, R4, R5,** and **R6** and scenario 2 includes equilibrium feedbacks called **E1, E2, E3, E4, E5, E6, E7, E8, E9,** and **E10.**

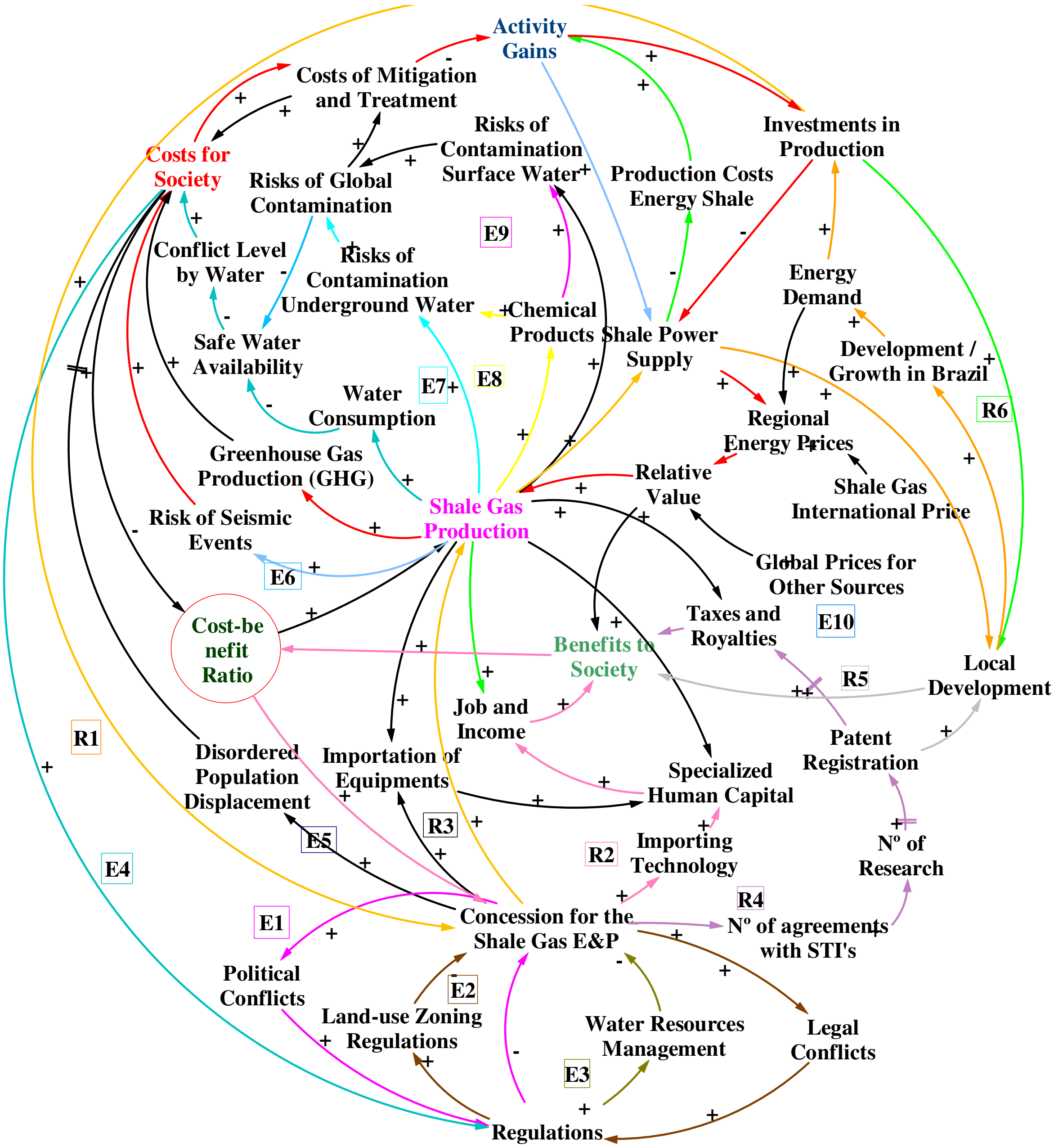

Figure 3 SD Soft Modelling

The combined analysis is represented in Figure 3, which described the interrelation between the set of variables of the model. For simplicity, feedbacks only loops R5 and E8 were chosen to illustrate the systemic thinking of this model and are highlighted in Figures 4 and Figure 5.

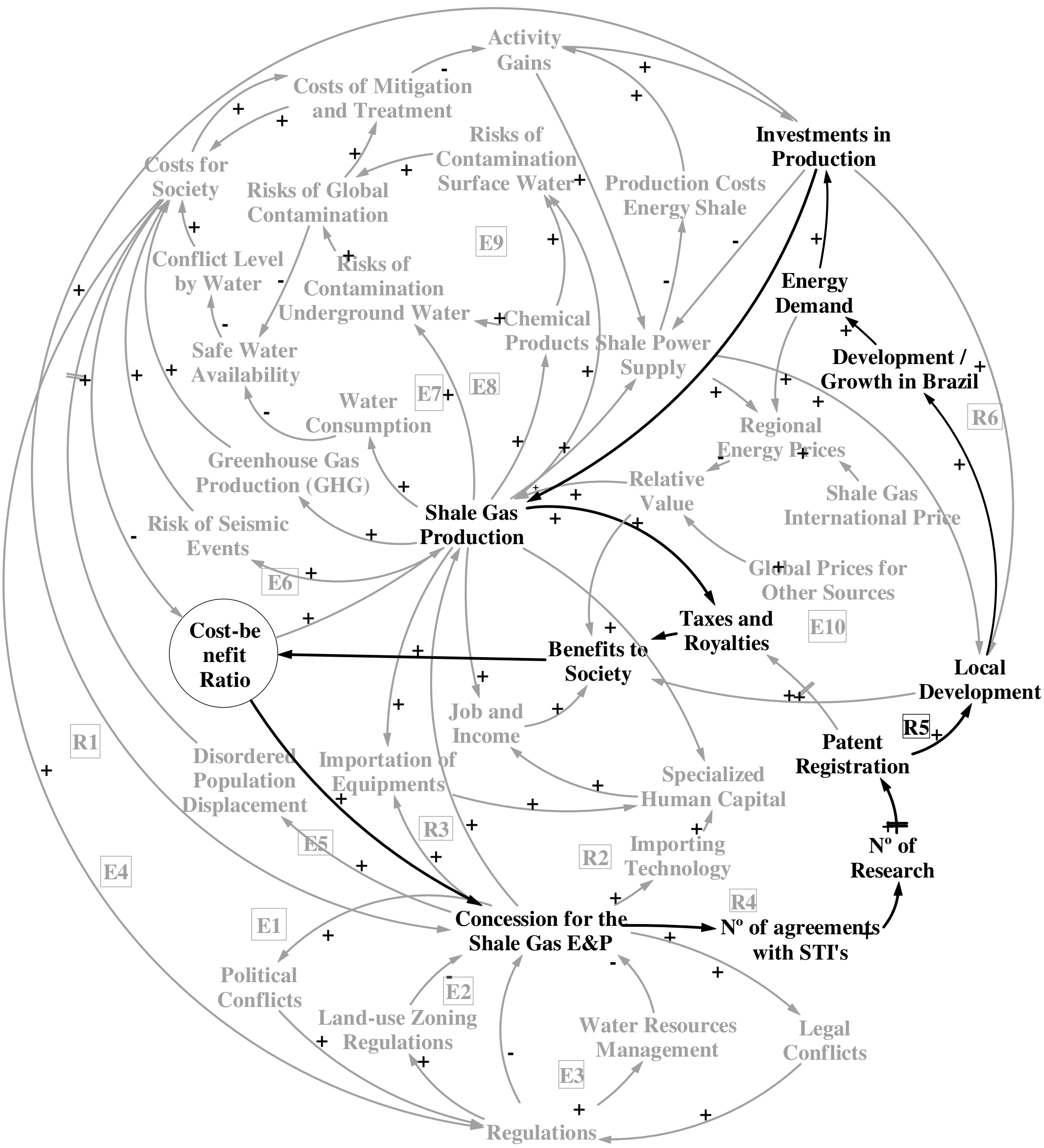

Figure 4 Reinforcement Feedback (R5)

In all loops as well as in **R5**, the analyse can start in any variable, because the feedback is a loop (Figure 4). The increase in the **production of shale gas** generates an increase in the payment of **taxes and royalties** related to this activity, increasing the economic **benefits for society** with the circulation of more currencies. This generates an increase in the **cost-benefit ratio**, giving arguments for the government to increase the number **concession for the shale gas E&P**. The increase in the number of concessions for the shale gas E&P can increment the **number of agreements with STIs** due to the need to increase the **number of researches** related to this new exploratory activity. This expansion in the number of searches may generate an increase in the **number of patents** registered,

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this growth can generate local development, consequently a **development / growth of Brazil**, which makes it possible to raise the **demand for shale energy**, justifying the intensification of **investments in producing shale gas** and leading to an increase on the initial variable **production of shale gas**.

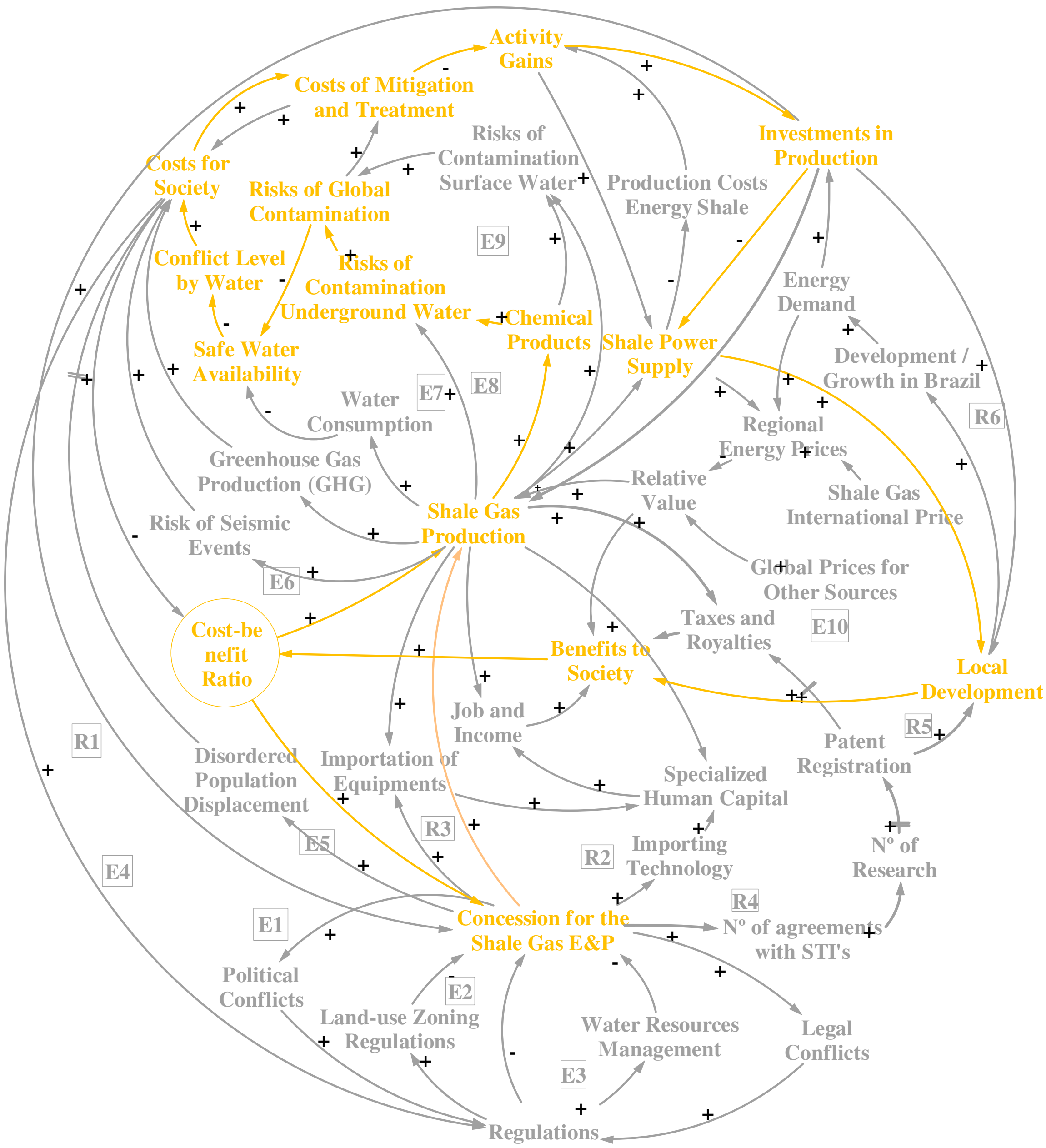

Figure 5 Equilibrium Feedback (E8)

As for the loop E8 and departing again from variable production of shale gas an increase would lead to an increase in the variable's chemicals. In the process of shale gas production, a large amount of chemicals is used in the shale flow. The increase in gas production will result on the need to increase the amount of chemical products used in this shale gas production (Figure 5). Due to the characteristic of this productive process, the increase in this quantity of chemical products also increases the probability of the risks of groundwater contamination. Because of the higher risk of groundwater contamination, a reduction of safe water availability may occur which can intensify the conflict level by water. The conflicts over water may come from other conflicting productive activities of industry, agribusiness, or human and animal consumption. The intensification of this conflict raises the costs for society in the alternative search of new sources of water resources or the rationing of their use. Costs can be intensified due to the heavy use of chemicals in farming. Due to the manipulation of these chemical products, the increasing use of trucks and the arrangement for the flowback, the probability of accidents also increases driving also an increase in mitigation and treatment costs. This would lead to a reduction in the related activity gains and discourage investment in production that would reduce shale energy supply. Reducing shale energy supply would inhibit local development, thereby reducing benefits for society and cost-benefit ratio. As the cost-benefit ratio would be reduced the economic arguments would not be strong enough to justify more concessions. By this factor, the concession for the shale gas E&P would be reduced and consequently, there would be a reduction of shale gas production.

4 Conclusions

Large investments are being considered for the exploitation of shale gas to ensure access to non-conventional sources of energy in different countries. Although U.S. emerges as the main leader for shale gas production, other countries are also analysing the possibility of investing in the sector. However, the reputation of these exploitation activities is highly negative given its foreseen environmental and social impacts. These impacts are discussed globally by government agencies, the scientific community and the civil community, and have already resulted in suspension or a moratorium on this type of activity in several countries.

This study proposed a system dynamic model to analyse the impacts of shale gas exploitation. This approach allowed us to characterize the complexity of activity by presenting the expected impacts as interrelated variables in close loops. From this causal link diagram, it was possible to visualize positive and negative scenarios derived from the possible exploitation of shale gas by fracking. As such, the results can contribute to better decision-making processes in what concerns the evaluation of shale gas as a new source in the energy matrix in different countries, with particular focuses on Brazil.

An independent analysis of all variables cannot clearly show how the economic gains from shale gas exploitation could be offset by the short-, medium- and long-term environmental risks of such exploration. As such, the use of systemic thinking as a management tool can be of great value when dealing with this complex system for the introduction of a new energy source in the country.

For the particular case of Brazil, the regulation can still be classified as fragile and the widespread possibility of forming contaminated groundwater corridors is a matter of concern. Guarani Aquifer, which is the second-largest transboundary aquifer in the world and ensures water supply to four Latin American countries (Uruguay, Paraguay, Brazil, and Argentina), could be strongly affected but shale gas exploitation activities. This water concern underlines the need to properly integrated environmental, social and economic dimensions in the impact assessment.

In summary, the study allowed us to propose and demonstrate a methodology based on soft modelling by system dynamics for impact assessment of shale gas as a new source of energy. Moreover, it opened also important routes for further research, namely the need to move from the soft to the hard system dynamics approach. The hard modelling could be used to better assess the relative importance and delays associated with different loops. This analysis should also contribute to recognize and properly acknowledge the relevance of the impacts under a national and local perspective which should reflect the socio-demographic and economic characteristics of the affected regions.

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INCREASING THE ECONOMIC POTENTIAL OF RECYCLED POLYVINYL BUTYRAL BY REDUCING ITS ATMOSPHERIC DEGRADATION

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Keywords: circular economy, waste, windscreen, PVB, atmospheric humidity
Abstract: The global market for polyvinyl butyral is segmented based on the end-user industry into the fields of construction, transport and electrical engineering. The application possibilities of recycled polyvinyl butyral (PVB) depend on its thorough preparation for use. This paper aims to analyse PVB in terms of its atmospheric degradation, to which it is susceptible, like most thermoplastics. By correctly determining the gravimetric water content, we can more precisely set the test conditions and thus increase its application possibilities to various areas of industry. Precisely because of fundamental properties such as excellent durability, stability and superior mechanical strength, it makes PVB a more advantageous choice for automobile manufacturers. Also, this product protects against infrared radiation and UV, noise reduction. With the growing number of automobiles, together with the change in consumer preference for safety, we expect demand to increase in the polyvinyl butyral market in the following years.

1 Introduction

According to the European Commission statistics reports, it is currently estimated that between 8 and 9 million automobiles are scrapped each year in Europe [1]. In Slovakia, this amount reaches 30,000 automobiles per year. [1] One important aspect directly related to car glass recycling is that laminated glass represents up to 3% of the total material in an automobile at the end of its life.
In Europe, this laminated glass means approximately 480 000 tonnes per year, which come exclusively from end-of-life automobiles [1]. However, there will come a time when each product ends its life and eventually ends up as waste [1,2].

The European Union's priority is to re-use this waste in the production process (Fig. 1). The essence is the application of the circular economy to the production process itself, to the design. It is not that easy with automobile [2,3]. An old automobile contains several dangerous substances such as oil, acid, chemical compounds contained in liquids, such as brake fluid, coolant, airbag detonators, etc. Therefore, the old automobile is included in the category of "hazardous waste" [3]. Manipulation and disposal of an old automobile in Slovakia, according to the Waste Act No. 79/2015 Coll. may be performed only by an authorized processor of waste automobiles.

Figure 1 Circular economy application into automobile industry [2, Authors own processing]

From automobile laminated glass recycling, it is essential to focus on the use of new advanced technologies and thus achieve high purity polyvinyl butyral film. Economic gains are a necessary aspect for processors and customers (Fig. 2), as the production costs of cleaned polyvinyl butyral are between 4 and 5 EUR per kg, while the current expenses for resin PVB are between 9 and 13 EUR per kg [3]. Another important aspect is that it obtains a recycled product with similar technical properties as a resin material that can be used for primary use, in laminated glass production, as opposed to what currently happens with polyvinyl butyral waste [4]. It is essential to use innovative laminated glass recycling technology that will improve the environment for all existing processes, bringing high industrial value and high economic efficiency [2,5].

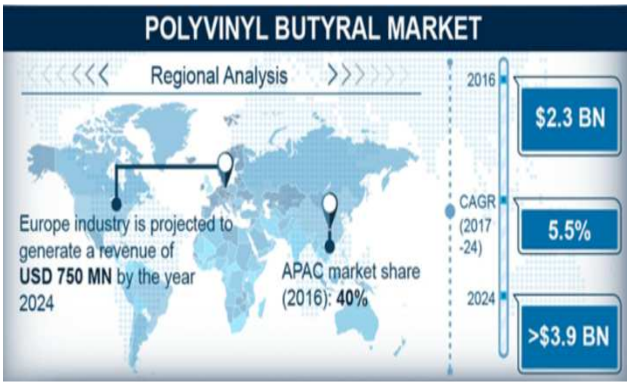

Figure 2 Global forecast analysis for polyvinyl butyral (2016-2024) [4]

The automotive market is a crucial factor in the growth of global polyvinyl butyral in the period 2016-2024 [1]. Polyvinyl butyral is used in the production of laminated glass of architectural and automotive applications. Automobile manufacturers use laminated glass to make roof windows, side and rear windows and windscreens [6]. These laminated glasses are produced by joining PVB (Fig. 3) between layers of two glass panels under extreme pressure and temperature conditions.

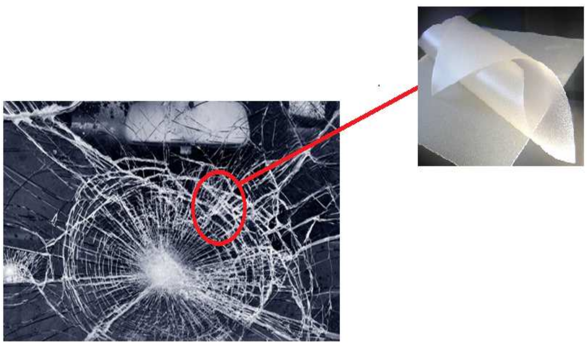

Figure 3 Recycled polyvinyl butyral as safety interlayer in the windscreens [14]

Laminate glass is used in the automobile for safety reasons, as it protects against head injuries in accidents [6-8]. PVB has key properties such as excellent durability, better edge stability and excellent mechanical strength, which makes them a more advantageous choice for car manufacturers. In addition, this product provides protection against infrared and UV radiation, noise reduction, and offers overall vehicle safety [8]. With increasing automobile production, together with a change in consumer preference for automobile safety, demand in the polyvinyl butyral market is likely to increase [9].

2 Research Methodology

The preparation of recycled polyvinyl butyral before use in laboratory and industrial applications is a crucial step [5,6]. Because polyvinyl butyral is loosely stored in "big bags" in the warehouse after recycling, the surrounding moisture is absorbed thereby the material itself. [8]. Recycled polyvinyl butyral contains impurities that were present after the recycling process, due to processing, packaging, storage. Therefore, it is necessary to get the material to the state that is most suitable from an economic and processing point of view before starting work [10]. PVB storage capacities are limited in many countries. Accordingly, some countries were already increasing storage costs and trying to make manufacturers and PVB processors re-use this type of waste and returned it to the production process [11,12].

Figure 4 Recycled polyvinyl butyral [13,14]

The polyvinyl butyral was prepared in the laboratory under the ambient temperature 21 °C and 60% humidity. Characteristics of the determination of the gravimetric water content in the sample of recycled polyvinyl butyral are presented in the Table 1.

Table 1 Characteristics of the determination of the gravimetric water content in a sample of recycled polyvinyl butyral

Weight of the test sample before analysis	6 x 10 g
The temperature in the laboratory drying equipment	60 °C
Sample drying time	24 h
Standard	DIN ISO 11465

Reduction of atmospheric degradation of recycled PVB by gravimetry water content

Polymers materials (including natural polymers) are perhaps the most sensitive materials to changes in chemical structure due to external conditions and the resulting changes, especially in physicomechanical and chemical properties [13]. The most important factors that trigger the chain mechanism of chemical changes in the polymeric material are UV radiation, heat, the presence of oxygen and especially ozone [6]. Mechanical stress and possibly the presence of chemicals, especially organic solvents, usually also contribute to the acceleration of chemical degradation processes [7,9].

The events that take place in the polymer due to these factors are called the general term degradation (or ageing), with a gradual decrease in molecular weight after the initial phase of degradation and, in the presence of oxygen or ozone, the oxidation of polymer macromolecules.

These changes are, of course, undesirable because the polymer is usually degraded and polyvinyl butyral is no exception [11].

The water content of the sample was determined by gravimetric determination of the water content, which represents the amount of water contained in the test sample [7].

The water content was determined as follows, according to mathematical relations [14]:

$$w = (mw / md + mw) . 100\% \qquad (1)$$

where individual quantities mean:

w- gravimetric water content [%]
m_w- the weight of sample before analysis, wet sample [g]
m_d - the weight of the sample after analysis, dry sample [g].

3 Results and discussion

The six randomly selected samples of recycled polyvinyl butyral were analysed. After the separation of PVB itself, the waste still contains glass particles, which reduces the scope of its use. External storage of PVB material is not recommended because moisture and ultraviolet radiation generally degrade the properties of PVB [3,12].

Also, the possibility of primary PVB pollution increases [8]. Due to the sticky and soft surface of the PVB waste film, it is assumed that if improper storage, a lot of impurities will easily stick to the surface and thus reduce the quality in the area of use of the recycled product [13]. PVB storage capacities are limited in many countries. Accordingly, some countries are already increasing storage costs and trying to make manufacturers, respectively [1,13].

The following Table 2 is a summary of the results before and after the measurement. The samples were weighed on laboratory scales of the mark Kern EW N, which work with a measurement sensitivity of 0.001 g.

Table 2 Results of gravimetric water content analysis in a sample of recycled polyvinyl butyral [14]

Sample	Weight before analysis m_w [g]	Weight after analysis m_d [g]	Gravimetric water content w [%]
1.	10.060	10.030	0.500
2.	10.036	10.002	0.500
3.	10.050	10.019	0.500
4.	10.080	10.033	0.501
5.	10.053	10.024	0.500
6.	10.082	10.042	0.500
Average value	10.060	10.025	0.500

From measurements, we observed that the water content of a sample of recycled polyvinyl butyral has an average value of 0.500%. The sample was dried in a laboratory drying equipment at 60 °C for 24 hours (Table 3). For this type of thermoplastic, the essential water content is max. up to 1.5%.

Table 3 Final material characteristics of recycled polyvinyl butyral [14]

PVB-polyvinyl butyral, recycled	
Form	flakes
Colour	colourless
Size	20-30 mm
Material purity	more than 97%
Impurity content	less than 3%
Residual humidity	ca. 1.5 %
The proportion of glass particle content	less than 2%

The test sample meets the prescribed requirements and is ready for further use, given the necessary analyses and processing capabilities of this type of thermoplastic.

4 Conclusions

Long since in 2012, the European Commission adopted strict government regulations on reducing emissions for automobiles. The manufacturers make them switch to the use of lightweight plastics as a substitute for metals. A high percentage of the use of plastic materials (or components) is expected in the future due to the growing demand from consumers, where weight reduction, low consumption and, conversely, high vehicle performance play an important role. With recycled polyvinyl butyral, which we obtain after recycling car parts, we will increase the economic potential of using this commodity on the market. With the eco-design, the manufacturers solve the issue of circular economy in the design of the final product.

By determining the gravimetric water content in the sample of recycled polyvinyl butyral, we reached a value of 1,5%, which means excellent application and processing possibilities for this type of recycled material.

Its most notable features include:

- Toughness;
- Flexibility;
- Neutral colour (possibility to add colour pigments);
- Non-conductibility;
- BAT (Best Available Technology).

Recycled polyvinyl butyral can be used as:

- Binder for materials (metal, inorganic, organic, magnetic);
- Binder for fabrics;
- Matrix for composite materials coatings;
- Adhesives.

By using polyvinyl butyral in various areas of industry, we are thus meeting the EU's goals, where sustainability plays an important role.

Our next research priority is to increase the share of the use of recycled PVB in new products, where we will work following the principles of circular economy and the products will be customized according to customer´s demand.

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FROM PRODUCTION PROCESS TO PRODUCTION SYSTEM – HOW TO MANAGE THEIR INTERCONNECTION – THE CHALLENGE OF TODAY´S ENVIRONMENT FOR COMPANIES

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Keywords: production system, production process, optimization
Abstract: This paper deals with two very important concepts – namely production system and production process and it is also oriented on the way of their optimization. This paper is divided into three main sections. First section treats with production system, while you can find their model of production systems and summarized principles of production system. Second section is oriented on the production process, which is the basic part in production companies and errors in production process have a significant impact on the company. Third main section is about optimization of production process and production system, while there are debated stages of optimization and optimization as the necessary criterion of successful company.

1 Introduction

Mass production is considered as the 20th century production system and optimized production is referred as the 21st century production system. Optimization of production processes is a concept applicable for company at any stage of development. In addition, there are situations where it is simply necessary to optimize production, because otherwise the company will be unprofitable.

If profitability is achieved in terms of cheap labour, cheap raw materials and energy, due to the availability of these resources, then, as prices of these factors increase, production becomes more expensive and thus less cost-effective. The company must reduce costs and apply more efficient production technologies.

The production process of a production company is characterized by a set of technological, handling, control and management activities, the purpose of which is to change the shape, dimensions, composition and quality of input materials and semi-products in terms of required technical and economic conditions of the produced product.

The production process is carried out through production systems, which are defined as a technologically, temporally, spatially and organizationally unified grouping of material resources (materials, energy, production and working resources) and labour forces aimed at the production of a selected range of products. Thus, production is, in essence, a purposeful combination of production factors in order to create material outputs, or services, through a production system.

The complexity of the market environment forces companies to pay particular attention to improving operating conditions. The company must function in such a way that the transformation of inputs into outputs takes place with optimal consumption of production inputs, optimal choice of production processes, resources and with optimal usage of production capacity. But at the same time, it has to enable the company's competitiveness, the realization of economic goals and increasing of efficiency.

2 Production system

Today´s markets place high demands on production. This leads to the necessity to optimize all processes in companies as much as possible and to make quick decisions in company management [1]. Primarily, it is important to organize the company's production system so that production costs decrease and that quality is not only maintained but also increased. In this point of view, the development of such systems in companies is carried out in accordance with different criteria and becomes a priority [2].

The production system is a system to convert demand information into products. This system is composed of humans, machinery and the space provided by normally a kind of building. They are generally called resources, human resource and mechanical resource. Sometimes we also include utility because this is also a type of resource. Using these resources, the production system converts demand information into the products to be supplied.

The conventional view is to regard raw materials or parts as input into the production system, which converts them into the products.

Production management includes the following obligatory components [3]:

- Identification and purpose of goals, where units involved in production should be directed.
- Collection and analysis of information about the current state of the production sectors of company.
- Creation of production system, tasks and programs that are economically justified.

A well-functioning and efficient production system of the company must meet the following requirements [4]:

1. Compliance with the principle of direct production due to the appropriate location of units in the company.
2. Cooperation and specialization of workplaces, respectively production workplaces.
3. Organization of the activities without duplication of links and steps.
4. Maximum simplification of the production structure: the composition of the units should be minimal but sufficient for work.
5. Flexibility and mobility of the entire structure, allowing it to be quickly renewed without being fragmented and adapted to new market conditions and requirements.
6. Development of a production system without bottlenecks, with respect to the proportionality of units, capacity and capacity of machines.

The first feature of the production system is its effectiveness. It is responsible for the ability to produce finished goods or services. By assigning common goals, all elements of the structure act in a coordinated and productive manner. Since the company is complex with different purposes, its production system is characterized as multi-purpose.

The openness of production systems is a feature that makes it possible to exchange various data, materials and even energy with the outside world.

Specific features are the decisive factor in which production will be organized in the company. They are built on different types of relationships between structural elements and are influenced proportionally, with variables such as profit of production system, parallel actions, production rhythm, continuity, and direct flow process.

Model of production system is shown in Fig. 1 and example of production system is shown in Fig. 2.

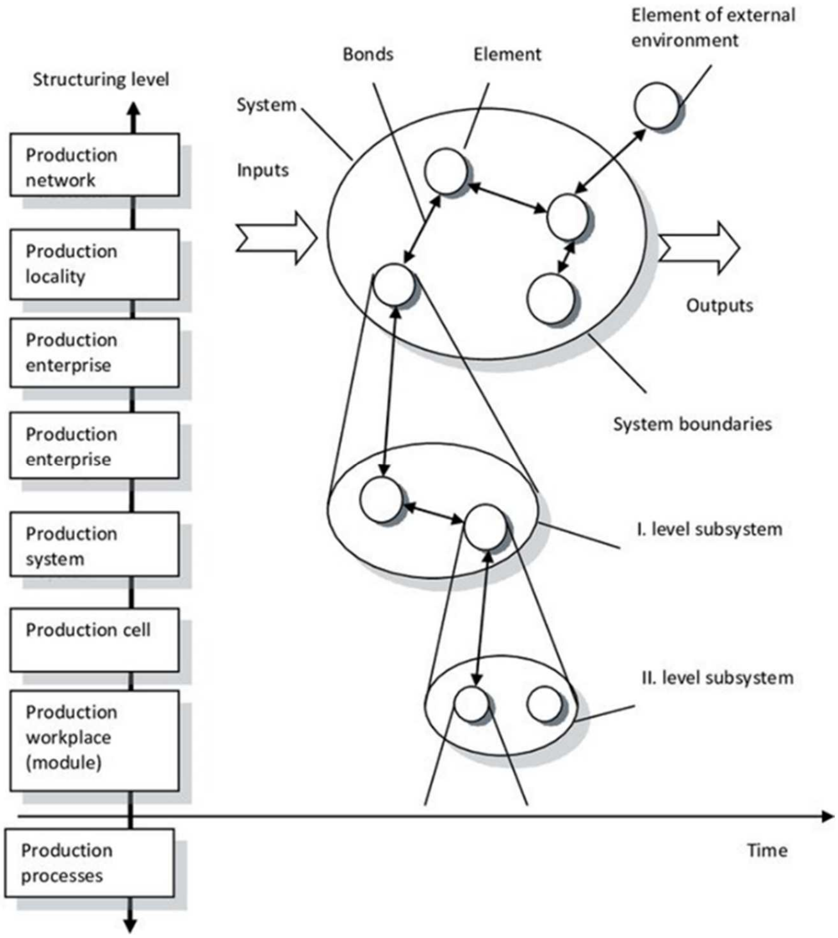

Figure 1 Model of production system [5]

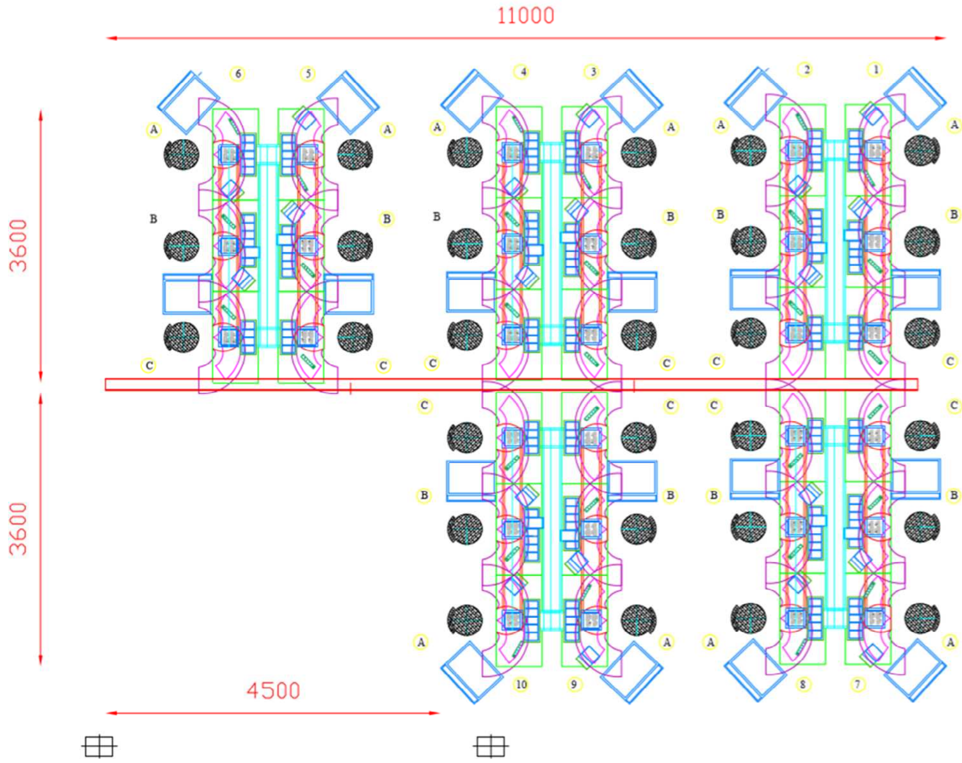

Figure 2 Model of production system

When a system of this class is developed and improved in the working environment, certain characteristics are achieved. The main of these characteristics are [5,6]:

- Reliability – is the system's ability to function continuously despite changes in internal or external conditions to maintain balance even after unpredictable failures in individual areas. Internal reserves and managerial tools regulate this feature. The higher the reliability, the more limited the frequency and range of phenomena that interfere with its stable operation.
- Efficiency – is the property of the production system in the production of finished products or services. The result is displayed when the structure is properly organized.
- Manageability – is an indicator of management effectiveness. Managed is a recognized system that achieves a goal in a given time and material condition.
- Uncontrollable system – is one that doesn´t solve assigned tasks or is poorly managed – one that reaches the goal, but not too precisely, with a basis for temporary or material constraints.
- Level of manageability – is characterized by the proportion of processes that are accessible and not subject to modification.
- Flexibility – is a feature of the system to adapt to new market conditions without losing integrity and efficiency.

We can also summarize principles of production system (Tab. 1).

Table 1 Principles of production system [7]

Principle	Basic characteristics
Proportionality	Proportional productivity per unit of time of all production divisions in the company (workrooms, workplaces) and job positions.
Differentiation	Department of the production process for production of identical products between individual business units (for example, for technological processes).
Combination	Unification of all parts or parts of different production processes of a certain product type within one workplace, trade, production.
Concentration	Performance concentration of certain production operations to produce technologically homogeneous products or to perform functionally homogeneous work in certain areas and at certain workplaces.
Specialization	Forms of labour division in business. Providing a limited range of works, operations, parts and products for each business division.

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Universalization	A particular workplace or production unit is engaged in the production of products and parts of a wide range or in the execution of various production operations.
Standardization	According to the principle of standardization in the organization of the production is meant the development, creation and application of uniform conditions that ensure its best flow.
Parallelism	Simultaneous execution of the technological process on all or some of its activities. The implementation of this principle significantly shortens the production cycle of the product.
Directness	The requirement for directness of motion of work objects during the technological process, i.e. on the shortest route of the product passing through all the stages of the production process without returning to it.
Continuity	Minimization of all breaks in the production process of a particular product.
Rhythmicity	Realization regularly the same number of products.
Automation	Maximum possible and economical release of personal from the cost of manual work based on the use of automatic equipment.

2.1 Production process

The production and economic activities of any company are aimed at production of a certain types of products. The production process is at the heart of the company's production activity. It is the sum of all the people's actions and work tools, which are necessary for the company to produce final product. Fig. 3 shows the basic scheme of production process [8,9].

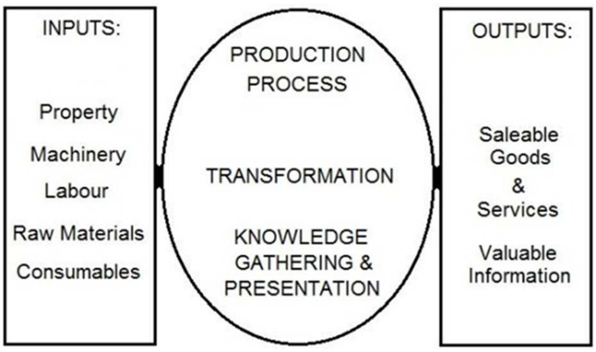

Figure 3 Basic scheme of production process [8]

The production process is based on the technological process. It contains targeted steps that are focused on change and determine the status of the work. The finished part of the technological process, carried out at one workplace by one or more workers, is called technological operation.

Basic technological operations are focused directly on the change of the subject of the work (change of form, molecular composition, state, appearance, size). Examples include crushing, oxidation, extraction, polymerization, etc. In addition to technological core operations, the main product production process also includes a number of auxiliary operations (transport, control, product sorting, etc.) designed to facilitate basic operations [10].

The production process consists of work and automation processes as well as natural processes that usually don´t require work. In factories that produce complex products, production processes are very diverse. In a rational arrangement, it is necessary to classify production processes according to the most important properties.

The economic efficiency of the rational organization of the production process is reflected in the:

- reduction in the product cycle,
- reduction in production costs,
- improvement in the use of tangible assets,
- increase in working capital turnover.

Example of production process is shown in Fig. 4.

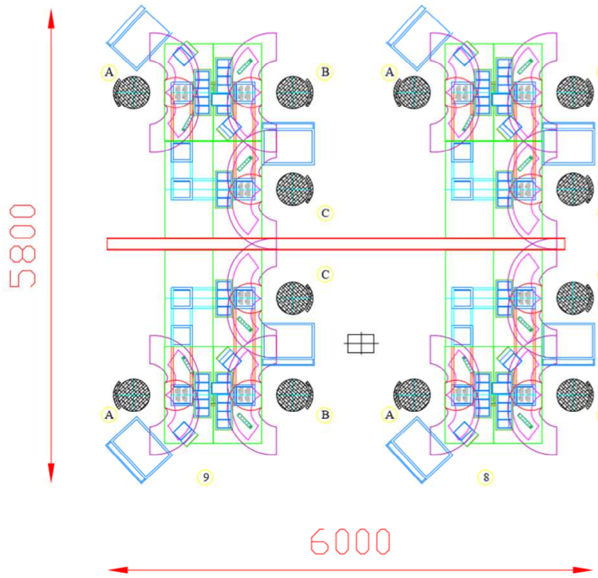

Figure 4 Basic scheme of production process

2.2 Optimization of production processes and systems

In a modern market economy, companies are competitive, if they are one or two steps ahead of their competition. It is about timely assessing the requirements of consumers, respectively doing their job faster and better. It can be done in different ways. One of the ways is the optimization of business processes.

Optimization is the improvement of the business processes with the aim of achieving the best results under appropriate conditions. Optimization is necessary, if [11-16]:

- there is an increase in errors and a worsening in the quality of work,
- it is necessary to increase corporate manageability,
- increase the transparency of their activities,
- there has been a change in the positions like managers or director,
- the state company goes into private ownership,
- the task is to introduce information systems,
- an integrated company is under construction,
- business management has decided to change direction or simply expand production.

This process can happen once in a life cycle, but it can also become a permanent process. However, qualitative implementation of optimization requires certain conditions. First, the availability of internal work resources - experts who are aware of optimization activities. Secondly, it requires the enthusiasm and moral preparedness of team and managers. Third, there is a risk of errors or damage.

After all moral and other preparations, an optimization team will be set up, which includes heads of departments and managers. Those start the optimization; whose classical procedure consists of five stages (Fig. 5):

1. Process description – "what is the process".
2. Process description – "as it should be".
3. Development improvement.
4. Making improvements.
5. Monitoring of improved processes.

The first stage of optimization is the description of business processes. There are two ways to do this at this stage – first describe all the processes currently in progress in the company, or verbally choose the few with the highest priority for improvements and already work with them.

In the first case, after describing everything, team gains a complete picture of the processes in the company and selects the priority. This can be done from priority criteria. The priority criteria are shown in Tab. 2.

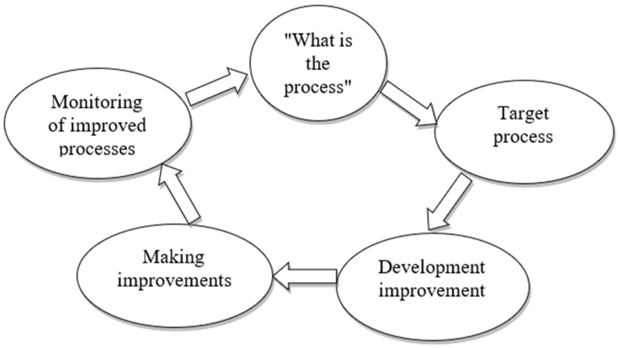

Figure 5 Stages of optimization [17]

Table 2 Priority criteria [1]

Criteria	Characteristics	Impact on process selection
Severity of the process	It characterizes the degree of contribution of the process to achieving the company's goals.	Most important for the selection of business processes.
Problem of the process	It shows the degree of process inconsistency, requires efficiency indicators.	The selection is stopped on the processes, where the difference between current and necessary efficiency indicators is greatest.

3 Conclusion

Nowadays the creation of the product is very difficult. Input has to pass from many levels and hands to become the output. Moreover, the coordination of men, money, material and machine is also necessary. Also, technology is developing rapidly and the adaptation of emerging technology to daily life is very fast. Within this context, production technologies are developing rapidly and parallel to this production instrument's costs are decreased. In this way, producers can make investments more easily by getting current technology. In parallel with industrial development, some parameters such lost time, labour, raw materials must reduce. When considering expected product variety, especially modification on the produced product is a difficult process. Revising of the production system according to the final product is substantially increased the amount of lost time. In addition, in this revision process previously realized investment is becoming inert and this quite increases costs. It is almost impossible the creation of a separate production line for each product in a company which has a lot of variety of products. Nowadays in this needed speed production process, instead of conventional production systems flexible manufacturing systems began to be preferred in the industry.

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OVERVIEW OF THE CURRENT METHODS FOR REDUCTION OF ARTIFACTS IN CT AND MR IMAGING FOR IMPLANTS MADE BY ADDITIVE MANUFACTURING

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Keywords: Computed tomography, magnetic resonance imaging, artifacts, reduction of metallic artifacts.
Abstract: When diagnosing a patient, using computer tomography and magnetic resonance imaging, who has metal implants, it is important to minimize the resulting artifacts and increase image quality. The aim of this review article was to point out standard and advanced techniques for reducing these artifacts. We can reduce these artifacts by a variety of methods such as low-intensity magnetic field scanning, non-magnetic metal implant orientation, and broadening the receiver bandwidth. In computed tomography with dual energy, we can reduce the artifacts using algorithms too.

1 Introduction

At present, in the field of orthopaedics and implantology, implants of various materials such as metals, plastics, ceramics are used in various injuries and bone defects such as fracture fixation, intervertebral disc replacement, artificial joint replacement, fractures of the head bones. First of all, the safety of the patient must be taken into account when diagnosing patients with implants using computed tomography (CT) and magnetic resonance imaging (MR).

The spectral CT is known as Dual Energy CT (DECT) uses two X-ray energy spectra. For this sensing technique, different energy-sensing is used for materials with different attenuation properties. Compared to mono-energetic CT, where we obtain one set of images, itis commonly used DECT, where we get several types of images **Chyba! Nenašiel sa žiaden zdroj odkazov.**. For orthopaedic implants of titanium alloys and stainless steel, there are still concerns about patient safety in magnetic resonance imaging. In some cases, the MR examination was refused for these patients [3].

In the studies of Walde et. al. CT and MR examinations have been found to be more sensitive than conventional X-ray diagnostics [5]. Secondly, these implants impair the visibility of various pathological findings by radiologists, since metal implants create artifacts that obscure surrounding tissues and the space around them [2].

This artifact is limited by the use of different techniques to reduce artifacts created by metal implants.

1.1 *Factors of metal artifacts origin*

Artifacts can be caused by scattering, photon starvation, beam hardening, noise, edge effects, a combination of these factors. Artifacts in the magnetic field can cause serious deviations due to the sensitivity between the metal implant and soft tissue [5]. Metal non-magnetic implants are associated with magnetic field sensitivity, size and shape, but also with imaging parameters.

2 Standard and advanced artifact reduction techniques on MR imaging

When a metal object in the MR is magnetized, it encapsulates its own magnetic field and thereby distorts the external magnetic field, leading to a loss of signal strength. Titanium orthopaedic implants produce smaller artifacts than implants consisting of cobalt-chromium alloys or stainless steel (Figure 1) [2].

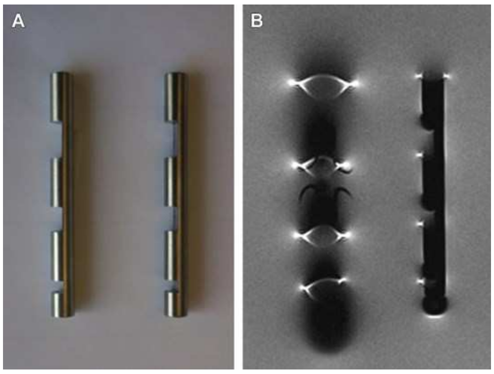

Figure 1 A- on the left side is a metal rod made of stainless steel, on the right side a titanium rod, aB- Demonstration of metal sensitivity imaged at low magnetic field strength [2]

2.1 Low magnetic field scanning

Using low-intensity magnetic field scanning, we can reduce the artifact's intensity. The areas we need to diagnose near small titanium implants can also be scanned with greater magnetic field strength (Figure 2).

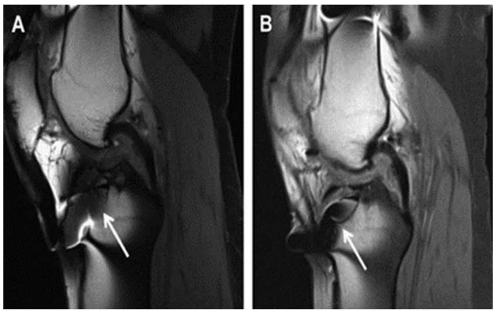

Figure 2 A- patient's knee scanned with intensity magnetic field 1,5T, B – patient's knee scanned with intensity magnetic field 3T [2]

2.2 The parallel orientation of the implant

Artifacts caused by a metal implant can also be reduced by placing the implant parallel to the external magnetic field (Figure 3) [2].

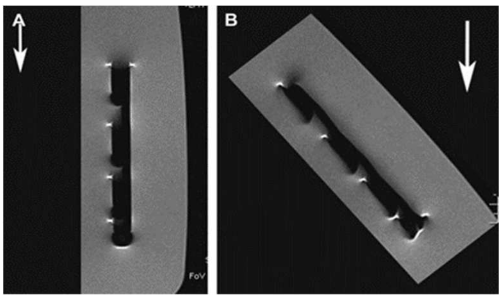

Figure 3 Titanium rod imaged A- parallel with the main magnetic field, B- Titanium rod is shown when rotated by 45° [2]

2.3 Increase receiver bandwidth range and use fast picture rotation tracking with short picture spacing

Increasing the frequency coding strength reduces the magnetic field sensitivity of the metal implant (Figure 4). Using this technique, we minimize signal loss and result in smaller artifacts than with rapid reflection tracking [2].

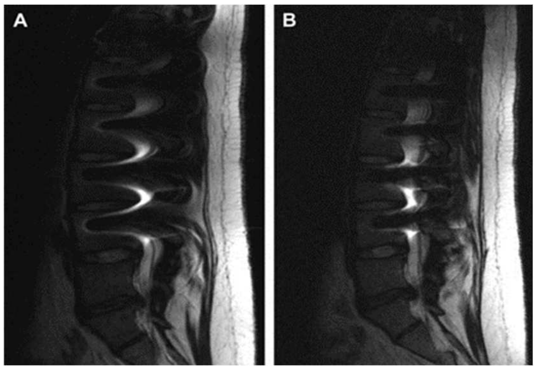

Figure 4 A- Lumbar spine imaged by 130Hz bandwidth B- lumbar spine imaged by 400Hz bandwidth [2]

These methods of reducing metal artifacts can be performed without modification in the hardware interface [2]. Advanced techniques for reducing metal artifacts include various techniques such as view angle tilting, slice coding for correction of metal artifacts, image obtained by combination of variable resonance of multiple images.

3 Metal artifact reduction on Computer tomography

The main causes of metal artefacts are photon starvation (absorption of photons by dense material and subsequent shade behind the implant), beam scattering and beam hardening.

Common techniques for reducing artifacts are to optimize reconstruction and retrieval of parameters by increasing voltage and current, narrowing collimation (narrowing in one direction), reducing cutting thickness, reducing beam width, and using a suitable software filter [1].

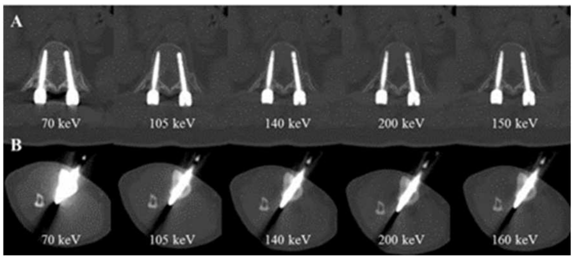

Figure 5 A - vertebral screws, B - tibia screws shown by increasing the voltage [1]

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3.1 Method of increasing current, narrowing collimation and cutting thickness

This method of increasing current reduces photon starvation by increasing the total number of photons in the X-ray beam. By narrowing, we can reduce the width of the scanned partial volume but increase the image noise [2].

3.2 Method of reducing beam width

Many CT scanners use only one-dimensional lattices that block photons in the x, y planes, in which the photons are not blocked in the z plane, and therefore, by reducing the width, It is possible to reduce the variance [8].

3.3 Method of extending the scale of computer tomography

Commonly available CTs use a 12-bit range but some scanners can be scaled up to 10 times more attenuation. With these scanners can show a much wider range to help us isolate these attenuations differences [9].

The use of monographic CT scanners may be useful in reducing the effects of beam curing, e.g. in the evaluation of infections, inflammations of the oral cavity in the implantation of a dental implant, when visualizing the oral cavity (Figure 6) [4].

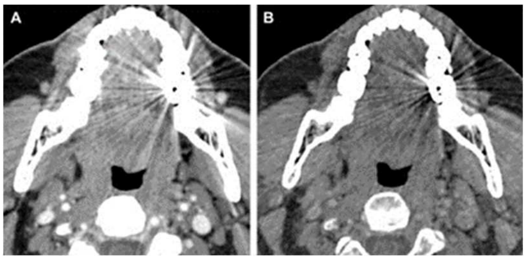

Figure 6 A – CT imaging of the oral cavity at 70keV, B - CT imaging of oral cavity at 100keV [4]

4 Metal artifact reduction by algorithms

CT scanners from companies such as Siemens, Phillips, GE, Toshiba use algorithms to reduce metal implant artifacts [5].

Table 1 Available CT scanners, algorithms for artifacts reduction

	Dual-energy CT	MAR algorithms
Siemens	Dual-source and TwinBeam	MARIS, MAR
Phillips	Dual-layer detector	O-MAR
GE	kV-switching	SMAR, MARS
Toshiba	Dual spin	SEMAR

These algorithms are based on a painting of diagnostic images, painting of images with a previous image, frequency distribution or a combination of these techniques [9]. None of these methods show good results in reducing metal implant artifacts, since they create additional artifacts when scanning, which lead to larger errors in Hounsfield units [7].

In general, a combination of these algorithms and imaging using conventional monochromatic CTs can reduce artifacts (Figure 7), but it also affects the resulting appearance of the metal implants in the images, or creates other artifacts [5].

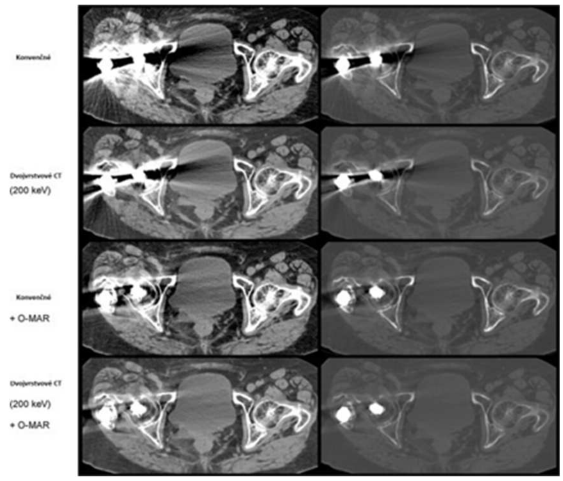

Figure 7 120kVp conventional CT, dual-layer CT, conventional CT + O-MAR, and dual-layer CT + O-MAR [5]

5 Advanced metal artifacts reduction techniques on CT

Advanced techniques for reduction of metal artifacts include diagnostics by mono-energy CT with dual-energy scanner. Beam hardening is one of the main causes of artefacts [2]. This is because the X-ray tubes generate a polyenergetic beam. If all the photons had the same energy, the beam hardening would be the same and would be eliminated because the photon energy would remain the same as before and after the metal implant has passed.

Diagnostic images can be reconstructed using a DECT scanner and subsequent special image processing. Using DECT to diagnose, we can display tissues with the same tissue volume. DECT diagnostics consists of 3 methods. The first method uses two X-ray tubes, one with higher energy (140kVp) and the other with lower energy (80kVp). The second method uses alternating generation of low-energy beam and generation of the high-energy beam. The third method uses a single X-ray tube and captures photons with different energies (Figure 8) [2].

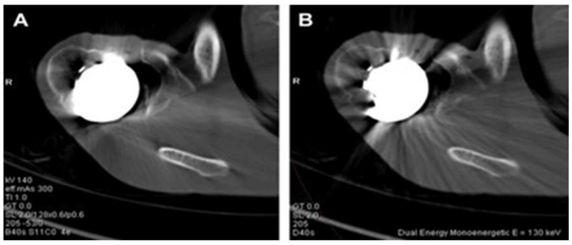

Figure 8 CT images with arm arthroplasty A - diagnostics at 140kVp dose, B - application of 130kVp dose adapted technique [2]

6 Conclusion

The aim of this article was to point out the standard and advanced techniques for reducing metal artifacts by CT scanning and magnetic resonance imaging. These standard and advanced techniques can reduce artifacts on diagnostic images. Techniques for reducing artifacts in MRI examinations include optimal implant orientation, use of bandwidth extension, and lower magnetic field intensity scanning. Standard techniques for reducing artifacts in CT scanning include the optimal orientation of the implant using narrow image collimation and increasing beam width to reconstruct data. Further reduction of artifacts can be achieved by using a dual-energy monoenergetic CT scanner and using various algorithms [2].

In the future, it will be necessary to develop additional algorithms to reduce artifacts. Using these reduction methods, we can better diagnose pathologies and better evaluate images of complications of metal, plastic, and ceramic implants. In another study, I would like to address the issue of artifact occurrence and their reduction in implants made of materials such as Titanium (Ti6Al4V), PEEK (polyetheretherketone), PEKK (polyetheretherketone), composite (PEEK + ceramics, PEKK + ceramics).

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