SUSTAINABLE PRODUCTION MANAGEMENT APPLIED TO COLD FORMING TECHNOLOGIES

Mitica AFTENI
Lecturer, "Dunarea de Jos" University of Galati, Romania
E-mail: mitica.afteni@ugal.ro
ORCID: 0000-0001-8292-1863

Cezarina CHIVU
Lecturer, "Dunarea de Jos" University of Galati, Romania
E-mail: cezarina.afteni@ugal.ro
ORCID: 0000-0003-2296-4751

Gabriel Radu FRUMUSANU
Professor, "Dunarea de Jos" University of Galati, Romania
E-mail: Gabriel.frumusanu@ugal.ro
ORCID: 0000-0003-3038-8758

Viorel PAUNOIU
Professor, "Dunarea de Jos" University of Galati, Romania
E-mail: viorel.paunoiu@ugal.ro
ORCID: 0000-0001-7846-4102

Florin SUSAC
Associate Professor, "Dunarea de Jos" University of Galati, Romania
E-mail: florin.susac@ugal.ro
ORCID: 0000-0002-5890-3195

Abstract: *In today's globalization of businesses, the behavior of the industrial consumers registers a change regarding the products available on market. The industrial consumers become increasingly selective when they decide which components are to be integrated into their final products. The trend observed in business processes is to accommodate the former production processes with the sustainability requirements and recommendations. By considering the markets requests, the manufacturers start to develop sustainable products and associated processes considering the entire life cycle of the product. One of the main jobs of the designers is to integrate in all development and production phases the applicable requirements and finally to come in front of customers with a product which satisfies the technical requirements, on one side, and the sustainability requirements, on the other side, without affecting the capability of the product to be used in a safe way. Safety should be considered in an integrative approach related to producer and user, environmental impact and business efficiency.*

Keywords: *sustainability, production processes, cold forming technologies, strategies, management, rethink, material usage rate*

Classification JEL: *O14, L61, M11*

UDC: *[658.5:621.7.016.3]:502.131.1* ***DOI:*** *https://doi.org/10.53486/ser2026.50*

1. Introduction

In today's market the behavior of the consumers registers changes regarding the requested products. Consumers ask for sustainable products, manufactured in a responsible manner and transparency regarding the manufacturing processes and activities. The application of sustainability in production processes involves designing the manufacturing activities in a new approach which considers as an input data the

requirements related to the optimum usage of the raw materials and an indirect input the evaluation of the potential impact on the environment.

Considering the manufacturing processes as business core activities in this paper, a new integrative approach of the processes was studied considering the R Strategies applied in case of cold forming processes of bearings cages. Machining operations occupy an important place in manufacturing technologies because of their practical usage in giving the final shape to the produced part (Pimonev, 2022).

Based on internal supplier-customer approach of activities developed in an industrial company, a flow diagram which shows the integration of R-strategies in business activities was developed. At the same time, the associated customer and manufacturers strategies were identified according to the final scope of the R-strategies. By considering the *Rethink* strategy applicable to the design of manufacturing process phase, a new technological process - which integrates the usage of the waste amount of material from one piece to produce other smaller pieces - was designed. The analyzed methodology was then used to predict the results in terms of material consumption rate, productivity and impact on the standard cost of the analyzed products.

2. Literature Review

Considering the above-mentioned expectations and requests from customers, the producers have in front of supplementary pressure to move forward from their past production systems to approach and implement the more sustainable systems to assure both the technological requirements and the economic results of their activity. In the paper (Manco, 2023) a sustainability-oriented methodology has been developed and applied for two different production strategies: reuse and remanufacturing strategies which are supposed to maintain the original functionalities of the resources, which promotes the circular economy principles, and new productions, both operated through additive manufacturing technologies.

In the paper (Khaled, 2022) a review regarding the studies focused on the sustainability pillars - Economic Sustainability Pillar, Social Sustainability Pillar, Environmental Sustainability Pillar - was presented. By implementing the strategy of transition from the linear approach of manufacturing activities to the sustainable ones, the industrial companies could obtain: the preservation of the resources, the increase of the total efficiency, the optimum energy consumption, the reduction of the emissions, and the minimization of the carbon footprint, the improvement of water consumption and waste management. One of the most important results is the assurance of health and safety at work for entire company personnel. In the paper (Frumusanu, 2017) proposed an efficiency-based classification of manufacturing workstations. The classification method is helpful in process planning, process programming and workstation acquisition.

In the paper (Otero, 2011) a sustainable production system is generally defined as the manufacturing system, usually product-oriented, designed by introducing environmental criteria (eco-design), taking into account not only the product stage of manufacturing, but also considering all life cycle stages, from the obtaining of resources, to the final treatment and recycling once their function as a product is over. In paper (Trost, 2022) models on sustainable production planning and control processes were presented considering the following indicators: the availability of human capital in the context of socially-oriented

production planning, aspects of employee satisfaction, health & safety, utilization of energy and raw materials can be taken into account in the decision-making process in order to assure an adequate and stable supply. In the paper (Afteni, 2021) a study regarding the monitoring and reassessment of suppliers was developed based on the analysis of the supplier performance which consists limited only to quality and delivery performances.

In paper (Realizing the Transition towards the Circular Economy: Models, Methods and Applications, 2020) over the last decade, the "Value Stream Mapping" has been adapted to include more environmental (waste) indicators as part of a growing. In paper (Ortiz, 2025) a systematic literature review regarding the influence of the sustainability factor in production planning was developed. The study mentioned reveals that economic and environmental factors are used more frequently in production planning processes, while an integrative approach of the three dimensions, including the social sustainability, is missing.

In the paper (Hesran, 2019), a review regarding the operations scheduling for waste minimization was developed, the main conclusion being that the incorporation of sustainability aspects into the operational production scheduling can bring substantial improvements without the need for high investments. A classification based on six criteria that embrace the complexity of this topic is made, and various concerns linking scheduling and waste are identified.

In the paper (Pimonev, 2022), a review regarding resource saving by optimization and the machining environments for sustainable manufacturing was developed. The machining process productivity improvement must increase production volume while reducing resource consumption, leading to a more sustainable process.

The paper (Todos, 2022) presents a study regarding the sustainable business development from the environmental, social and governance criteria perspective and conclude that in the last decades the concerns regarding the reduction of the negative effects of industrial processes rise to new concepts that promote the awareness of humanity regarding the interdependencies between economic, political, natural, and social phenomena, at a global level.

The paper (Rastegary, 2025) concerns a study regarding the Assessment of LEVEL(S) Key Sustainability Indicators was developed showing that the LEVEL(S) framework is an important tool for guiding sustainable building design, offering a structured methodology for assessing environmental performance. LEVEL(S) considers qualitative and quantitative metrics, ensuring that both measurable environmental impacts and broader sustainability considerations are accounted for.

Regarding the analysis and management of cold forming processes, a series of studies were performed to identify and propose methods to control the processes, associated equipment and obtained parts. In the paper (Teodor, 2019), it presents the application of statistical process control to a cold forming process. In the paper (Paunoiu, 2022), was studied the 3D scanning's ability to accurately monitor the die and the corresponding part to reduce design iterations, saving time and resulting in parts that more accurately match to the CAD model.

The paper (Paunoiu, 2024) proposes the kinematic solution for hydraulic press that meets necessary strength requirements and does not involve lengthy assembly or disassembly times. By starting from the limitations of the mentioned literature regarding the integrative approach of the manufacturing activities considering the sustainability indicators in all phases of a product lifecycle, the present paper addresses these points in terms of integrating

the technological criteria, economical criteria and raw material consumption criteria based on R-strategies applied in the case of bearings cages manufacturing processes.

3. Methodology

The present study was developed based on industrial data collected from an industrial company.

Step 1: Design of an integrated flow diagram, figure 1, used then to identify the decisions points and decision owner and the correlation with the identified R-strategies in the case of an industrial product development process and activities.

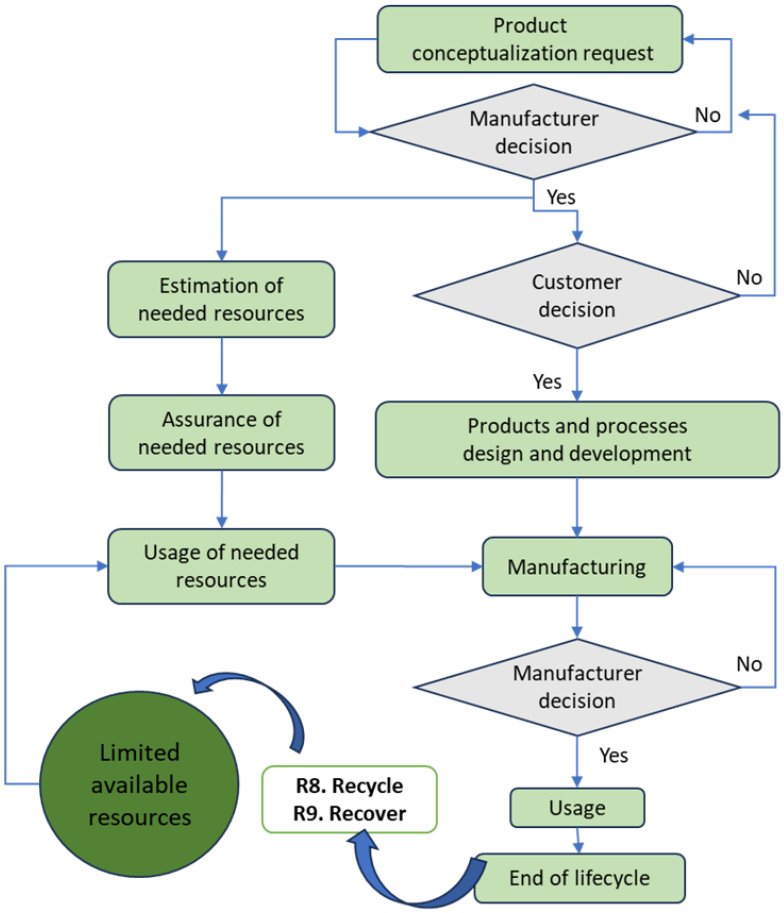

Figure 1. Integrated flow diagram designed for a product development process

Source: *Authors' elaboration*

Step 2: Identification of the correlation among the product development phases, the decisions points, the decision responsible, the R-strategies and the final scope of decisions considering the input and output in product development processes and phases, according to table 1.

Table 1. The correlation among the decisions responsibility, the product development phases and the R-strategies scope

Customer actions	R-Strategy	Manufacturer actions	Strategy scope
Decides what to buy	R0	Specific to quotation phase	

	Refuse	(select what to be produced)	Decrease the consumption of natural resources.
-	R1 Rethink	Specific to design and development phase	
Decide before placing an order	R2 Reduce	Specific to design phase (products and processes)	Extension of the product lifespan.
Decides based on his own experience and know how	R3 Re-use	Specific to design phase (products and processes)	
Decides based on his own experience and know how	R4 Repair	Specific to: - after market phase - manufacturing/assembly phase	
Decides based on his own experience and know how	R5 Refurbish	Specific to: - after market phase	
-	R6 Remanufacture	Specific to: - manufacturing/assembly phase	
Decides based on his own experience and know how	R7 Repurpose	Specific to manufacturing phases	
Decides based on his own experience and know how	R8 Recycle	Specific to: - the end of product life cycle	Materials recycling and energy recovery.
Decides based on his own experience and know how	R9 Recover	Specific to: - the end of product life cycle	

***Source**: Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

***Note:** In table 1 the R-strategies were grouped according to their impact on entire product lifecycle – concept – manufacturing – usage – end of life.*

- *Step 3:* Selection and usage of *Rethink* R-strategy in the case of a defined product. The study was performed using the *Rethink* strategy applied in the case of the manufacturing process for obtaining a bearing sheet metallic cage. The Rethink strategy was applied by considering that the waste material obtained from a cutting process of a part follows to be used as raw material for other smaller parts.

The study was conducted using the data for 1 main product, named in this study P0, from which the waste can be used to manufacture other 2 smaller products, named in this study P1 and P2. The product in which the mentioned part - namely the cage, is used is a spherical bearing composed (according to the picture from figure 2) by: the outer ring, the inner ring, two rows of rollers, the spacer ring and two cages.

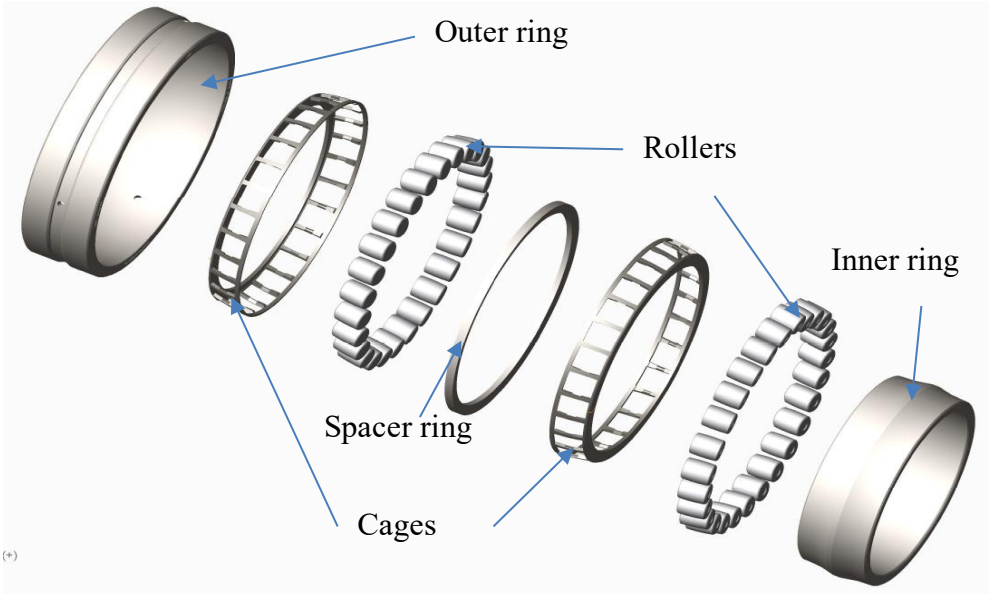

Figure 2. Spherical bearing components *- Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

Note: *From the components of a spherical bearing, the metallic cage was selected for the here-presented study. Two cages are used in a single bearing.*

Step 4: Identification of the manufacturing process steps for a bearing sheet metallic cage. The main manufacturing steps designed and used then in production to manufacture a cage are identified in table 2.

These steps are applicable to product P0, P1 and P2 in case that no Rethink strategy is applied.

Table 2. Manufacturing steps a metallic sheet cage

No.	Manufacturing process steps
1.	Cutting the metallic sheet in strips
2.	Cleaning
3.	Cutting the blank
4.	Stamping the cage
5.	Vibro-smoothing
6.	Cleaning
7.	Face turning I
8.	Face turning II
9.	Vibro-smoothing
10.	Washing and preservation
11.	Packing

Source: *Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

Step 5. Identification of sustainability indicators applicable in the case of cold forming technologies. The approach of cold forming process management from sustainable point of view involves the identification of the indicators that can impact on the sustainability of a product and then on the overall company results.

In table 3 the technological criteria, indicators and the sustainability approach are identified from technological point of view. In table 4 the formula used for computation of material usage rate (MUR) indicator and the obtained results in case of the mentioned products are depicted.

Table 3. Correlation among the technological criteria applicable in cold forming process and the sustainability approach

No.	Description of technological criteria	Associated indicator explanation	Sustainability approach
1.	Technological conditions for cut parts	Minimum distance between two perforations / from the edge of the blank to the perforated hole	Consumption of raw material
2.	Technological form	Efficient use of material	
3.	Optimal design of nesting scheme	Maximum possible number of parts at a minimum longitudinal feed step	

Source: *Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

Table 4. Computation of material usage rate indicators

Blank Diameter [mm]	Material cutting Indicator [%]	Sheet metal strip usage indicator [%]	Sheet metal utilization indicator [%]
	$K_c = \frac{A_0 r}{B \cdot p} \cdot 100$	$K_f = \frac{A \cdot n}{L \cdot B} \cdot 100$	$K_f = \frac{A \cdot n_t}{L \cdot C} \cdot 100$
166	80,5%	68%	64,9%
176	85,4%	76,5%	72,9%
256	41,8%	48,8%	46,3%
	where: A_0 – area of the cut contour, including holes, in mm²; r – number of cutting rows; B – width of the strip, in mm;	where: A – actual cut surface, in mm²; n – actual number of pieces obtained (considering end waste); L – length of the strip or sheet metal, in mm; B–width of the strip or sheet metal, in mm.	where: nt – total number of parts obtained from the sheet; C – sheet width, in mm.

Source: *Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

Step 6. Identification of the process phase to be studied from Rethink strategy point of view. The main steps that impact the consumption of raw material in the case of cold forming process is the cutting process. The material consumption in cutting processes depends on:

- Cut part characteristics, as: size, shape, placement on the strip, fiber direction.
- Die design, as: feed limiting system, additional material usage.
- Cutting process, as: inner and outer cutting edges.
- Cutting edge configuration, as: rounded edges, subsequent sectioning.
- Waste recovery, as: reuse of punched material and strip waste.

Step.7. Identification of the associated flow diagram for usage of waste material from one part to manufacture other smaller ones.

4. Results and Discussion

Based on the above-mentioned methodology and steps, the performed study shows the following results in terms of economic impact of the Rethink strategy on products standard cost and productivity, only by Rethinking the input in the case of cold process forming of bearing cages.

4.1. Material usage rate and recovered material

In table 6 it can be observed the impact of Rethink strategy application in the case of cold forming processes of bearing cages. The manufacturing process flow and associated process time and set-up time are improved by using the waste material from cutting phases of the product P0 to manufacture the cages for product P1 or product P2.

The use of Rethink strategy has the main purpose to predict the amount of material and associated costs saved by Rethink the process. In table 5 the percentage of material recovery can be observed by only reporting the diameter of the blank for products P1 and P2 which can be obtained from the blank of P0 product.

Table 5. Predicted percentage of recovered material

Product	Blank diameter [mm]	Recovered material [%]
P1	166	64.8% [166/256]
P2	176	68.7%[176/256]
P0	256	0

Source: *Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

4.2. Impact of Rethink strategy on process flow

In figure 3 a simplified flow diagram can be observed for the Rethinked process of cage manufacturing phases.

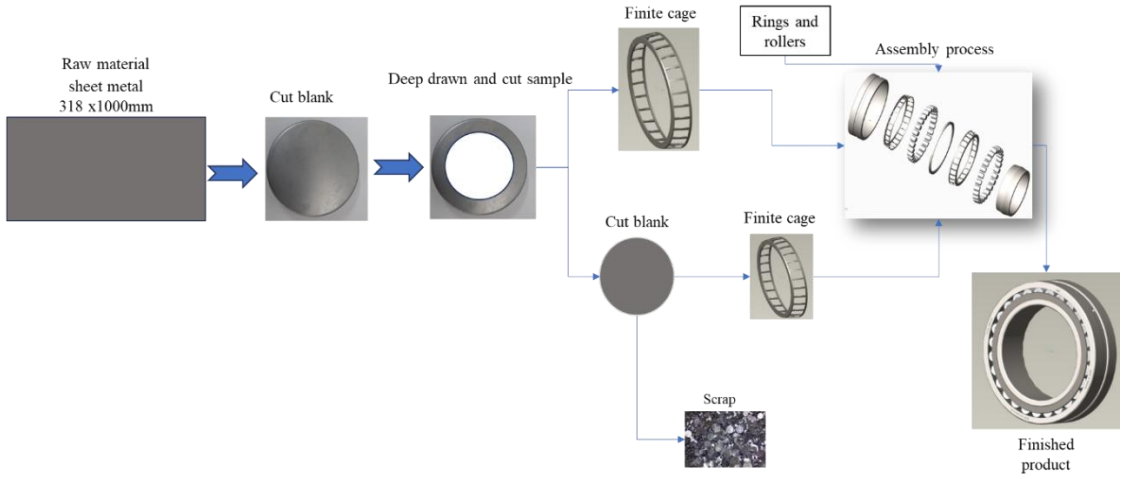

Figure 3. Simplified flow diagram for cold forming process

Source: *Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

4.3. Impact on set-up time, processing time and productivity

Table. 6. Comparative evaluation of the results in the case of Rethink application in cold forming processes of bearing cages

No.		Products				
		P0	P1		P2	
			Initial	R think application	Initial	R think application
1.	Number of manufacturing process steps for product P0	11	11	8	11	8
2.	Set-up time [min]	958	712	573	712	573
3.	Processing time [min]	5.6	2.3	1.9	3.4	2.8
4.	Productivity [pcs /hour]	11	26	31	18	21

Source: *Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

4.4. Impact on production cost

Considering the application of the Rethink strategy in the above-mentioned conditions and products it can be observed in figure 4 that the application of the proposed methodology could have a significant impact on the production cost of P1 and P2 products.

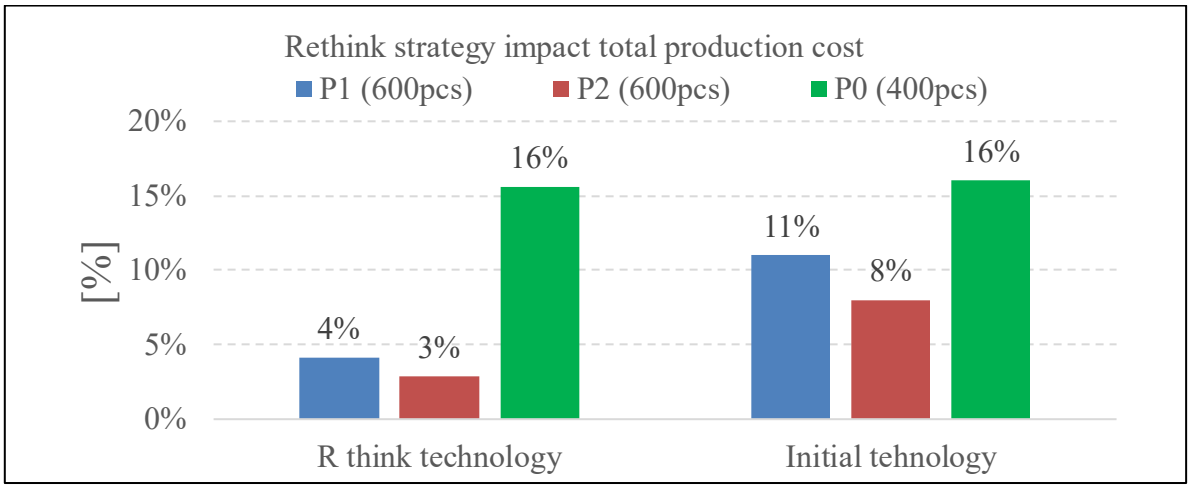

Figure 4. Impact of Rethink strategy application on production cost in the case of cold forming technology

Source: *Authors' elaboration based on industrial data collected from Company "Rulmenți SA", Bârlad*

Conclusions

1. Using the sustainability principles in management of different business processes shows several possibilities for overall results improvement.
2. Sustainability approach of manufacturing processes becomes an important element in the transition from a linear to a circular economy in case of all businesses.
3. In the case of manufacturing processes management, some strategies could be used to achieve sustainability expectations.
   - Re-thinking of the technological processes.
   - Analysis of the main consumers at the successive technological steps (set-up, material consumption, dedicated tools);
   - Combination of the technological steps in a way that can use the same quantity of raw material for different parts.

4. A flow diagram with different decision-points related to the R-strategies was identified and can be used in different phases of a product lifecycle management to assure the sustainability of business and product impact.
5. In the case of cold forming processes an indicator of sustainability can be defined as the material usage rate (MUR).
6. To estimate the material utilization rate (MUR), the shape of the blank and the nesting scheme are considered as main parameters.
7. An integrated method was developed to analyze the possibility of raw material consumption improvement in case of bearing cages design and production processes - blanks cutting phase applying the "rethink R strategy" step".
8. The method was developed with the main purpose of increasing the material usage rate (MUR) by integration of the specific indicators of cold forming processes:
9. Compliance with technological manufacturing conditions,
10. Correlation of the technological shape with next process requirements and technical-economic targets, and optimal design of cutting schemes, and
11. Bringing the amount of consumed material closer to the amount of the finished part.
12. The "rethink R strategy" step was studied in the case of the cutting phase of more bearing cages.
13. The proposed integrated method consisting in using the blank obtained from one cage to manufacture the other smaller cages shows a positive impact considering the following main results:
    - The flow chart is simplified by eliminating 3 main operations: cutting the sheet, cleaning and cutting the blank;
    - The set-up time is reduced from 712 minutes/lot to 573 minutes/lot;
    - The process time is reduced from 1.4 minutes to 1.25 minutes/pcs,
    - The productivity in case of small parts production, considering the yearly average sold bearings in last four years, can be increased by 15÷20%, and
    - The material consumption will be reduced with approximately (65 ÷ 68)%.
14. Regarding future research direction, the obtained results are to be tested experimentally, in a in case of manufacturing other types of bearings cages.
15. The sustainability approaches and principles could and should be applied at different business levels with the purpose of improving the efficiency on long-term.

Acknowledgements:

The *study was performed using industrial data collected from Company "Rulmenti SA.", Barlad based on the existing collaboration between the Department of Manufacturing Engineering from the Faculty of Engineering, "Dunarea de Jos" University of Galati and the mentioned industrial company.*

References

Afteni, C., Paunoiu, V., Frumusanu, G., Afteni, M., Evaluation, monitoring and auditing of suppliers in Supply Chain Management, *International Journal of Manufacturing Economics and Management*, ISSN 2784-1278 ISSN-L 2784-1278, Vol. I, No. 2 / 2021, pp 6-18, https://doi.org/10.54684/ijmem.2021.1.2.6.

Frumusanu, G., Afteni, C., Badea N., Epureanu, A., (2017). Energy-efficiency based classification of the manufacturing workstation, *IOP Conf. Series : Material Science and Engineering* 227 012047 *doi:10. 1088 / 1757-899X/227/1/012047, http://iopscience.iop.org/1757-899X/227/1/012047*.

Coleman, N., Fiorentino, G., Genovese, A., Lowe, B., Mecia, M., Ncube, A., Oliveira, M., Passaro, R., Santagata, R., Ulgiati, S., Langen, S. K., Zucaro, A., (2020) *ReTraCE Project, Realising the Transition towards the Circular Economy, H2020 MSCA-ITN-2018, D2.1 Integrated Assessment of Sustainability Profiles in Circular Production Systems. A Framework towards a comprehensive understanding*.

Hesran, C. L., Ladier, A-L., Botta-Genoulaz, V., Laforest, V. (2019). Operations scheduling for waste minimization: A review, *Journal of Cleaner Production 206,* 211- 226, https://doi.org/10.1016/j.jclepro.2018.09.136.

Khaled, M.S.; Shaban, I.A.; Karam, A.; Hussain, M.; Zahran, I.; Hussein, M. (2022). An Analysis of Research Trends in the Sustainability of Production Planning. *Energies*, 15, 483. https://doi.org/10.3390/en15020483.

Manco, P., Caterino, M., Rinaldi, M., Macchiaroli, R. (2023). A sustainability-oriented methodology to compare production strategies: The case of AM-based remanufacturing, *Journal of Cleaner Production 423 (2023) 138594; https://doi.org/10.1016/j.jclepro.2023.138594*.

Otero, M., Pastor, A., Portela, J.M., Viguera J.L., Huerta, M. (2011). Methods of Analysis for a Sustainable Production System, *Climate Change - Research and Technology for Adaptation and Mitigation, Dr Juan Blanco (Ed.), ISBN: 978-953-307-621-8, InTech, Available from: http://www.intechopen.com/books/climate-changeresearch-and-technology-for-adaptation-and-mitigation/methods-of-analysis-for-a-sustainable-productionsystem*.

Ortiz, D., Gómez-Gasquet, P., Fraile, F. (2025). The influence of the sustainability factor in production planning: a systematic literature review. *International Journal of Production Management and Engineering, 13(2), 250-265.*

https://doi.org/10.4995/ijpme.2025.23067.

Paunoiu, V., Teodor, V., Baroiu, N., Morosanu, G.-A., Epureanu, A., Gavrus, A., (2024). Contribution to the formability improvement in sheet metal stamping by a novel technique to control press kinetics, *Mechanics & Industry 25, 19,* ISSN 2257-7777, DOI 10.1051/meca/2024015, WOS:001248171300001.

Paunoiu, V., Teodor, V.G., Afteni, C., Costin, G., Baroiu, N., (2022). Application of 3D scanning in inspection of the automotive body parts, *Ingineria Automobilului*, ISSN:1842-4074, Issue 62, pp. 9-13, WOS:000782908700003.

Teodor, V. G., Paunoiu, V., Carausu, C., Baroiu N., Costin, G. A., (2019) Statistical control of forming process, *IOP Conf. Series: Materials Science and Engineering* 591 012071, Online ISSN: 1757-899X, Print ISSN: 1757-8981, pp. 1-8, WOS:000562929900071.

Pimenov, D., Y., Mia M., Gupta, M. K., Machado, A. R., Pintaude, G., Unune, D. R., Khanna, N., Khan, A. M., Tomaz, I., Wojciechowski, S., Kuntoglu, M., (2022). Resource saving by optimization and machining environments for sustainable manufacturing: A review and future prospects, *Renewable and Sustainable Energy Reviews* 166 112660, https://doi.org/10.1016/j.rser.2022.112660.

Trost, M., Herrmann, F., Terbrack, H., Claus, T., (2023). Established production planning and control and its enhancement with sustainability, Conference: 37th ECMS *International Conference on Modelling and Simulation*, DOI: 10.7148/2023-0320, (https://www.researchgate.net/publication/373186149_Established_Production_Planning_And_Control_And_Its_Enhancement_With_Sustainability).

Rastegari, M.; Del Pero, C.; Leonforte, F., (2025) Assessment of LEVEL(S) Key Sustainability Indicators. *Energies*, 18, 2027. https://doi.org/10.3390/en18082027;

Todos, I., (2022). Sustainable business development from the environmental, social and governance criteria perspective. *Journal „ECONOMICA*" nr.4 (122), *https://doi.org/10.53486/econ.2022.122.007*,