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Cause-effect Analysis Using A&DM System for Casting Quality Prediction

R. Sika *, Z. Ignaszak
Poznan University of Technology, 3 Piotrowo Street, 60-965 Poznan, Poland
* Corresponding author. E-mail address: robert.sika@put.poznan.pl

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Abstract

The paper indicates the significance of the problem of foundry processes parameters stability supervision and assessment. The parameters, which can be effectively tracked and analysed using dedicated computer systems for data acquisition and exploration (Acquisition and Data Mining systems, A&D systems) were pointed out. The state of research and methods of solving production problems with the help of computational intelligence systems (Computational Intelligence, CI) were characterised. The research part shows capabilities of an original A&DM system in the aspect of selected analyses of recorded data for cast defects (effect) forecast on the example of a chosen iron foundry. Implementation tests and analyses were performed based on selected assortments for grey and nodular cast iron grades (castings with 50 kg maximum weight, casting on automatic moulding lines for disposable green sand moulds). Validation tests results, applied methods and algorithms (the original system's operation in real production conditions) confirmed the effectiveness of the assumptions and application of the methods described. Usability, as well as benefits of using A&DM systems in foundries are measurable and lead to stabilisation of production conditions in particular sections included in the area of use of these systems, and as a result to improvement of casting quality and reduction of defect number.

Keywords: Cast iron, Data acquisition, Castings defects, Exploratory data analysis, Computer application

1. Introduction

Foundry is with no doubt one of the oldest and cheapest and at the same time, the most efficient techniques of metal alloys products manufacturing with the required shape, wall thickness and use properties [1]. It is a technology with a significant impact on the development of the global economy [2]. The application areas are visible primarily in the engineering, automotive, shipbuilding, energy, aeronautics and aerospace industries where, among others, engine pistons, hubs, compressor bodies, turbines and engines, water supply fittings, pumps and pump castings are used. On the other hand, the foundry is also used in artistic or jewellery techniques. The world production of castings amounts to over 100 million tonnes and its increase has been a steady 3% a year. Recognised key players are China (almost 50% of the world casting production) USA (over 10% of the world production) and India (also more than 10% of the world casting production). The global trend also applies to Europe and Poland. The leaders with doubt are Germany, France and Italy. Casting production volume in Poland amounts now to over 1 million tonnes, which is the 6th position among European countries [3]. The tonnage share of cast iron products in the whole machine and device sector ranges from about 50 to almost 90% [1,2]. It is also known that castings still cannot be replaced with another material (while maintaining shape and dimension requirements) with similar strength characteristics including fatigue in very high temperatures reaching even above 1,300°C in case of temperature of the flue gas acting on the turbine blades of the jet engine [4].

From the beginning of the 21st century, the Polish foundry industry has been noting a progressive trend of support through global co-operation of government, R&D centres and foundries with programmes supporting foundry technologies financing – Triple Helix Model (The World Foundry Organization, EU programmes, governmental programmes) [5]. Further to the above, more and more technologically advanced casting production support machines and devices and installed in enterprises. Many of these devices are used to supervise foundry production processes from moulding sand parameters control systems (in case of sand-based moulds casting manufacturing), through mould production (automatic DISAMATIC moulding lines), metal melting control devices to final cast quality control [6-8].

Unfortunately, on the other hand the multitude of the collected data in databases does not always result in improvement of manufactured casting quality expected by the foundry staff and technologists. Following the IT market and its offer in the field of computer systems used to support foundry processes supervision one may come to the conclusion that there are no dedicated simple IT solutions facilitating decision making. For several years, although scientific groups' work in the field of computer-aided decision making in casting production has continued [[11]-[13]], these tools usually indicate solutions within individual problems (e.g. the produced moulding sand quality control – impact on casting defects during the metal-mould contact [10] or the alloy's chemical composition affecting strength characteristics of cast, supercast or treaded from selected casting sites samples – Re, Rm, HB [11]). In real production conditions casting quality depends on many partial processes influenced by a number of factors [13,14]. There is therefore a need to design a global computer system for collecting data relating to casting production and their further exploration to search for cause-and-effect relationships affecting casting quality.

In this paper, the authors present the results of many years of research in Polish and European foundries in the field of designing systems for acquisition and data mining (A&DM). It should be noted that details of the procedures helpful in the design of such systems are presented in the paper [15] and here they will only be quoted. The need to design a computer system supporting fast and intuitive analysis in the field of predicting the causes of casting defects appeared in one of the Polish foundries in 2005. Initially, the system was a response to the Assurance Quality department's chronic problem of laborious and time-consuming analysis. After a successful implementation of the first test version, individual system modules, procedures and functions were over time extended and tested in other foundries, according to the needs and in close co-operation between technologists and management.

2. State of arts

This section provides an overview of the state of the art of foundry processes complexity and a short overview of computer systems classifiable as A&DM available on the market.

2.1. Complexity of foundry processes

Thanks to new possibilities of investment funds acquisition many companies decide to implement not only technological, but also organisational changes. Proper management of the company and its resources aiming at obtaining the best quality-price ratio plays and important part [16]. It is particularly important in the times of Industry 4.0, where customers' requirements and final acceptance conditions are becoming ever more severe [17].

Casting production and the necessary skills set are related not only to liquid alloy preparation but also to mould creation and the connection between them (mainly for iron alloys). In the case of small-sized casting produced in large series the aspects of meeting quality criteria are even more stringent. For individual casting assortments produced high stability of parameters occurring in automated processes is required, including homogenisation of wet moulding sand, the stability of the temperature of the liquid cast poured into the casting mould or strength parameters of the final casting.

In spite of the growing share of computer methods of controlling these processes, individual production departments, technical and administrative sections still use various paper documents. There might arise a problem, e.g. when employees read information in "circulation documents", i.e. original document copies sent to individual foundry departments and sections. Despite the ever – wider scale implementing ISO standards on quality management and enterprise management support information systems of the ERP type (Enterprise Resource Planning), which are to organise information flow within the company, employees often think otherwise: "People speak different languages – it is difficult to communicate" – an experienced technologist, a Polish foundry [14].

Informal documentation, i.e. notes in personal calendars and notebooks at the disposal of masters and/or employees, is often a source of valuable knowledge. Unfortunately, this knowledge is only available to the employees filling in the document. The authors know about cases when employees share the knowledge between themselves: "Sometimes I even make copies" – leading specialist on managing the computer department (Magmasoft®) [14]. The valuable information use only in the area of its own duties is not the right solution, as it is often useful for other groups within the technology-production and control circle. Additional, hand-written information on measurement control, material hardness, non-destructive testing (NDT) documents may be an example. Such documents are also used by technologists in production departments. Their availability should be universal and fast. Often, however, changes made to a document in the workshop file are not available to others. It is therefore recommended that these valuable computerisations are also stored in a publicly available electronic database.

Therefore, in the currently operating foundries, i.e. fairly high competition in the market, it is necessary to collect data which will be used for ongoing supervision and production processes control (knowledge capitalisation). This should be done electronically (databases, database management systems). Problems, which cannot be unequivocally explained with the help of an engineer's knowledge and experience, can be assessed by comparing technologically complex processes and their stability at different time periods for various product ranges manufactured.

Their fast analysis with the use of statistical data as well as data mining issues makes possible to discover new relationships. The above problems to do with data acquisition and collection methods become especially important in relation to final casting quality criteria as specified by the constructor-customer [18]. The first requirement, however, is well-developed and implemented process data acquisition, as far electronic as possible.

2.2. A&DM systems review

Today's growing customer requirements in the area of production processes quality control (external audits), the need for the foundry to quickly obtain information on cost reduction and sales increase as well as the multiplicity of available data sources and the associated increasing number of production parameters encourage foundries to use dedicated computer systems. The analysis of contemporary foundries status quo and literature reports shows [9-13, 16,17] that these are no ready-made solutions directly adaptable to foundry in order to assist employees in discovering new useful knowledge (knowledge discovery, KD).

Currently, rapidly growing computerization is used in almost every foundry department and office. On the one hand, computer systems supporting strictly technological process activities – from design to exploitation – CAx (Computer Aided) are used. On the other hand, planning and controlling ERP-type production systems are being installed in foundries by the number. They are – which needs to be emphasised – an essential element of foundry management in the sense of resource control (material, machinery, staff, money) [19].

Because of the many variants of computer systems naming and classification, it seems reasonable to separate individual system groups that use electronic data acquisition. There are four primary levels [19-21]:

- Level I refers to production processes control (including PLC and CNC control systems); here also included production preparation systems, mainly from the CAx (Computer Aided) class.
- Level II applies to data collection and SCADA visualisation (Supervisory Control and Data Acquisition), i.e. supervision, control and acquisition or HMI, i.e. human-machine interface; this system group is designed to facilitate machine and device operation by operators,
- Level III concerns production management systems and MES tracking (Manufacturing Execution System) – this system group is a link between group II and group IV,
- Level IV includes ERP type (Enterprise Resource Planning)production processes planning and control systems.

The authors suggest to maximally integrate the first three areas into A&DM computer system supporting production processes analysis also with the possibility of including statistical methods such as SPC (Statistical Process Control) as well as advanced data mining methods (computational intelligence methods for estimation, prediction, classification, grouping and discovering rules). It should be noted, however, that the number of parameters representing the causes of anomalies affecting the final casting evaluation can be undefined. To a large extent it depends on the possibilities and methods of their measurement and identification, as well as knowledge about the processes sequences and on the analysis and forecasting procedures. All these contribute to the quality control system chosen by the foundry.

Taking the above into account, we have analysed of systems available on the world market [19-22], which apart from data acquisition also enable their exploitation analysis with the use of statistical methods and artificial intelligence. Results are presented in table 1.

Table 1.
Evaluation of selected systems in terms of A&DM task realisation in foundries

System evaluation criterion	A&DM Support System				
	QDA	WH	CXS	STA	EM
Integration with devices and measuring instruments	5	5	5	3	2
Data acquisition with the possibility of pre-treatment and cleaning	3	3	3	2	1
Clear charts generation	5	5	4	4	4
Detailed reports generation	5	4	4	3	3
Access to basic statistical methods	5	4	4	5	5
Statistical process control with the possibility of preparing a pilot sample	4	4	4	5	4
System installation simplicity	3	2	3	5	5
Intuitive operation	4	3	3	2	2
Extensive help regarding A&DM issues in any foundry areas (sections)	2	2	2	0	0
Co-operation with an external database (supplemented by technologist)	2	2	2	0	0
Modular concept of a group of processes responsible for the casting production stage	2	1	0	0	0
Intuitive grouping of parameter value according to one assortment	2	1	1	0	0
Quick casting quality cause and effect assessment	2	2	2	0	0
Assurance Quality Support (e.g. quick access to the electronic atlas of defects)	2	2	2	0	0
Summary (number of points out of 70)	41	40	39	29	26

Legend: WH – Wonderware Historion by ASTOR, QDA – Quality Data Analysis by TQMSoft, CXS – CX-Supervisor by OMRON
STA – Statistica by StatSoft, EM – Enterprise Miner by SAS

The 5-point Likert scale was used for evaluation, and the results were obtained from own analyses and five primary conversations with European foundries staff (three Polish and two foreign). The criteria were consulted with foundry management staff in terms of functions useful to A&DM system users. The below criteria were generated with each foundry separately using the brainstorming method. Finally, criteria that were confirmed at least in three foundries were added to the table – ultimately, there were 14 factors verifying the system. The criteria were differentiated by authors according to the scale [0-5] according to their own experience in a specific system.

As can be seen from the above, the essential tasks of data acquisition and analysis with the possibility of using SPC methods are practically implemented (more or less intuitively) by each of the systems. The QDA system received the highest score with Wonderware Historia's and CX-Supervisor's similar ratings. Statistica and Enterprise Miner are useful tools for implements tasks in the field of statistics and data mining. Additionally, they require basic knowledge of mathematics and statistics ND Data Mining methods (artificial neural networks, approximate sets theory, genetic algorithms, etc.).

In each of the 5 cases, there is a problem at the stage of data acquisition [23,24] and process grouping according to the foundry characteristic departments (sections), which could significantly increase the user intuition in generating combinations of variants in the course of production parameters. In addition, A&DM systems should have the functionality of quick cause and effect casting quality evaluation and of casting defects statements. A useful option would be to view their detailed description (scheme, location of the defect, used destructive/non-destructive testing methods qualifying castings per existing defects), as well as viewing the history of process parameters, which may affect the final cast quality. And this is where the direction of A&DM systems is highlighted – well developed data acquisition and help in discovering new, useful knowledge with the help of intuitive, simple and proven procedures. In another paper, the authors describe in detail the procedures to be followed when designing an A&DM systems for complex production processes in foundries. These are [15]:

- [DAp-1] Hint and data matching algorithm
- [DAp-2] Data collection sequence
- [DAp-3] Data collection chronology
- [DAp-4] Preliminary estimation of data collected
- [DAp-5] Data normalization
- [DAp-6] Initial process evaluation

The authors' experience shows that in the case of casting data analysis, two types of analyses dominate alternately, depending on the specific need. In the first case, stability of selected technological processes in relation to accepted tolerance limits is assessed. When these limits are not set by an authorized technologist, there is immediately a warning about the need to make additions. Specific process states (above the accepted norm, or tolerance) can be referred to feedback e.g. from the maintenance department as to the stability of functioning of regular, newly purchased or modernized machines and devices, as well as to the final quality of cast products expressed by the faulty casting fraction.

The second case refers to a reversed situation, when based on the available knowledge about defective castings factions (inconsistent with the client's requirements and not sold – Class A), the history of processes responsible for creating a series of castings in which defects were discovered (cause-effect analysis) should be reviewed. The results of this approach were presented in the research part (the most common case related to the discovery of new, useful knowledge).

3. Research methodology

The paper clarifies the scope of applicability and usefulness of existing A&DM methods against the background of the topography of information sources in a typical iron alloy foundry. It was proposed to group the casting production processes referring them to four main sections: MOULD, METALLURGY, POURING, QUALITY. These sections do not close the set of parameters that can be subject to acquisition during casting production, therefore, at the stage of designing the A&DM system, as part of the supplement, an additional area (section) was proposed: ANOTHER.

Scientific research conducted by the authors concerned primarily the design of a foundry database according to the author's methodology of acquisition and data mining (15). This methodology is schematically shown in Figure 1. The implementation of this methodology took place simultaneously in several foundries using the A&DM database system.

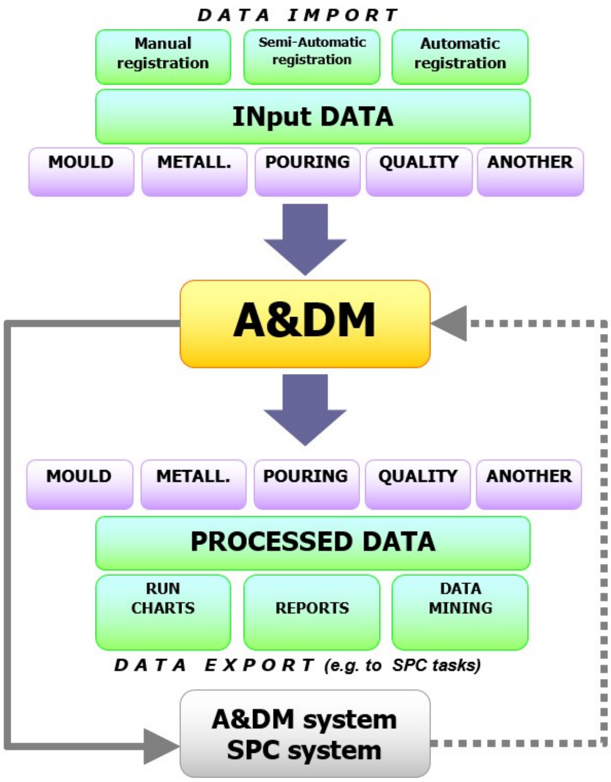

Fig. 1. A&DM system conception

This article shows the possibilities of data analysis based on selected assortments for grey and nodular cast iron grades (maximum 50 kg casting, casting into disposable wet moulding sand, poured on automatic moulding lines). Classic mathematical statistics was used to perform analyses in the area of individual section ("1-Parameter" analysis and "1-Process" analysis / "Many-Parameters" analysis) for one selected foundry assortment meeting the above criteria (working name CB3A100325). At the same time, detailed test results for a selected assortment made of 25 kg spheroidal iron (Table 2) are described in this paper. The research took into account the specificity of casting technologies, possible data sources, ways of obtaining the data, and above all an overview of the offered systems for acquisition and rapid analysis of production processes (discovering useful knowledge).

Table 2.
Summary of information on the analysed castings

GENERAL INFORMATION REGARDING ANALYSED ASSORTMENTS		
Green sand composition (average values): – Regeneration green sand (94%), Sand (1,8%) – Bentonite Special (0,45%) – Coal dust (0,05%) – Water (3,7%)	Tolerance limits: – Moisture M (2,75-3,46 %) – Permeability P_M (160-230 10^{-8}*m^2/Pa*s) – Compressive strength C_S (0,14-0,21 MPa) – Compactability C (36-44 %) – Temperature T (20-50 °C)	
Chemical composition of Alloy (average values): – C (3,49 %) – Si (2,01 %) – Mn (0,58 %) – P (0,12 %) – S (0,07 %)	Tolerance limits: – C (3,45-3,55 %) – Si (1,8-2,05 %) – Mn (0,5-0,6 %) – P (0,09-0,22%) – S (0,03-0,12%)	
Cast iron alloy composition (average values): – Internal scrap (47,9%) – External scrap (27%) – Coke (11%) – Pig iron (8%) – Limestone (4,5%) – Graphite (1,5%) – Ferrosilicon (0,1%)	Tolerance limits: – Pouring temperature T_{pour} (1330-1420 °C) – Pouring time t_{pour} (10-16 sec.)	
GENERAL STATISTICS OF DATA USED		
Analysis type	Effect Analysis	Cause Analysis
	21.05-28.12.2018	23.08.2018
Number of collected data records (M, P_M, C, C_S, T,)	2826	15
Number of collected data records (Chem. Comp.)	6456	30
Number of collected data records (T_{pour}, t_{pour})	1 331046	6 500

4. Research results

In the particular case, upon the Assurance Quality department's request, the QUALITY database was first analysed in terms of the number and frequency of emerging defects on the raw casting Surface from the 21st of May 2018 (assortment CB3A100325: ductile iron, net casting weight 25kg). During the assessment the Polish standard PN-85 H-83105 was used and W226 (sand holes), W202 (blows) and W101 (mechanical defect) were finally selected as the most frequent in occurrence in the analysed period. Also, an electronic atlas of defects (continually expanded since 2012) is available for viewing with photos, defects' descriptions as well as quality controllers' notes which already at this stage may suggest some solutions to improve casting quality. It was suggested in order to widen the atlas of casting defects to additionally introduce defects in 3 classes: A – high occurrence, B – medium occurrence and C – low occurrence. Thanks to this and after agreeing with the customer, some class B defects may be released for sale with the same or modified configuration of customer acceptance conditions.

Figure 2 presents a column chart (screenshot from the original A&DM system), which shows the W226 defect (sand holes) and additionally – for comparison two other most frequent defects for this assortment in 2018, i.e. W202 (blows) and W 101 (mechanical defect). The chart present the weeks with the highest share of all 3 A type (high occurrence) defects within the company (internal defect). This disqualifies the castings for sale. Separately, there are defects released as defective and reported as complaints (external defects) after some time.

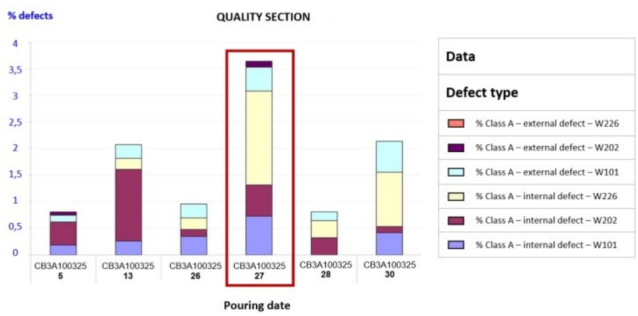

Fig. 2. Chart generated by the A&DM system regarding the key 3 assortment defects for several weeks

Figure 3 shows the week with the largest number of defective castings and the areas presenting the fraction of defects with the largest percentage share. Based on the standard [25], the reasons for the three most common defects occurrence were given (Table 3), which should be carefully analysed along with the production technology specification for the specific assortment and the manufacturing processes history.

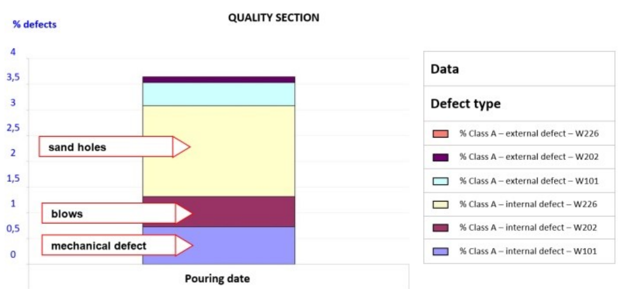

Fig. 3. Chart generated by the A&DM system on the percentage share of the 3 key assortment defects for 1 week

As can be seen, some mechanically damaged castings were noticed by the controller. This defect should not be associated with the production process and will be omitted in further analyses. Having an insight into the quality structure of the analysed casting and knowing the potential defect's causes the production process history in specific sections: MOULD, METALLURGY and POURING should be examined. Charts generated for the latter two sections showed that almost all the parameters analysed were within their tolerance limits.

Table 3.
Data summary on the analysed casting cases

Sand holes (W226)
- too high mass looseness,
- mould or core scorching,
- inaccurate mould blow before pouring,
- not securing overflows and inflows from getting dirty,
- keeping the mould too long before pouring,
- too low strength of core or coverage.

Blows (W202)
- too high mass looseness,
- mould or core scorching,
- excessive humidity or hygroscopicity of the mass,
- too low mass permeability,
- excessive content of gaseous components in mass or protective coating,
- excessive mould or cores beating,
- use of excessively moist cores,
- insufficient material degassing.

Mechanical defects (101)
- careless casting transport or storage,
- damage to the casting when knocking out,
- improper or careless removal of inflows, overflows, superflows and other technological surpluses,
- incorrect design of the filling system.

In the Metallurgy section, the chemical composition of the alloy, the chemical elements of which did not show quantitative deviations from the norm, was analysed (Fig. 4).

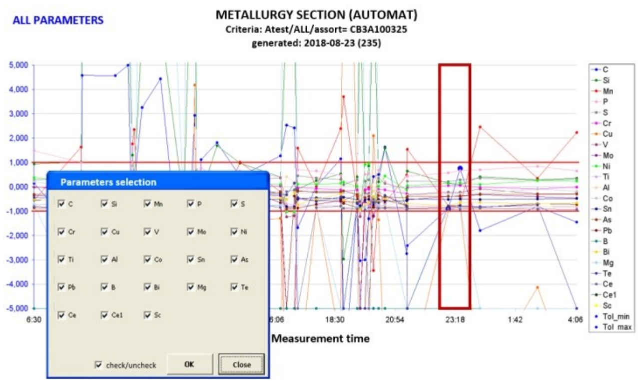

Fig. 4. Run-Chart diagram of the detected dependencies in the METALLURGY section with a potential impact on the W226 and W202 defects

In the Pouring section these were: T_{POUR} (pouring temperature), t_{POUR} (pouring time), $T_{INITLADLE}$ (initial temperature in the ladle) and A (power level of the transformer supplying the flooding furnace inductor). The T_{POUR} parameter values slightly exceeded the upper and lower tolerance limits (Fig. 5). There were several of them and taking into account potential defect causes, their participation was omitted in further analysis.

In the Mass section (Figure 6 – values after data normalisation [15]) significant dependencies were discovered. These dependencies could have some impact on the W226 as well as W202 defects occurrence. On the one hand, too high moulding sand moisture (the recorded value is beyond the upper tolerance limit) could result in a blow defect, whereas the fact of low mass permeability may cause a sand hole defect.

Fig. 5. Run-Chart of the detected dependencies in the POURING section with a potential impact on the occurrence of the W226 and W202 type defects

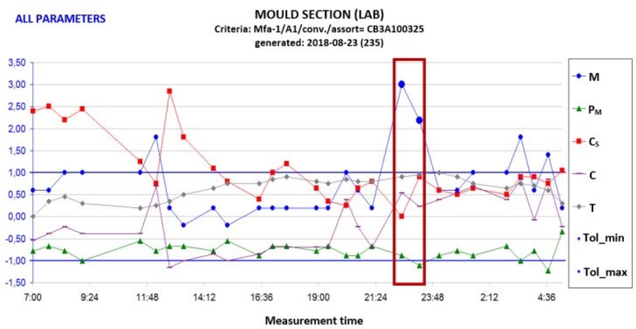

Fig. 6. Chart of the detected dependencies in the Mass section with potential influence on the W226 and W202 type defect

5. Conclusions

The paper presents specific features of the foundry industry in terms of well-developed data acquisition and discovering useful knowledge at the stage of relatively simple fast analyses. Data visualisation as well as understanding parameter relations are an important aspect of assessment of A&DM systems usefulness for computer-aided production processes.

The methods developed within the A&DM system for the analysis of properly collated and error-free data provide valuable knowledge regardless of the user's acceptance level of the system in the foundry. However, user expectations, the level of detail and generalisations at the stage of data visualisation may vary.

The A&DM system is dedicated to management and, above all, to employees whose responsibilities are directly related to production, i.e. controllers and masters. They are a kind of monitoring related to the scope of their responsibility for the process and give the possibility of almost instant analysis of variability of parameters derived from selected data sources. The approach proposed by the authors was appreciated during foundry audits by new customers, especially foreign companies. It was noticed that visualisations made with the use of the A&DM system are the starting point for formulation of hypotheses resulting from observation and summaries comparison as well as graphs.

The authors' research shows that the benefits resulting from dedicated A&DM systems implementation will be visible in the coming years, especially in the era of Industry 4.0. Firstly, however, attention needs to be paid to the potential data sources in the foundry and a proper development of data acquisition along with the A&DM system configuring. Such a solution may accelerate the improvement of parameters' stability particular foundry sections without the need of expensive advanced production processes supervision systems, often hardly accepted by staff.

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References

[1] 49th Census of Word Casting Production. (2015, December). Modest Growth in Worldwide Casting Market. Retrieved October 22, 2018, from http://www.globalcasting magazine.com.

[2] Dańko, J. & Holtzer, M. (2006). The State of Art and Foresight of World's Casting Production. *Metalurgija.* 45(4), 333-340.

[3] Foundry Chamber of Commerce Catalog, 2017.

[4] Yokokawa, T., Koizumi, Y., Harada, H., Suzuki, T., Aoyagi, T. & Kimura, T. (2008). Estimation of metal temperature at failed part of turbine blade for civil jet engine. *Journal of the Japan Institute of Metals*. 71(9), 693-698.

[5] Choi, S., Yang, JS. & Park, HW. (2015). The Triple Helix and International Collaboration in Science. *Journal of the Association for Information Science and Technology.* 66(1), 201-212.

[6] Fedoryszyn, A. (2007). Assessment of systems for mechanisation of casting production. *Archives of Foundry Engineering*. 7(3), 83-86.

[7] Perzyk, M. and others (2000). *Foundry*. Warsaw: Scientific and Technical Publication.

[8] Ajax Foundry, The DISA MATCH Moulding Principle, Sydney-Australia, Retrieved November 9, 2018, from http://www.ajaxfoundry.com.au/services.html.

[9] Sika, R. (2013). Acquisition and data mining for the Data Mining systems needs on the example applications in foundry industry. PhD Thesis – Prom. Zenon Ignaszak. Doctoral dissertation. Poznan University of Technology, Poznan, Poland.

[10] Sika, R., Jarczyński, A. & Kroma, A. (2019). The influence of selected parameters of the cast iron casting process using the DISA MATCH automatic moulding line on the formation of alloy-mould contact defects. Mechanical Engineering. In Gapiński B., Szostak M., Ivanov V. (Eds.), *Advances in Manufacturing II.* 4, 416-433. Springer.

[11] Perzyk, M. & Soroczynski, A. (2010). Comparative Study of Decision Trees and Rough Sets Theory as Knowledge Extraction Tools for Design and Control of Industrial Processes. *International Journal of Industrial and Manufacturing Engineering*. 4(1), 234-239.

[12] Perzyk, M. (2007). Statistical and Visualization Data Mining Tools for Foundry Production. *Archive of Foundry Engineering*. 7(3), 111-116.

[13] Saalem, M. and others (2014). Advanced Quality Control. In Foundry Manufacturing Process, 71st Word Foundry Congress, Bilbao.

[14] Sika, R. (2006). Studies on the structure of the SAP R/3 and the possibility of its adaptation to the management and quality control in the Iron Foundry in Srem,. MsC Thesis – Prom. Zenon Ignaszak. Master of Science dissertation. Poznan University of Technology, Poznan, Poland.

[15] Sika, R. & Ignaszak, Z. (2019). Data Acquisition procedures for A&DM systems dedicated for foundry industry, Lecture Notes in Mechanical Engineering, In Ivanov V. and others (Eds.). *Advances in Design, Simulation and Manufacturing II*. 4, 692-701. Springer.

[16] Malinowski, P., Suchy, J.S., Lelito, J. (2014). New trends in simulation process and data management in foundry industry, 71st Word Foundry Congress, Bilbao.

[17] Gramegna, N. (2017). Smart casting process control and real time quality prediction The digitalization of foundry plays a key role in competitiveness introducing new integrated platform to Control the process and predict in real-time the Quality and the cost of the casting, 9th VDI Conference with Specialist Exhibition on Casting Technology in Engine Construction: Potential for the Next generation of Vehicle Propulsion, vol. 2304, (pp. 227-234).

[18] Górski, F., Zawadzki, P. & Hamrol, A. (2016). Knowledge based engineering as a condition of effective mass production of configurable products by design automation. *Journal of Machine Engineering*. 16(4), 5-30.

[19] Ćwikła, G., Skołud, B. (2013). Data acquisition characteristics from production systems for the needs of business management, In Midor K., Biały W. (Eds.). *Support systems in production engineering.* 32-45.

[20] Cottyn, J., Van Landeghem, H., Stockman, K., Derammelaere, S. (2009). The combined adoption of production IT and strategic initiatives - Initial considerations for a Lean MES analysis. In Computers & Industrial Engineering, 2009, (1629-1634), Troyes, France: IEEE.

[21] Younus, M., Peiyong, C., Lu, Hu, Fan, Yuqing (2010). MES Development and Significant Applications in Manufacturing - A Review. In Education Technology and Computer (ICETC), Vol. 5 (97-101), Shanghai, China: IEEE.
[22] Larose, D.T. (2006). *Discovering Knowledge in Data: An Introduction to Data Mining*. New York: Wiley-Interscience.
[23] Kochański, A. (2010). Data preparation. *Computer Methods in Materials Science.* 10(1), 25-29.
[24] Pyle, D. (2003). *Data Collection, Preparation, Quality, and Visualization*. San Francisco: Morgan Kaufmann Publishers.
[25] PN-85 H-83105, Casting Division and terminology of defects, Poland, 1985.