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Risk management in the mining sector through complex systems

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ABSTRACT
There is a wide diversity of concepts related to complexity. What the Santa Fe Institute (USA) calls "systemic" corresponds to what Morin (Morin, 2006) calls "complex". Mariotti (2000) outlines the need for a unified terminology. When understanding complexity, it can be perceived as a fabric (what is woven together) of heterogeneous inseparably associated constituents (…) (Morin, 2006). According to different authors, the main drivers of complexity can be found in human behaviour and in uncertainty. This structural of dynamic complexity can be organizational, technological, or nested in human relationships. The complex interrelationship that exists between individuals within an organization or project and its influence on competitiveness can be studied by individual emotional intelligence and organizational behaviour (Love, Edwards, and Wood, 2011).
According to ISO 31000:2009, risk management "*refers to a coordinate set of activities and methods that is used to direct an organization and to control the many risks that can affect its ability to achieve objectives*". When concerning any sector, industry, services, project, or activity, the use of models or theories are required as guidelines. Therefore when its basic elements comprehend human behaviour and/or uncertainty, in order for risk management to be effective and adapted as much as possible to reality, it must be operational within complex systems, as already demonstrated in different R&D environments. Risk management faces particular challenges when approaching more specific needs, such as in the mining sector. The ILO convention (C175, 1995) concerning Safety and Health in Mines, establishes "*that workers have a need for, and a right to, information, training and genuine consultation on and participation in the preparation and implementation of safety and health measures concerning the hazards and risks they face in the mining industry*", and furthermore recognizes "*that it is desirable to prevent any fatalities, injuries or ill health affecting workers or members of the public, or damage to the environment arising from mining operations*". In this context, risk assessment of integrated operations can be improved by complex risk models and dynamic environments (Grøtan, Størseth and Albrechtsen, 2011).
Hence, complex systems can provide decision makers with a supporting tool comprising a three axis analysis model. Each of the three axes (X, Y and Z) comprehends a multi-variable linear function f i: X: f_1 (management variables related to mining); Y: f_2 (variables related to risk management systems) and Z: f_3 (variables related to complex systems. Designing, developing, and testing a risk management decision-making model within complex systems, transversal to other hazard sectors of all economic activities, may provide organizations with sustainable and integrated risk management indicators.
KEYWORDS: complex systems; risk management, uncertainty, human behaviour, high hazards

1. INTRODUCTION

Risk management is an important tool for any business sector. In an economy of global scale and high volatility due to the uncertainty of markets, this tool is even more important because through it high productivity gains can be obtained.

In some industries risk management has to be taken particularly seriously because of the effect of project failure on public safety or on the environment, e.g. in the mining sector due to risk perception, feasibility decision-making, and uncertainty. Technical and socioeconomic complexity and organizational culture are among the main characteristics of complex systems. In the same sense the mining sector is by nature complex, and major hazards, socioeconomic impacts and resource nationalism must all be considered.

The present study intends to present the aforementioned variables in a multi-variable linear function analysis methodology approach through complex system modelling, and effectively correspond to a risk management tool in the mining sector.

2. COMPLEX SYSTEMS

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In physical sciences when joining or connecting a large number of systems, the macroscopic or collective properties of the outcome system are not generally related with the properties of their individual constituents. In this case, the resulting system is a complex system. Complexity, as in collaborative design, comprehends the interaction of many participants working on different elements of the design (Klein et al., 2003), such as in diverse economic activity sectors, i.e. the mining sector.

2.1 Complex thought

The complex thought is an instrument of change and resilience, and is a method in the sense of Descartes. Its main objectives are laid out in Table 1 (Mariotti, 2010).

Table 1: Objectives of complex thought.

ID	Description
1	Understand the uncertainty and learn to live with it
2	Learn to deal with paradoxes and situations that cannot be resolved by the binary logic
3	Provide more thinking flexibility
4	Better understanding life, the nature systems and the systems created by man
5	Provide better relationships in the natural world
6	Better understand the ego and learn to deal with it in a less self and hetero destructive mode

Contrasting a dynamic and ever-changing world, human mental models support decision-making processes, which are normally conservative and narrow-minded. "*Like organisms, social systems contain intricate networks of feedback processes, both self-reinforcing (positive) and self-correcting (negative) loops"* (Sterman, 2006).

2.2 Complexity as a diversity of concepts

Complexity is far from being a simple concept or a single point of view: from the Santa Fe Institute (USA) "systemic" designation, through to the Morin (2006) "complex" classification, to the need for a unified terminology claimed by Mariotti (2000), complexity overlaps multiple labels and approaches. According to Morin (2006) complexity must be perceived as a "fabric" (what is woven together) of heterogeneous inseparable associated constituents (…). In general, complexity is defined in terms of potential states in a system or a number of components (Sterman, 2006), and what is particularly important to identify is the origin of complexity, its level, and its implications (Ameen and Jacob, 2009). Human behaviour and uncertainty are the keystone of basic research in complexity, as established by many authors.

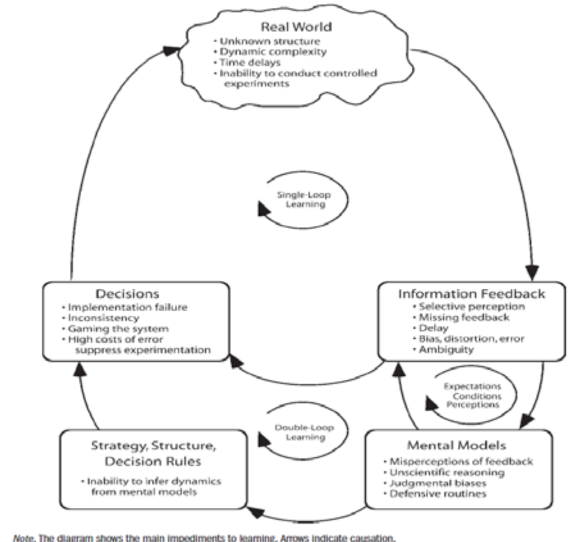

Figure 1: Feedback process of learning (Sterman, 2006).

2.3 Complex systems and complex projects

A complex system implies software, cultural and political issues, and people and organisations that can affect the whole or a part of a system (Marashi and Davis, 2006). With more complex systems, more control must be exerted on the local environment (Sayama, 2003). Knowing the nature and ways of expression of complex systems in organizations can be an important tool for managers (Amaral and Uzzi, 2007).

Each different context (simple, complicated, complex, or chaotic) requires different managerial responses (Snowden and Boone, 2007). In this sense, the 'soft' world of systemic thinkers is complex, chaotic and ever changing, but it is also true that a process of questioning can be a suitable learning system (Checkland, 2011).

Organizational behaviour and individual emotional intelligence may support studies concerning the complex interconnection between individuals in an organization or a project team and competitiveness (Love, Edwards, and Wood, 2011). Cognitive systems engineering maintains that an individual's cognitive system is capable of controlling their behaviour using information about the self and the situation, where prior information (competence, knowledge) can be applied to a specific situation (feed-back, indicators) and constructs (hypotheses, assumptions) (Hollnagel, 1998).

The discussion about complex behaviours of a system at different scales does not explain why the systems are simple or complex, however, a profile that quantifies the relationship between independence, interdependence, and scale of collective behaviour may accomplish this (Bar-Yam, 1997). When a complex system adapts to disruptions and changing conditions, this is called resilience.

Resilience is also understood as an emergent property of complex systems (Dahlberg, 2015).

Resilience engineering (for safety management) exists to help people to deal with complexity under pressure in order to achieve success (Hollnagel, Woods, and Leveson, 2006). To understand the complex systems approach in the design and implementation phases, one must recognize the many differences between the traditional practices of engineering and the natural evolutionary process (Bar-Yam and Kuras, 2003). The response of hierarchical control structures, control and central planning are limited and inadequate as a solution to complex social problems in the functioning of complex organizations (Bar-Yam, 2003).

Marashi and Davis (2006) propose a systemic methodology based on negotiation and argumentation to help in the resolution of complex issues and to facilitate evaluation options during design of systems. The decision-making processes supported by the quantification of complex areas are reinforced because they help set priorities and direct management efforts (Sivadasan, et al, 2010).

To deal with ambiguity and interdependency, people seek a plausible sense of resolve that makes sense (Weick, Sutcliffe and Obstfeld, 2005). The multiple perspectives related to complex situations are supported by the combination of two methods: “multiple criteria decision making” and “techniques from soft systems” (Petkov, et al, 2007).

Research has shown that the complexity of projects is imperative to establish exceptional preventive measures (Domingues, 2012). In order to obtain a measure of project complexity, Fitsilis and Damasiotis (2015) study the effect of time, cost, and quality, as well as the three in combination. This analysis shows that project complexity can have a logical and valid representation.

Other researchers present a framework for project complexity that identifies both technical and organizational complexity. For Bosch-Rekveldt et al. (2011), the majority of the elements in the technical category of the proposed framework have a structural character, like the number of goals, largeness of scope, number of tasks, and dependencies between tasks, and uncertainties in goals and methods are covered in the elements of the technical category. Further, the stakeholder’s multiplicity and multi-objectivity are covered in elements like goal alignment (technical category) and the number of stakeholders and the variety of stakeholder’s perspectives (environmental category) (Bosch-Rekveldt et al., 2011).

3. COMPLEX RISK MANAGEMENT

Complexity offers an interesting theoretical framework for the interdisciplinary studies of integrated safety management and risk management methods (Le Coze, 2005). A risk management strategy must be developed in order to identify as many potential risks as possible and then to decide how to deal with them. Risk analysis is an important process of risk management that can identify and evaluate risk that has to be controlled, minimized or accepted. This is essential information for the identification of threats, and is a vital element for decision-making (Bosch-Rekveldt et al., 2011).

The focus of engineering is on the risk factors, development, and implementation of the measures of control; from design, construction, operation processes, systems maintenance, and operation limit states such as emergencies, and start/stop processes (Domingues et al., 2013).

Traditional risk analysis is not sufficient to recognize the heterogeneity of the input criteria (*wildness in wait*) because it does not recognize the difference between the assumptions aimed at emerging order nor the possibility of heterogeneity of criteria to be incorporated in such apparent order. “*Hence, (…) Risk Assessment (as part of Governance) should be recognized as a (social) knowledge practice (…)*”, (Grøtan, Størseth and Albrechtsen, 2011).

Perminova et al. (2008) explained the link between uncertainties and risk management and introduced a new perspective on how to manage uncertainties in projects. Traditional risk management assumes risk as uncertainty, while the author understands risk as one of the implications of uncertainty. They define uncertainty as “*a context for risks as events having a negative impact on the project’s outcomes, or opportunities as events that have beneficial impact on project performance*” (Perminova et al., 2008).

Risk management needs to be thoroughly defined; such is the case in ISO 31000:2009, where risk management “*refers to a coordinate set of activities and methods that is used to direct an organization and to control the many risks that can affect its ability to achieve objectives*”. In a similar context, an important change related to risk perception can be found in ISO 9001:2015. The risk management integration approach is now a major component of the organisational culture.

According to Afgan, and Veziroglu (2012) the change of social elements (health hazards) is a property of complex systems. Some of these social changes are an inherent characteristic of a system, therefore, mutual interaction between the system and its surrounding are imminent and changes in their interaction rate will affect it safety. If these processes are in steady state, the system is considered safe. It is of interest to investigate the essential characteristics of construction site systems (or other hazardous sectors like the mining sector), which may lead to resilience changes.

In the prevention domain, the most effective elements of a safety program are the support of top management commitment, the selection of human resources (own or outsourced) and strategic management. In turn, the least effective factors are the records, accident analysis, and planning of emergencies (Hallowell and Gambatese, 2009). The role of safety technicians and the need for training concerning the impact of maintenance activities in the industrial process have been specified for the oil refining industry (Cardoso et al., 2014).

In order to demonstrate how risk can be managed in high-risk workplaces, one may utilize an analysis of communication gaps (Rasmussen and Lundell, 2012). Jaafari (2001) states that risk management should have a strategy-based project management approach, using life cycle objective functions as the main drivers for risk reduction and value addition. Systematic management of complex projects requires important information skills and decision support systems which can combine the management of "hard" and "soft" aspects, and facilitate decision evaluation on a real time basis (Jaafari, 2001).

4. DISCUSSION

Guidelines for risk management need the support of models and/or theories in every sector, industry, service, organization, or project. Thus, in order to achieve effectiveness and adaption to reality, risk management as a consequence of its basic elements, human behaviour and uncertainty, must be operational within complex systems, as already applied in various R&D environments.

Risk management faces particular challenges when approaching specific needs. In the mining sector, "*workers have a need for, and a right to, information, training and genuine consultation on and participation in the preparation and implementation of safety and health measures concerning the hazards and risks they face in the mining industry"*, as established by ILO convention C175 (1995) concerning Safety and Health in Mines. The same ILO regulation furthermore recognizes *"that it is desirable to prevent any fatalities, injuries or ill health affecting workers or members of the public, or damage to the environment arising from mining operations"*. Risk assessment of integrated operations is enhanced by dynamic environments and complex risk models (Grøtan, Størseth and Albrechtsen, 2011).

The mining sector faces unprecedented challenges due to unexpected internal factors (lack of trained people and frequent equipment failures) and external factors (mineral commodity prices, market volatility, increasing regulations, dwindling profits, and changing global demand) and inadequate risk management can lead to failures in production or even serious injuries to people and the environment. These events can interrupt projects and even cause the complete loss of the business (Kumar, 2015). Badri (2015) *"puts into perspective the complexity of the challenge of integrating OHS into industrial project risk management"* and emphasizes that the interdisciplinary nature of this problem must be the starting point of any research (Badri, 2015).

The mining industry is complex due to the numerous operations; however, its principal concern is safety. Haas and Yorio (2016) consider the performance of a health and safety management system (HSMS) "*a critical and pressing issue for organizations*". Their study analyses the state of current HSMS methods, recommending reports based on three metric categories: organizational performance, worker performance, and interventions. Nelitz, at al. (2015) consider the principal environmental stressors in this field to be: human intrusion in ecosystems, gas emissions, noise and dust in the air, soil disturbance and contamination, linear infrastructure, traffic and solid waste in land, and water pollution. These vectors must be considered for any risk management analysis in the mining industry.

5. CONCLUSIONS

Complex systems can be a supportive tool for decision-makers. An algorithm proposal is designed based upon a three axis (X , Y , Z) analysis model. Each of the three axes represents a multi-variable linear function f_i:

X : f_1 (mining management variables);

Y : f_2 (risk management systems variables);

Z : f_3 (complex systems variables).

A risk management decision-making model, designed, developed and tested within complex systems, aimed at being transversal to other hazard sectors in any economic activity, may provide sustainable and integrated risk management indicators for organizations.

Table 2: Variables proposal.

VECTOR ANALYSIS					
X		Y		Z	
M	Mining	RMS	Risk Management Systems	CS	Complex Systems
f	related to mining	f_2	related to risk management systems	f_3	related to complex systems
x	major hazard industry	y_1	Risk perception	z_1	technical complexity
x	Resource nationalism	y_2	feasibility decision making	z_2	Organizational culture
x	socio economic impacts	y_3	uncertainty	z_3	socio economic complexity
x_n		y_n		z_n	
PLAN ANALYSIS					
$XY : (f_1, f_2$		M vs RMS		e.g.: (Haas and Yorio, 2016)	
$XZ : (f_1, f_3$		M vs CS		e.g.: (Nelitz, at al., 2015)	
$YZ : (f_1, f_3$		RMS vs CS		e.g.: (Badri, 2015)	
VOLUME ANALYSIS					
$XYZ : (f_1, f_2, f_3)$		M vs RMS vs CS		Risk Management Within Complex Systems in Mining	

The analysis methodology proposed above is supported by a three-dimensional scope, F = (f_1, f_2, f_3) (complex systems, risk management, mining sector), with F being a comprehensive model of analysis that can be used to determine scenarios among different options, where several objectives can be set, such as "zero accidents". The mining sector can thus be thought of as a complex system and the risk involved in the sector understood as a management variable and integrated through the risk management function.

6. REFERENCES

Afgan, N. and Veziroglu, A. (2012). Sustainable resilience of hydrogen energy system. International Journal of Hydrogen Energy, 37, 5461-5467.

Amaral, L. A. N. and Uzzi B. (2007). Complex Systems - A New Paradigm for the Integrative Study of Management, Physical, and Technological Systems. Management Science, 53(7), 1033-1035.

Ameen, M. and Jacob M. (2009). Complexity in Projects: A Study of Practitioners Understanding of Complexity in Relation to Existing Theoretical Models. In School of Business 2009, Umeå University: Umeå, Sweden.

Badri, A. (2015). The Challenge of Integrating OHS into Industrial Project Risk Management: Proposal of a Methodological Approach to Guide Future Research (Case of Mining Proj. in Quebec) Minerals 5, 314-334. doi:10.3390/min5020314.

Bar-Yam, Y. (1997). Complexity Rising: From Human Beings to Human Civilization, a Complexity Profile, N.E.C.S. Editor, New England Complex Systems Institute: Cambridge, MA, USA.

Bar-Yam, Y. and Kuras M. L. (2003). Complex Systems and Evolutionary Engineering, in An AOC WS LSI Concept Paper, Complex Systems Institute and The MITRE Corporation.

Bar-Yam, Y. (2003). When Systems Engineering Fails - Toward Complex Systems Engineering, in International Conference on Systems, Man & Cybernetics, I. Press, Editor New England Complex Systems Institute: Piscataway - NJ, USA.

Bosch-Rekveldta, M., Jongkindb, Y., Mooia, H., Bakkerc, H., Verbraeckb, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. International J. of Project Management, 29(6), 728-739.doi:10.1016/j.ijproman.2010.07.008.

Cardoso, A., Queiroz, S., Fernandes, A., Roçadas, A. S. and Diogo, M. T. (2014). Técnico de Segurança numa refinaria: responder às especificações de uma indústria. Proceedings Book of SHO 2014 – Intern. Symposium on Occupational Safety and Hygiene, Guimarães, Portugal.

Checkland, P. (2011). Autobiographical retrospectives: Learning your way to 'action to improve' – the development of soft systems thinking and soft systems methodology. International Journal of General Systems, 40(05), 487-512.

Dahlberg, R. (2015). Resilience and Complexity: Conjoining the Discourses of Two Contested Concepts. Culture Unbound, Volume 7, 541-557. Published by Linköping University Electronic Press

Domingues, M. S. Q. (2012). Uma abordagem aos projetos complexos na perspetiva da prevenção. Dissertation of Master Degree in Engineering of Occupational Safety and Hygiene, University of Porto, Portugal, 92 p.

Domingues, M. S. Q., Roçadas, A. S. A., Fernandes, A. F., Silva, C. O., Martins, J. M. M., Cabral, A. M. and Diogo, M. T. (2013). Complex Systems Application at Risk Prevention in Processing and Use of Hydrogen Technologies. In IV Iberian

Symposium on Hydrogen, Fuel Cells and Advanced Batteries, Estoril, Portugal.

Fitsilis, P. and Damasiotis V. (2015). Software Project’s Complexity Measurement: A Case Study. Journal of Software Engineering and Applications, 8, 549-556.

Grøtan, T. O., Størseth, F., and Albrechtsen, E. (2011). Scientific foundations of addressing risk in complex and dynamic environments. Reliability Engineering and System Safety, 96(6), 706-712. doi: 10.1016/j.ress.2010.12.009.

Haas, E. J. and Yorio, P. (2016). Exploring the state of health and safety management system performance measurement in mining organizations. Safety Science 83 (2016) 48–58.

Hallowell, M. R. and Gambatese, J. A. (2009). Construction Safety Risk Mitigation. Journal of Construction Eng. and Management, 135(12), 1316-1323. doi: 10.1061//asce/co.1943-7862.0000107.

Hollnagel, E. (1998). Commentary Comments on “Conception of the cognitive engineering design problem” by John Dowell and John Long. Ergonomics, 41(2), 160-162.

Hollnagel, E., Woods D. D., and Leveson N. G. (2006). Resilience Engineering Concepts and Precepts. Aldershot, Hampshire, England: Ashgate Publishing Limited. 410.

International Labour Organization (1995). Convention N. 176 - Safety and Health in Mines Convention.

Jaafari, A. (2001). Management of risks, uncertainties and opportunities on projects: time for a fundamental shift. International Journal of Project Management, 19(2), 89-101. doi:10.1016/S0263-7863(99)00047-2.

Klein, M., Faratin, P., Sayama, H., and Bar-Yam, Y. (2003). The Dynamics of Collaborative Design: Insights from Complex Systems and Negotiation Research. Concurrent Engineering, 11(3), 201-209. doi: 10.1177/106329303038029.

Kumar, P., Rathore, I. (2015). The Need of Mining Industry – A SWOT analysis. International Research Journal of Earth Sciences, 3(8), 32-36.

Le Coze, J. (2005). Are organisations too complex to be integrated in technical risk assessment and current safety auditing? Safety Sc., 43, 613–638.

Love, P., Edwards, D., and Wood, E. (2011). Loosening the Gordian knot: the role of emotional intelligence in construction. Engineering, Construction and Architectural Management, 18(1), 50-65. doi: 10.1108/09699981111098685.

Marashi, E. and Davis, J. P. (2006). An argumentation-based method for managing complex issues in design of infrastructural systems. Reliability Engineering & System Safety, 91(12), 1535-1545.

Mariotti, H. (2000). Reducionismo, "Holismo" e Pensamentos Sistêmico e Complexo (Suas consequências na vida cotidiana). In P. Athena (Ed.), As paixões do ego: complexidade, política e solidariedade. São Paulo, Brasil.

Morin, E. (2006). Introdução ao Pensamento Complexo. Edit. Sulina, ISBN: 978-85-205-0598-4.

Nelitz, M. A., Beardmore, B., Machtans, C. S., Hall, W. A., and Wedeles, C. (2015). Addressing complexity and uncertainty: conceptual models and expert judgments applied to migratory birds in the oil sands of Canada. Ecology and Society 20(4):4. doi:10.5751/ES-07906-200404

Perminova, O., Gustafsson, M., Wikstro, K. (2008). Defining uncertainty in projects – a new perspective. International J. of Project Management, 26(1), 73-79. doi:10.1016/j.ijproman.2007.08.005

Petkov, D., Petkova, O., Andrew T., Nepal T. (2007). Mixing Multiple Criteria Decision Making with soft systems thinking techniques for decision support in complex situations. Decision Support Systems, 43, 1615–1629.

Rasmussen, J. and Lundell, Å. K. (2012). Understanding “communication gaps” among personnel in high-risk workplaces from a dialogical perspective. Safety Science, 50(1), 39-47. doi: 10.1016/j.ssci.2011.06.009

Sayama, H. (2003). Workplace Construction: A Theoretical Model of Robust Self-Replication in Kinematic Universe. In Eighth International Symposium on Artificial Life and Robotics.

Sivadasan, S., Smart, J., Huatuco, L. H., et al., (2010). Operational complexity and supplier–customer integration: case study insights and complexity rebound. Journal of the Operational Research Society, 61(12), 1709-1718.

Snowden, D. J. and Boone M. E. (2007). A Leader's Framework for Decision Making. Harvard Business Review.

Sterman, J. D. (2006). Learning from Evidence in a Complex World. American Journal of Public Health, 96(3), 505-514.

Weick, K. E., Sutcliffe K.M. and Obstfeld D. (2005). Organizing and the Process of Sensemaking. Organization Science, 2005. 16(4), 409-421.