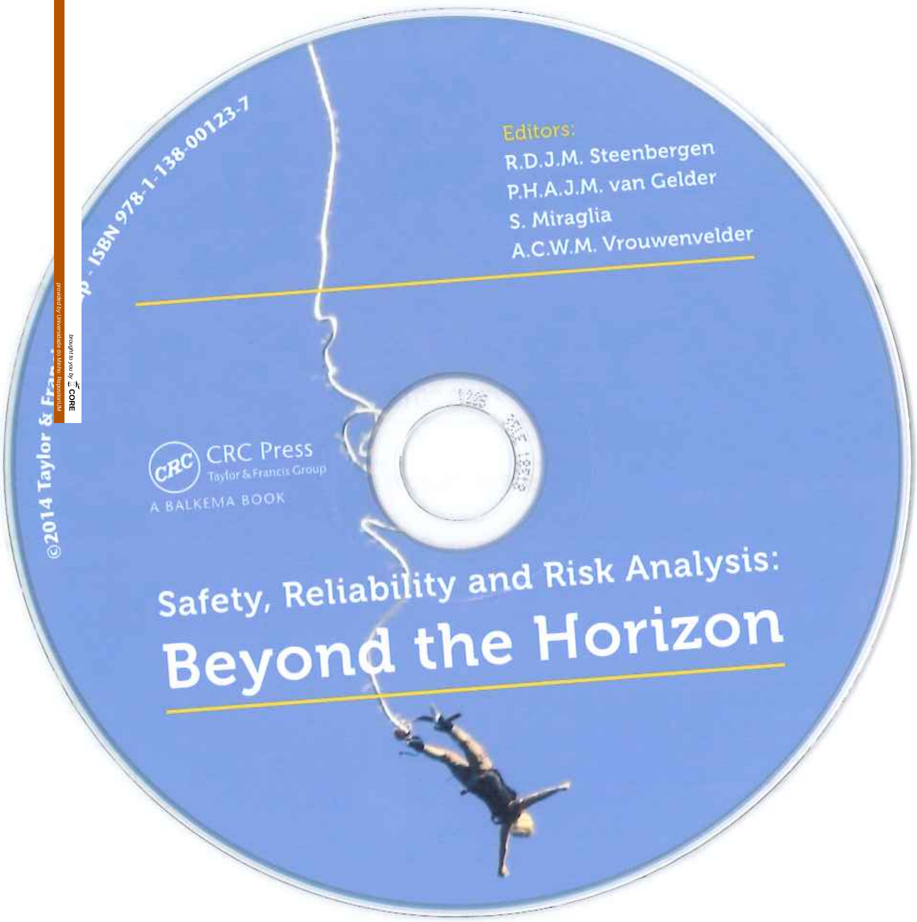
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Promoting safety during process variability: A multidisciplinary challenge

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ABSTRACT: Variability can be defined as the inherent instability of any type of process. In manufacturing settings, some efforts in reducing process variability have been developed, but zero variability seems to be, so far, an infeasible target. Ergonomic studies have been showing that workers are usually the ones responsible for residual variability. However, it can have impact over the safety of workers. The main purpose of this paper is to demonstrate that the need for managing residual variability in addition to putting the workers in a position of transgressors, it also exposes them to unforeseen risks. To achieve that, three examples of variability situations are described. The main method applied was the Ergonomic Analysis of Work Activity. It is argued that there is the need for a multidisciplinary approach, including not only OH&S professionals, but also human resources and engineering designers, to promote safety during process variability.

1 INTRODUCTION

Variability can be identified in any productive setting. In manufacturing, it can: be observed both in products and in processes; be originated from different sources; and happen throughout the production phases. Process variability may occur because: machines break down, tools wear and tear, raw materials and final products change, unforeseen events occur, unexpected errors and malfunctions appear, and so on.

Process variability has an impact over the quality of products, productivity, costs and systems reliability. A process with high variance levels is considered an out of control process. The research results of Mapes et al. (2000) demonstrate that high-performing plants have processes and procedures with lower levels of variability and uncertainty than low-performing plants. But besides the well-known influences over the production, it is possible to argue that process variability has also an impact over the workers' safety and health.

Despite the efforts in automation and a variety of methods and developed techniques—statistical process controls, quality tools, scheduling techniques, and operation management strategies, etc.—to mitigate process variability, it cannot be completely eliminated. Zero variability seems to be, so far, an infeasible target in manufacturing processes. Therefore, there is always a residual amount of variability to be managed. The issue is, then, to better understand who is doing such management, and how it is being done.

1.1 *Variability in the activity-centered ergonomics approach*

Focused on the residual management issue, the Activity-centered Ergonomics has built one of its basic assumptions. It is argued that variability is one of the causes of the differences between task and activity (Guérin et al. 2007, De Keyser 1992, Daniellou 2005). The Activity-centered ergonomists recognize variability as being an inherent component in any industrial activity as is the occurrence of unexpected events (Guérin et al. 2007, Daniellou 2005), despite of being generally underestimated by the formal organization (Garrigou et al. 1995, Perrow 1967). The existence of variability is considered one of the reasons why users do not utilize the systems as it is expected, modifying it momentarily or permanently (Béguin 2003).

In fact, workers are considered those responsible for managing the residual variability. Ergonomic analyses have been highlighting the importance of the operating strategies (Guérin et al. 2007): alternative behaviours to manage variability, developed by workers, beyond the ones previously prescribed by the formal organization. These strategies may pursue the anticipation or the correction of process deviations. They can be developed individually or collectively, and are based on workers' knowledge and experience accumulated over time. The ability to develop them is advocated as being one component of competency (Schwartz 1998). Such strategies are also considered as an unavoidable artifice to accomplish a task (Garrigou et al. 1995) and make production possible.

However, for ergonomists, the aim in studying variability is not suppress it (Guérin et al. 2007). Activity-centered Work Analysis aims to emphasize the way workers manage process variabilities and to understand its impacts over the workers and their work. This more hermeneutical approach (Taylor 1981) seems to be worth to be explored in the field of occupational safety and health.

The main purpose of this paper is to demonstrate how variability situations may lead to workers exposure to unforeseen risks. In order to achieve this, three examples are presented.

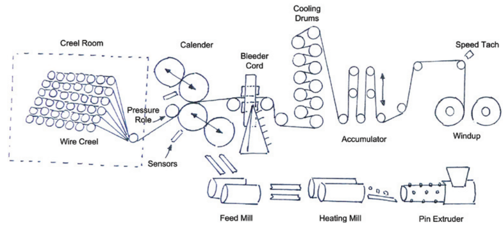

Figure 1. Scheme of the metallic sheet type calendering process.

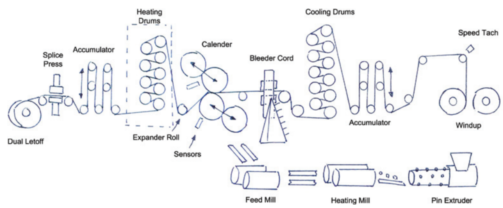

Figure 2. Scheme of the textile sheet type calendering process.

2 CASE CONTEXT

The described variability situations were collected from a research conducted in a manufacturing company, part of the automotive chain. The study focused on the calendering process, an intermediary process that produces continuous sheets from rubber compounds incorporated with reinforcing materials such as textile fabrics or wire cords. The calendering process is an important step in the production of tires, because the quality of the sheets is critical to the tire performance.

The calendering machine, a calender, is a heavy-duty machine equipped with three or more chromeplated steel rolls, which revolve in opposite directions, in specific speeds (Rodgers & Waddell 2005). The equipment analyzed is a Z shaped four roll calender. Besides the steel rolls, a number of other accessory equipment ensure the production process: let-off stations and creel rooms for unwinding the reinforcing materials; extruders, heating and feeding mills for preparing the rubber compound; accumulators for avoiding machine slowdown; heating and cooling drums; tension controllers and so on. A number of measurement and control systems guarantee the quality of the final sheets.

The overall equipment, including the accessory systems, measures around 84 meters in length, 16 meters wide and 8 meters high. It weighs 150 ton, consumes about 395 kW/h and produces more than 50.000 meters of material/day.

The calender produces eleven different products, divided in two types, according to the reinforcing material used. Figures 1 and 2 display general schemes of the overall process for each product type.

Like other processes in the plant, the calendering follows a 24/7 schedule, requiring 5 work shifts. Each calendering work shift is formed by 6 machine workers. The process employs a total of 25 machine workers that are company employees, and an extra 4 outsourced workers. Also, maintenance and cleaning staffs often act directly on the machine.

3 MATERIALS AND METHODS

The variability situations presented here, were identified in the context of an ergonomic intervention, which was based on an action-research strategy (Stringer 2007), whose goal was to generate ergonomic criteria to the design of a processing machine. The intervention consisted of two phases, according to the Future Work Activity method (Daniellou & Garrigou 2002). Considering the first one, it aimed to characterize reference situations (de Keyser 1992), and the Ergonomic Analysis of Work Activity (Guérin et al. 2007) was the main method applied.

Field studies enabled the research party to familiarize with the technical process, progressively winning the workers trust (De Keyser 1992).

It also assisted in mapping the workers activities, including their actions and their visualization and communication needs (Wisner 1987). This phase also included the identification of problems experienced by the workers and the risks involved in the work setting.

The collected data was granted through a systematic observation of the work activities and the machine routines. Open and semi-structured interviews, spontaneous and concurrent verbalizations were also used as data-collection techniques. Data collection also included the analysis of relevant documents available, like company specs, work instructions and safety procedures.

When the variability situations were occurring, data were being recorded: the time of the occurrence, number of workers involved in the situation and actions performed by each one, communications established among them, and so on. Then, the workers were questioned about what they had done, why they had carried such actions, the frequency of the specific occurrence or similar situations, etc. All data were recorded in a logbook.

The field research lasted for seven months, comprised between November 2010 and June of 2011. It took around forty-one data-collecting days, each day consisting of approximately six hours of direct contact with the workers. As the company works in rotative shifts, all the shift groups were involved in the research. In order to include the weekend shifts, data collecting were also performed during weekends.

4 RESULTS

Although variability situations were considered, in the beginning of the intervention, one of the research focus, they proved to be of great importance in the analyzed context. They were observed throughout the data collection days and in different work shifts.

Three of such situations are described as follows: the first two occurred throughout the field observations and could be directly observed. The third situation, besides not having been observed, was reported by the workers during the data collection. It was selected because it was directly connected to a work accident.

4.1 *First variability situation*

The calender changeover between two product types, is made using a fabric called set-up liner. It guarantees the marking of the path that the fabric needs to follow along the equipment rolls during the calendering. In this regard, the set-up liner is bound to the edge of the cords from the product already in processes, and is then pulled over the equipment, until the product is completely removed from the machine. The set-up liner stays threaded along the whole equipment while the changeover is done. In order to start the subsequent production, the other edge of the set-up liner is attached to the cords of the reinforcing material, and then it is able to pull it through the equipment. The use of the set-up liner allows a shorter changeover time.

A metallic stick, around 150 cm long, is used to attach the set-up liner to the cords. Throughout its use, the stick becomes bent, because of the tension efforts made by the machine during the set-up. The stick is also occasionally used by the workers for other activities, which contributes to its damaging.

The observed variability situation occurred because the stick broke during a changeover. This situation implied the need of disconnecting the machine and interrupting the set-up, in order to avoid further consequences, such as the loss of the marking path. If the threading along the equipment is lost, the cords must be put back along the machine, passing through each of the rolls and drums. Along the machine there are around forty rolls, and the length of the path is over 300 meters.

To solve the problem, the workers needed to reach the place to mend the set-up liner with the cords again. To do that, they were forced to enter a zone in the equipment they have no access to, protected by a metallic fence. Some of the rolls and drums are also difficult to reach, and there are no tools or systems to assist in the task. The workers acted collectively and they used several strategies to fix the situation: some straightened the stick, others fastened the cords with adhesive tape. According to a worker, the incident was easy to be solved, despite the consumed time:

> *"I stopped the machine and I made the splice … it is simple, but it delayed 'our life' …"*

4.2 *Second variability situation*

The calendering process consumes rubber compounds as raw material. The rubber is fed, still uncured and in strips, to the calender stocks. Variations among different rubber compounds may have a direct impact on the control of process variables, such as the feeding strip speed and the required temperature to feed the calender stocks. There are differences among the compounds hardness, and it is also influenced by the environment temperature. The workers explained:

> *"this rubber R123 [rubber code] is easier to control… it is more homogeneous and always goes right … but it is not always like this, it is relative … it depends on*

the period of the year … then we must act in different ways … in summer [the product] comes out with more bubbles … because of the temperature … it vulcanizes …"

In addition to the sources of variation cited above, there is the influence of the rubber supplier. The rubber sheets are generally produced in the factory, in the first step of the tire production process, called mixing. However, sometimes rubber supplied from another factory is used, due to the lack of compound in the plant.

The observed variability situation occurred during a calendering running, caused by the exchange of the compound. Initially, an imported compound was being used, and because of being harder, it demanded higher temperatures employed in the preparation phase and on the calender rolls. As the process parameters were adjusted to the imported rubber, changing into a compound produced in the same plant—softer—caused the vulcanization of the rubber of the calender stock.

Vulcanized rubber cannot be used in the process, because it implies a product outside of the specification. The worker explains that vulcanized rubber does not bond in the cords:

"if vulcanized rubber is used, the metallic part will appear"

However, in the observed situation, before such failure appeared in the product, the worker had already anticipated the situation, observing the formation of small lumps of rubber in the calendered sheets.

The worker replaced the vulcanized rubber from the stock to avoid the machine stop and to ensure that a minimum of scrap was produced. To remove the vulcanized rubber and to put a new piece of rubber on the upper stock, the worker cut a strip of rubber from the feeding mill, and to reach the stock, climbed up a ladder, staying in a zone of difficult access and high risks, where there is no protective device.

4.3 *Third variability situation*

To feed the calendering of metallic type, steel wires, supplied in spools, are placed on spindles of a rack inside the creel room. During the calendering, the wires are continuously pulled and the spools unwound.

In some cases, as reported by the workers, it may occur that a certain wire can be inappropriately unwound, as if it was twisted. That may be caused by an inadequate preparation of the wires during the creel room preparation, a task performed before the start-up of the calendering. The workers have strategies to avoid this problem: before the calendering starts, the creel workers check all the wires of the creel room, to see if any wire fell over the spoke and became twisted. This can also be caused by a spool with twisted wires coming from the supplier. The worker stated that nowadays, it happens with one specific supplier:

"the problem of the spool with the twisted wire occurs more with the spool from ABC [supplier] … they made a simulation to correct it … but it did not work …"

The feeding of the calendering with twisted wires has consequences for the quality of the material, because a greater tensioning is needed to unwind it. The workers can identify that there is a twisted wire in the calendering only after its start. They observe the uniformity of the surface of the sheet already calendered—the twisted wire makes a mark on the material—or by the noise of the spool as soon as it is unwound. The worker stated:

"[I know that there is a problem] by the noise … the spool makes a sound like rec, rec … a different noise"

To correct the situation, the worker must remove the twisted wire and replace it with another one. After identifying the specific twisted wire, the worker cut it using scissors. To proceed to the replacement, the worker pulled the wire from an available spool up to the calender rolls zone, and put it between two rotating rolls which automatically began to pull the wire. Both the action of cutting the wire and replacing it are of high risk to the worker, once they are executed while the machine is running.

5 DISCUSSION

The variability situations described were cause by different variation sources, and in all of them, workers' interventions were needed to overpass the situations. None of them are expected to happen in production under controlled conditions.

The first case is a situation of variability caused by the wear and tear of a working tool. In this specific situation, a protective device, designed to protect the worker, became a new source of risk. There is no available tool or system to help reaching certain areas of the equipment.

In the second case, the situation is caused by a variation of a raw material. The worker is exposed to new risks, since it has to achieve a zone of the equipment which is of hard access and where there are no protective devices. The worker has no tool to assist the activity of removing the vulcanized compound and a faster correction cannot be done with the tools and systems available in the machine.

The third reported situation may result from an out of specification raw material or by a lapse in a previous task. Here again, the worker was exposed to new risks. It became evident because of an accident that occurred when this study was being conducted. The accident happened with a machine worker when he was performing the activity: when he was replacing the wire, it got twisted when going through the calender rolls and made a lace that stuck on two of the worker's fingers, causing him a deep cut. As reported, the consequences were not worst because the type under processing uses a thin wire (the machine produces sheets with two types of wires, in different thicknesses). The worker reported that if the wire was the thickest one, he certainly would have his fingers amputated in the accident.

The described situations demonstrate how variability can have an impact on the workers' safety. Workers were exposed to unforeseen risks in order to solve problems that emerged from process variability situations and to ensure the production within the quality parameters and productivity goals. This is because occupational risks are generally assessed for normal production situations, in which the process variables are under control. Situations like those demonstrated, generally become the focus of OH&S professionals after the occurrence of seriously accidents. And, not rare, the consequences are a greater number of protection barriers, security procedures and the penalization of workers. Borys et al. (2009) suggest that learning from successful performance variability is as important as learning from failure.

However, it is possible to argue that this is not only an OH&S issue, as workers are usually trained to act in normal work conditions, and machines are designed to be used in normal and controlled situations of functioning (Daniellou 2005).

5.1 *Training*

It is crucial to highlight to the professionals responsible for workforce training, usually the human resources staff, their role in promoting safety in variability situations. Sinclair (1992) argues that employees must be trained and retrained in the most efficient manner, as people will be necessary in manufacturing plants for many years.

The author (Sinclair 1992) suggests three levels of training. The first level is the training of the workforce to make use of the technology available. In a second level, the training should aim at the fitting of technology to the tasks that users have to carry out in normal operations, i.e., learning how to match the technology to its specific environments. And finally, a third level of training, where, perhaps by accidental discovery or perhaps by deliberate tailoring of the system, the technology is used for purposes other than those intended by the system designers.

5.2 *Design*

Also, it is crucial to consider the existence of variability situations during the design of an equipment. Béguin (2003) suggests that a designer-user interaction should be organized in order to articulate the inventiveness of both parties.

The amount of equipment controls and areas which need interference along an actual work setting is generally higher than it is foreseen. It is possible to highlight the fact that not only the machine workers, but the maintenance and cleaning workers, whose work is usually neglected during the equipment design, also need to act upon the machine.

Recent studies (Béguin 2011, Béguin & Duarte 2008, Trotter et al. 2012) aimed to understand how the knowledge of variability situations and operating strategies can be taken into account in the design of industrial machines, tools and workplaces.

Many other studies have discussed how uncertainty can be managed (Grote 2004) and how to promote safety through design (Hale et al. 2007, Schupp et al. 2006).

5.3 *The shop floor workers involvement*

The workers experience and knowledge accumulated over time is crucial to the promotion of safety during variability situations. The importance of taking the users' knowledge into account is advocated by Hale et al. (2007). Ergonomic techniques have been trying to commit workers to the search for solutions, being subject to controlled experiments, or getting involved in participatory processes. That is the case of simulation techniques which have been not only producing technical improvements, but also promoting the development of individual and collective activity (Daniellou 2007).

6 CONCLUSION

However great the deployed efforts, variability situations can be identified in all productive settings. The impacts of variability situations over occupational safety and health should not be ignored. Training and tools must be provided to allow workers to act safely in unanticipated situations. This means that the promotion of safety in process variability situations is a challenge not only to the occupational safety professionals, but also to other experts. It is a multidisciplinary effort that must involve human resource professionals, engineering designers, and comprise the workers' involvement.

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REFERENCES

Béguin, P. 2003. Design as a mutual learning process between workers and designers. *Interacting with computers* 15(5): 709–730.

Béguin, P. 2011. Acting within the boundaries of work systems development. *Human Factors and Ergonomics in Manufacturing & Service Industries* 21(6): 543–554.

Béguin, P. & Duarte, F. 2008. A inovação: entre o trabalho dos projetistas e o trabalho dos operadores. *Laboreal* 4(2): 10–14.

Borys, D., Else, D. & Leggett, S. 2009. The fifth age of safety: the adaptative age? *Journal of Health & Safety Research & Practice* 1(1): 19–27.

Daniellou, F. 2005. The French-speaking ergonomists' approach to work activity: cross-influences of field intervention and conceptual models. *Theoretical Issues in Ergonomics Science* 6(5): 409–427.

Daniellou, F. 2007. Simulating future work activity is not only a way of improving workstation design. *Activités* 4(2): 84–90.

Daniellou, F. & Garrigou, A. 2002. Human factors in design: sociotechnics or ergonomics? In M. Helander & M. Nagamachi (eds), *Design for Manufacturability: A systems approach to Concurrent Engineering and Ergonomics*: 55–63. London/Bristol: Taylor & Francis.

De Keyser, V. 1992. Why field studies? In M. Helander & M. Nagamachi (eds), *Design for Manufacturability: A systems approach to Concurrent Engineering and Ergonomics*: 305–316. London/Bristol: Taylor & Francis.

Garrigou, A., Daniellou, F., Carballeda, G. & Ruaud, S. 1995. Activity analysis in participatory design and analysis of participatory design activity. *International Journal of Industrial Ergonomics* 15(5): 311–327.

Grote, G. 2004. Uncertainty management at the core of system design. *Annual Reviews in Control* 28(2): 267–274.

Guérin, F., Laville, A., Daniellou, F., Duraffourg, J. & Kerguelen, A. 2007. *Understanding and transforming work: the practice of Ergonomics*. Lyon: ANACT—National Agency for the Improvement of Working Conditions.

Hale, A., Kirwan, B. & Kjellén, U. 2007. Safe by design: where are we now? *Safety Science* 45(1–2): 305–327.

Mapes, J., Szwejczewski, M. & New, C. 2000. Process variability and its effect on plant performance. *International Journal of Operations & Production Management* 20(7):792–808.

Perrow, C. 1967. A Framework for the Comparative Analysis of Organizations. *American Sociological Review* 32(2): 194–208.

Rodgers, B. & Waddell, W. 2005. Tire Engineering. In James E. Mark, Burak Erman and Frederick R. Eirich (eds), *The Science and Technology of Rubber*. 3rd Edition:619–662. San Diego: Elsevier Academic Press.

Schupp, B., Hale, A., Pasman, H., Lemkovitz, S. & Goossens, L. 2006. Design support for the systematic integration of risk reduction into early chemical process design. *Safety Science* 44(1): 37–54.

Schwartz, Y. 1998. Os ingredientes da competência: Um exercício necessário para uma questão insolúvel. *Educação & Sociedade* 19(65): 101–140.

Sinclair, M.A. 1992. Human factors, design for manufacturability and the computer-integrated manufacturing enterprise. In M. Helander & M. Nagamachi (eds), *Design for Manufacturability: A systems approach to Concurrent Engineering and Ergonomics*: 127–146. London/Bristol: Taylor & Francis.

Stringer, E.T. 2007. *Action Research.* 3rd Edition. Thousand Oaks: Sage Publications.

Taylor, D.H. 1981. The hermeneutics of accidents and safety. *Ergonomics* 24(6): 487–495.

Trotter, M.J., Salmon, P.M. & Lenné, M.G. 2012. Improvisation: theory, measures and known influencing factors. *Theoretical Issues in Ergonomics Science* DOI:10.1080/1463922X.2012.656153.

Wisner, A. 1987. Por dentro do trabalho. Ergonomia: método e técnica. São Paulo: FTD/Oboré.