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Neither Leading Nor Lagging: Why Process Safety Indicators Need to Go Beyond the Time Dimension

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Process Safety Indicators (PSIs) are expected to provide decision makers with synthetic and still valuable insights on the evolution of the risk systems they are supposed to control. As it is the case in almost all areas of management, the simplifications such tools may vehicle are subject to legitimate criticisms. In the field of safety, focus has been put on the ambiguities surrounding the interpretations of the lea/lag properties of PSIs.
This paper ambitions to demonstrate that the discussion around the leading/lagging typology of PSIs is not only a matter of conflicting and still legitimate interpretations but the result of an ill-defined typology that does not satisfy the epistemic basic requirements of scientific typologies. In doing so, it appears necessary for the process safety community to move beyond this approach to establish a more comprehensive and less ambiguous framework for assessing the performance of a safety monitoring system.

1. Introduction

Process safety indicators can be defined in several ways. Swuste et al (2016) have already provided a literature review with more than 15 distinct definitions of PSIs. We will therefore limit ourselves in this paper to the globally unifying and straightforward definition provided by Reiman & Pietikainen (2012) which characterises PSIs as any measure that seeks to produce information on a (safety) issue of interest.
PSIs are already recognized as valuable tools for process safety improvement. A large set of international organisms have issued guidelines and recommendations promoting and framing the use of such tools (HSE, 2006); (OECD, 2008); (CCPS, 2011); (CEFIC, 2011). In addition, detailed post-accident investigations confirm the necessity of a well-chosen, calibrated and implemented set of PSIs (CSB, 2007); (HSE, 2010b).
However, this abundant literature does not seem to answer all the challenges and criticisms regularly addressed to PSIs both from academics and practitioners. One of the key issues still subject to controversy is the leading/lagging typology usually applied to PSIs. Said simply, leading indicators are expected to anticipate safety deterioration whereas lagging ones should reflect in hindsight such an evolution. This (apparently) simple distinction is still raising intense debates that have not yet reached satisfactory closure. The special issue of *Safety Science* (Safety Science 47, 2009) in 2009 dedicated to the leading/lagging typology is a good summary of the variety and sometimes conflicting representations surrounding the significance of this typology. The special issue gathered a set of representative academics and practitioners reacting to Hopkins's (2009a) paper which pointed some incoherencies in the way the leading/lagging distinction had been treated in the CSB investigation of the BP Texas City explosion in 2005 and by the HSE in its PSI guidelines (HSE, 2006). The various contributions were divided into those supporting this typology while diverging on its signification (Kjellen, 2009) (Dyreborg, 2009) (Hudson, 2009) and those suggesting that the debate be moved from typology-related issues to more compelling topics (Woods, 2009) (Wreathall, 2009), such as the ability to generate learning (Zwetsloot, 2009).
This paper ambitions to demonstrate that this debate is not just the result of a legitimate variety in opinions. It is the direct consequence of an ill-defined typology that needs to be deeply requestioned. Our argument is that the leading or lagging dimension, whilst it remains arguably of interest for practitioners, is not an acceptable criterion to elaborate upon a scientifically sound typology of PSIs.

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This paper will start with a short introduction to the epistemics of typology conception as it is deployed in various scientific areas so to identify key expected qualities for a typology to be operational. The second part will analyse the way the lead/lag typology behaves with respect to these criteria so to uncover the mechanisms through which the time dimension fails to provide, alone, a sufficient basis for a PSIs typology.
In doing so, this paper does not deny the relevance for decision makers to seek for leading time when dealing with major risks. However, it emphasizes the need for higher scientific analysis in order to derive, out of this relevant and legitimate need, a scientifically sound and unambiguously applicable typology of PSIs.

2. On the definition and design of science-based typologies

Typologies can be defined as organized systems of types that breaks down an overarching concept into component dimensions and types (Collier, LaPorte, & Seawright, 2012). Typologies play a key role in science in general and in social sciences in particular (Senders & Moray, 1991) (Bailey, 1994). Indeed, to describe or approach complex social realities, distinguishing various types reveals helpful to identify recurrent patterns or explain observed heterogeneities. Typologies also invite us to identify salient attributes of concepts which eventually helps refining their meanings and establishing a productive connection between these meanings and the terms associated to them (Collier, LaPorte, & Seawright, 2012). Said simply, typology elaboration is a valuable mean for deepening our understanding and improving our abilities to use a given concept.
An ideal typology should display some recurrent characteristics. The first is *internal homogeneity* and refers to the need for elements within a type to be as similar as possible (Kluge, 2000). *External heterogeneity* is a second property pointing the need for differences between types or classes to be as strong as possible. In addition, the total set of types should be exhaustive by covering all aspects of the overarching concept (Hambrick, 1984) (Merradi, 1990). Finally, a possible but not compulsory property is the ability of a typology to order a set of types through *hierarchical relationships*. In this final case, typologies do not only distinguish different categories, they provide a classification that may serve as a measuring scale of the overarching concept.
In order to achieve satisfactory performances on these quality criteria, the process of typology design has been subject to several efforts of formalisation (Bailey, 1994) (Kluge, 2000) (Collier, LaPorte, & Seawright, 2012). The following four building blocks are widely agreed upon in each typology elaboration methodology:

a. *The overarching concept*: A detailed description of the concept under study is performed to identify in the next step the set of salient dimensions or attributes characterizing it. As a complement, we believe it necessary for this description to also make explicit the frontiers of the concept under consideration by clarifying the reductions and simplification one operates when moving from reality to the concept he is interested in. For instance, defining a concept of interest as *safety indicators* leaves open the idea that the typology will apply for both workplace and process safety which may lead to dangerous misuses as discussed by Hopkins (2009a).
b. *The set of attributes:* As discussed earlier in this paper, one overarching concept may be explored through different set of attributes depending on the typology objectives. For instance, if the objective is to categorise indicators depending on available input data, one will pay attention to the various types of measurement scales upon which indicators are to be built: nominal, ordinal, ratio or cardinal scales (Bouyssou & Vincke, 2009). These typologies are widely used in multicriteria decision theory where the main concern is to fit the indicator with the information structure through which a decision maker expresses his preferences. In the case of process safety, these aspects are usually put aside, and focus is rather oriented, at least for one understanding of the lead/lag typology, on distinguishing indicators that are useful before or after the accident occurs.
c. *Attributes combination:* Considered altogether, the set of attributes and their combinations will define the frontiers separating categories. For instance, the cross tabulation of two attributes will create a matrix where each cell distinguishes a theoretical type. All theoretical types being not necessarily meaningful for the typology's purpose, some combinations can be removed or merged to identify a minimal set of relevant types (Lazarsfeld & Barton, 1951).
d. *Types characterization:* A description of each type is now feasible based on the specific combination of attributes that shaped it. Such a description provides an account of the key properties that create homogeneity inside the type and heterogeneity when compared to other types. It also specifies how the resulting typology, as a whole, is helpful in answering the typology's specific objectives.

In the followings, the four building blocks introduced here will serve as the lens through which the PSIs lead/lag debate will be analysed so to uncover what appears to be closer to scientific inconsistencies than it is to disagreements or legitimate variability in expert interpretations.

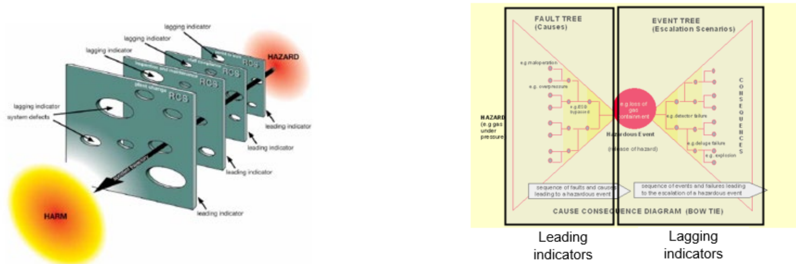
3. The lead/lag debate analysis through the lens of typology design principles

Our analysis material is based primarily on the discussions triggered by Hopkins' paper (2009a) in the PSI Safety Science special issue (2009). This globally represents more than 20 different contributions from both academics and practitioners. In addition to these elements, we have also considered other contributions that either provide further details on one specific perspective of the lead/lag typology or introduces new perspectives as it was the case for Reiman & Pietikainen (2012).
Out of these elements, we defined two key issues that we believe representative of the debate orientations:

- The ability to unambiguously distinguish leading from lagging indicators.
- The ability for lagging indicators to retrospectively demonstrate the relevance of leading ones.

3.1 On the distinction between what is leading and lagging

In his answer to the comments on his initial paper, Hopkins (2009b) emphasised the variety of representations associated to the lead/lag typology and organised them into two categories. The first is defined as *relativist* and is based on the HSE (2006) work distinguishing leading from lagging indicators relatively to a given safety barrier. By referring to the well-known Reason's Swiss cheese model, the HSE defines leading indicators objectives as the identification of "*failings or holes in vital aspects of the risk control system during routine checks…*" whereas lagging indicators aim at revealing *"failings or holes in that barrier discovered following an accident or adverse event*". The second conception is more classic and is defined as *absolutist.* The model used here is the usual bowtie with the loss of containment event separating left and right sides where respectively leading and lagging indicators are to be searched for. Not only Hopkins uncovers the coexistence of these different conceptions, he also puts a finger on how each of these conceptions fails individually to put in coherence its own rules with the way they are applied. In the case of the relativist vision, he proves how some indicators can sometimes be considered as leading and others as lagging depending on circumstances. When it comes to the absolutist type, he spots the inability of both theorists and practitioners to agree on a sharp frontier between what should be considered as the left side of a bowtie and source of leading metrics on one hand and the right-side source of lagging ones on the other hand.



Relativist vision of lead/lag **Absolutist vision of lead/lag**

Figure 1 Relativist VS absolutist visions of the lead/lag typology of SPIs.

However, the discussion triggered by Hopkins left aside a third representation of the lead/lag typology that we may characterise as *holistic*. It is based on the definitions by EPRI (2001), Kjellen (2009) and Reiman & Pietikainen (2012) where leading indicators are expected to track organizational evolutions which may both positively or negatively influence on the final level of risk. Accordingly, it is not the time dimension or the barriers that serve as a segregating frontier between the lead and lag; it is the ability of an indicator to anticipate the system's vulnerability evolutions, for the better or the worse (Reiman & Pietikainen, 2012).
Considering altogether these three different conceptions of the lead/lag typology demonstrates how the divergences discussed here are deep. Not only different conceptions of the same typology are revealed, but some of these conceptions struggle with their own ability to display a consistent way of sorting leading from lagging indicators.
Coming back to the four building blocks of typology elaboration, these limits may be discussed as the following:

i. The lead/lag typology relies on a unique attribute to distinguish different categories of indicators. Unfortunately, this attribute reveals to be ambiguous as it may take different identities from one user to the other: Events (mostly loss of containments), barriers or even organisational evolutions are coexisting interpretations of the unique attribute used in this typology. Accordingly, we believe what needs to be discussed is less the relative accuracy or usefulness of each of these interpretations than the questioning of this attribute's origins and why it takes so many different shapes in process safety.
   A quick historical perspective reminds us that the lead/lag typology has been imported from the economic field (Wreathall, 2009) where some indicators are defined as leading because of their supposed character

to anticipate economic turning points. If a turning point in economy enjoys a quite uniform understanding- being a trend inflection in a quantitative series- it appears that different concepts may serve as turning points in safety. It is either an event of some importance, an evolution of barriers performances or more broadly any organisational evolution with an impact on safety. This heterogeneity is most probably the reflect of the variety of safety models upon which safety may be built. When safety is understood as the absence of risks, the focus is put on identifying the various combination of events leading to a loss of containment. It is therefore not surprising that the turning point takes the form of an event. When safety is understood as the combination of events and latent conditions contributing to create moving holes in the system defences, light is shed on these holes which evolutions become the turning points to track. Finally, when safety is seen as an emerging property resulting from multiple interacting dynamics, PSIs need to focus on a much broader spectrum of organisational factors known as impacting safety.
Accordingly, the lead/lag typology suffers from the assumption that a unique attribute may successfully serve as an efficient frontier for an overarching concept (safety performance indicators) referring to multiple and somehow incompatible safety models.

ii. We have seen how Hopkins observations uncovered internal inconsistencies in each of the two first conceptions of the lead/lag typology. Using events or barriers performances as an attribute fail to build up, for each of these conceptions, a shared understanding of what is leading and lagging. These limits have even reinforced the idea that each indicator may display various potentials for both leading and lagging depending on the context of use (Dyreborg, 2009) (Ericson, 2009) (Hale A. , 2009) (RSSB, 2011). Accordingly, these two conceptions seem to show weaknesses with regard to two major qualities expected from typologies being internal homogeneity within a given type and external heterogeneity between types. Said in other words, where the frontiers separating different categories of a concept become so porous, one is entitled to question the very relevance of the whole typology.

3.2 On the ability to demonstrate any relationship between leading and lagging indicators

Another central topic is the ability to relate leading with lagging indicators (Mearns, 2009). Said simply, how a process safety manager, investing efforts in deploying what he considers as leading indicators and taking actions accordingly, can demonstrate an improvement in safety through lagging ones?
Here again, two distinct approaches suggesting a lead-lag connection can be spotted in the literature.
The first is the well-known events pyramid (figure 2) originally introduced in the sphere of process safety by the API 754 (2010) and largely adopted since then by several practitioners' guidelines (CCPS, 2011) (EPSC, 2012). This model assumes a statistical correlation between four categories (tiers) of events ranged according to their levels of consequences (see figure.2). From top to down, the consequences levels decrease while their frequency increasing their statistical validity. In addition, focusing on events at the bottom tiers (3 and 4) provides managers with opportunities to relate to everyday organisational practices requiring their interventions so to avoid major events occurrence. Accordingly, the leading character of indicators increases with their focus going down to the basis of the pyramid while lagging indicators focus on top events in Tiers 1 and 2.

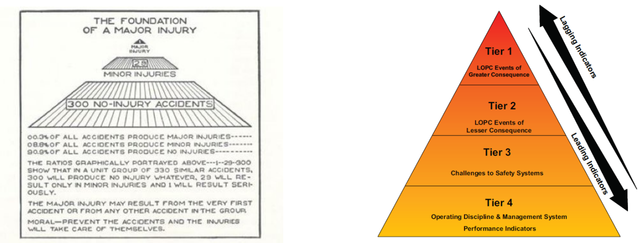


Figure 2 From Heinrich pyramid to API 754 (2010)

This model, as appealing as it may appear, is actually based on the seminal work of Heinrich (1950) followed by Bird and Germain (1986) who looked for statistical relationships in workplace safety between near incidents or dangerous behaviours on one hand and major injuries on the other hand. When it comes to process safety, such a linear relationship has never been proven valid and may even appear intuitively wrong if one remembers the complex and non-linear relationship between events composing the causal chain of accidents and the levels of possible consequences (Hudson, 2009). Accordingly, it seems difficult to assume any theoretical validity for this first approach which leaves us at this level with the incapacity to relate leading and lagging indicators.
The second approach we identified has been suggested by the HSE (2006) and is based, as discussed previously, on identifying leading and lagging indicators for each safety barrier (described as Risk Control Systems). Actually, by considering individually each RCS, this perspective adopted an original standpoint by

drastically shortening the logical pathway between leading and lagging indicators. In a bowtie, leading and lagging indicators can be separated by a long chain of multiple combination of events making the establishment of a relationship hardly practicable. In the HSE work, leading indicators focus on the actions or activities (described as critical elements) required for a RCS to function correctly whereas lagging ones assess whether this same RCS is ultimately delivering its expected contribution to safety. In this case, the pathway we are interested in is the one describing the relationship between a set of critical elements and a desired performance of a given RCS. For instance, when it comes to the RCS "*Inspection and maintenance*", the critical elements identified by the HSE are the ability to perform required inspections and maintenance intervention within due delays. Of course, more sophisticated models can allow for additional critical elements to be identified: maintenance personnel competence, equipment ageing, etc... However, it is fair to recognize that this perspective makes it easier to both elaborate and criticize such pathways making the relationship between leading and lagging much more convenient to establish and improve.
From the typology elaboration perspective, the following remarks can be made:

i. The introduction of the Bird pyramid in the process safety domain reveals the importance of clearly and, as sharply as possible, delimiting the frontiers of the overarching concept of interest. In our case, this needs to be done by further reaffirming the process safety specificities and better describing the associated models currently accepted in the process safety sphere. Further on, academics should probably devote more efforts to help practitioners elaborating this frontier as the latter ones evolve in integrated contexts where financial, quality, workplace and process safety are altogether considered when assessing a company's global performance. Such contexts make it favourable for models to travel from one domain to another without always re-questioning their validity regarding their new application.
ii. If different types need to be as distinct as possible, they also should make sense when considered collectively. In our case, efforts triggered by leading indicators should lead to visible results through lagging ones. Establishing this relationship seems however impaired by the complexity of the mechanisms at hand and the lack of data resulting from the extreme rarity of major accidents. However, the HSE work, although based on a model displaying complex mechanisms, succeeded in shortening the logical distance between leading and lagging by focusing them on individual RCS. In doing so, it abandoned the use of events counting as a measure of lagging indicators and left aside the issue of RCS interactions which appears as a necessary tradeoff to strengthen the lead/lag relationship.
   We believe cutting through the lead-lag pathway is also feasible in both the absolutist and holistic perspectives. Instead of focusing the lagging indicators on the number of incidents or accidents of some importance, the focus would be on intermediate results which may be more easily related to efforts measured by leading indicators. For instance, if efforts are put to improve workforce awareness of process safety incidents, a lagging indicator can simply monitor the evolution of incidents declaration instead of assessing the final number of accidents which may be influenced by several other factors. A direct consequence of such an evolution would be the acceptance that various entities within the same organisation may differ, for their specific use, on what should be considered as leading and lagging. In other words, the lead or lag property of a SPI would be more the result of its organizational use than an intrinsic property that he carries regardless of who and how it is used.

4. Conclusions and perspectives

Through the lenses of typology design, it appears that the inability of the safety community to reach a shared understanding of what makes an indicator genuinely leading or lagging can be retraced to, at least, two causes. The first is the variety of underlying safety models and representations that each indicator can simultaneously carry. These models can be both specific to process safety and imported from other management areas (quality management, workplace safety…). What makes things worse is that even when people agree on the safety model to use, relying on the time dimension as a single distinctive factor between different categories of indicators fails both on internal homogeneity and external heterogeneity criteria. The second cause is that the leading or lagging property of an indicator is highly related to the specific applications users associate to them. Indeed, when implanted in real life, one single SPI may have various social uses, especially when they serve to mediate interactions between different parts of one organisation. Consequently, what is leading for one (organizational part) can be lagging for another although the technical metric used remains identical.
Those elements invite the safety community to address the issue of SPIs typology by going beyond the technical aspects to consider what may represent distinctive properties both in terms of underlying safety models and social functions. Actually, a more comprehensive and scientifically consistent typology of SPIs cannot avoid to be multidimensional so to address all the three facets of every SPI:

- *The technical facet* represented by the metric and its associated calculation terms;

- *The management philosophy facet* encompassed in the definition and models one associate to the concept of process safety and;
- *The social facet* relating to the set of various uses one or a group of stakeholders may decide to associate to it.

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