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Conducting HAZOPs in continuous chemical processes: Part II. A new model for estimating HAZOP time and a standardized approach for examining nodes

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A B S T R A C T

The HAZOP organization phase entails two main tasks to ensure the success of the study, especially when reviewing complex continuous chemical processes (e.g., petroleum-refining processes). The first task deals with selecting the nodes, as we discussed in Part I of this paper. It addresses that task by proposing and justifying tools for and criteria on how to break a process into manageable sections that could be reviewed independently (i.e., nodes selection). Part II describes the development of a time-estimation model for planning HAZOP sessions. Its practical value was confirmed with field work and data analyses of five HAZOPs. Furthermore, we focus on optimizing the time spent in examining selected nodes. This papers also introduces a Deviations Structural Hierarchy (DSH) for treating deviations. Finally, considering the Nodes Selection Methodology (NSM) defined in paper I, the HAZOP time-estimation model (HTEM), and the Deviations Structural Hierarchy (DSH), we present the key tools, criteria, and guidelines for leading HAZOPs for highly complex processes.

Keywords: Process hazard analysis; HAZOP; HAZOP time-estimation model; Deviations Structural Hierarchy; Nodes Selection Methodology

1. Introduction

One important factor to consider when managing HAZOP studies is the time required to execute the entire analysis, especially when numerous P&IDs must be reviewed. Through our field work and data analysis described in Part I of this paper, we developed a mathematical model to predict the expected time to carry out a HAZOP study in continuous chemical processes (e.g., petroleum-refining processes). As explained therein, five HAZOPS were conducted following the proposed criteria. The analysis of the findings proved valuable in formulating an improved HAZOP time-estimation model, thereby simplifying the current cumbersome ones. Two models were available prior to the present one. Thus, Freeman et al. (1992) ma de the first attempt to plan HAZOP studies with an expert system, establishing a way to assess how long and how many work hours a HAZOP study entails. The authors based their estimate on the number of major equipment items to be analyzed, the system's complexity, and the experience of the HAZOP team leader. Five years later, Khan and Abbasi (1997) improved this model, adding new factors and variables; viz., preparation time, meeting time, delays, and report writing; it incorporates multivariable empirical equations. Additionally, the preparation time and study time are the function of three parameters: The number of P&IDs, the complexity of P&IDs, and the skills of the team leader.

The present model aims to simplify and improve prior ones by considering new predictors that define the complexity of the process, and by avoiding subjective variables (i.e., the team leader's experience). Certainly, not account for the experience

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Table 1 – Comparison between HAZOP time estimation models.

Model	Freeman et al. (1992) $T_H = T_P + T_S + T_W$	Khan and Abbasi (1997) $T_H = T_P + T_S + T_W + T_D$	Proposed model $T_H = T_P + T_S + T_W$
Preparation time estimation (T_P)			
Description	T_p depends on the number of P&IDs and its complexity (simple, standard, complex, very complex) by counting the number of pieces of equipment, pipelines and interlocks per P&ID	T_p depends on the number of P&IDs and its complexity (simple, standard, complex, very complex) by counting the number of pieces of equipment, and pipelines per P&ID	T_p depends on the number of P&IDs (P&IDs), the total number of pieces of major equipment (ME), and requires to follow the proposed Nodes Selection Methodology (NSM)
Input data	Number of P&IDs, and P&IDs complexity	Number of P&IDs, and P&IDs complexity	P&IDs, ME, NSM
Output data	T_p	T_p	T_p; and according to Part I: the number of nodes (Nd)
Sessions Time Estimation (T_S)			
Description	T_S depends on the leader skills (novice, average or experienced; according to the number of previous HAZOPs carried out), the number of P&IDs, and P&IDs complexity	T_S depends on the leader skills (novice, moderately experienced, experienced and highly experienced; according to the number of previous HAZOPs carried out), the number of P&IDs, and P&IDs complexity	T_S depends on the number of nodes (Nd) = f(P&IDs, ME), and requires to follow the proposed Deviations Structural Hierarchy (DSH)
Input data	Number of P&ID, P&IDs complexity, leader skills	Number of P&IDs, P&IDs complexity, leader skills	P&IDs and ME (or which is the same: Nd), DSH
Output data	T_S	T_S	T_S
Writing Time Estimation (T_W)			
Description	T_W depends on the T_p	T_W depends on the T_p	T_p depends on the T_p
Input data	T_p	T_p	T_p
Output data	T_W	T_W	T_W
Delay time estimation (T_D)			
Description	Not considered	T_D includes the time lapsed due to non-availability of members, documents, or any other essential items, and individuals responding time	Not considered
Input data		T_p, T_W	
Output data		T_D	

of the team leader will be possible only if we propose criteria to guide leaders during the HAZOP performance. Thus, our proposed model avoids including subjective variables, but only if the following two approaches are adopted when the organization- and execution-phases of the HAZOP analysis: (1) the Nodes Selection Methodology (NSM) (explained in the part I of the present paper) and (2) the Deviations Structural Hierarchy (DSH), which will be illustrated after showing the new model. Table 1 summarizes the key similarities and differences between these models.

2. The HAZOP time-estimation model

During the analyses of the five HAZOPs, we collected and recorded key variables for modeling purposes. Different parameters were studied: (1) time to collect and organize the key data needed for the study (T_P); (2) time to execute the HAZOP sessions (T_S); and (3) time to prepare the first draft of the HAZOP report (T_W). These three parameters were explored to find relationships between factors that inherently define the complexity of the process to be "HAZoped" (i.e., the number of pieces of major equipment, of P&IDs, and of PFDs, the total amount of "minor" equipment, e.g., FCVs, Pumps present in the process). After defining many combinations (all studied both from the point of view of mathematics and of process safety) we were able to establish a well-fitted regression between the time expected to complete a HAZOP study in continuous chemical processes and the ambit of the various combinations. This modeling approach is equivalent to that explained in part I of this paper when modeling the expected number of nodes to be selected. The two predictors enable us to easily to evaluate the complexity of the process are, again, the following: (1) The number of pieces of major equipment present in the processes (ME), which are clearly illustrated on PFDs and (2) the number of P&IDs required to define the process (P&IDs). Furthermore, we also recorded the time required to brainstorm each selected node for a deeper analysis and thus, to provide more reliable conclusions, especially for assessing the time needed to brainstorm the HAZOP sessions. Table 2 lists the key data used to develop the model. Hereafter, as illustrated in Table 1, the total time required to conduct a HAZOP study is defined as follows:

$$T_H = T_P + T_S + T_W \quad (1)$$

Finally, as discussed in Part I, modeling not only entails simple regressions using least-square models, but involves the following: (1) storing the regression statistics; (2) exam-