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DOI
10.3303/CET1977009

Publication date
2019

Document Version
Final published version

Published in
Chemical Engineering Transactions

CHEMICAL ENGINEERING TRANSACTIONS

VOL. 77, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano

ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977009

Developing Leading Safety Indicators for Occupational Safety Based on the Bow-Tie Method

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In order to control occupational accidents, it is crucial to have a clear view on the potential accident scenarios that are present in a company. The bow-tie method is a way to capture and visualise these accident processes in an integrative way. Included in the bow-tie are safety barriers (both technical as organisational and human) and management delivery systems that can intervene in these accident processes. Once bow-ties are composed, they are an excellent point of departure to assign indicators to the safety barriers and management delivery systems in order to control (i.e. prevent or mitigate) the accident scenarios. Two types of indicators can be distinguished. Firstly, there are general indicators that are linked to management delivery systems interrupting multiple accident scenarios, and which can yield a higher safety gain (as they intervene in multiple accident scenarios). Secondly, there are scenario-specific indicators targeting one specific accident scenario, and which can be valuable as they target a specific safety problem in the company. Some crucial aspects have to be taken into account when using indicators, such as sequentiality in follow-up and prioritization of indicators, and the focus on quality rather than quantity.

1. Introduction

Internal transport represents a well-known occupational hazard in many modern industrial environments. Pallet movers (Figure 1) are used for internal transport in several industries, and these machines are easy to operate, compared to for example forklift trucks. However, pallet movers are inherently dangerous machines. They often operate close to pedestrian workers, and charged with a load, their total mass can be well above two tons. Often, their load is not secured to the machine, leading to instability when gravity gets grip of the load.

Figure 1: Types of pallet movers – left: standard pallet mover, right: stacker

The company under investigation in this study is a manufacturing plant located in Belgium, which is part of an American multinational, producing consumer products all over the world. Pallet movers are used frequently for internal transport. Like many major American companies, also this company pays a lot of attention to the

Paper Received: 11 December 2018; Revised: 20 April 2019; Accepted: 4 July 2019

Please cite this article as: van Nunen K., Swuste P., Reniers G., Schmitz P., 2019, Developing leading safety indicators for occupational safety based on the bow-tie method, Chemical Engineering Transactions, 77, 49-54 DOI:10.3303/CET1977009

safety of their employees. However, the current accident investigation techniques that are being use do not substantially reduce the occupational accidents. As an alternative, a bow-tie analysis is proposed, providing a detailed and comprehensive insight into potential accident scenarios, including possible safety barriers (both technical and non-technical) and management delivery systems which can prevent or mitigate the accident processes. To test the bow-tie analysis, a pilot project was formulated, focussing on accidents during internal transport with pallet movers. Accidents with pallet movers represent a significant share of the total number of accidents. In the years 2015 and 2016, about ten percent of all recordable accidents with lost work time that occurred at the European plants of the multinational involved a pallet mover.
The research question of this study is: ‘Which accident scenarios are possible during internal transport with pallet movers and which safety barriers (both technical as organisational and human) and management delivery systems can influence (i.e. prevent or mitigate) these accident scenarios?’

2. Research methodology

To compose the bow-ties of accidents with pallet movers, a multi-method design was used.
Firstly, a literature search was conducted using the following search terms: ‘pallet mover’, ‘pallet jack’, ‘walkie-rider’, ‘pallet truck, ‘transpallet’, and ‘accident’. Safety related articles on pallet movers were rather scarce in literature. Therefore, articles on forklift truck accidents (using the search term ‘forklift’) were also included in the literature study, for as far accident processes had similarities with the ones of pallet movers.
Secondly, Belgian and Dutch national data on pallet mover accidents were requested. For Belgium, data on pallet mover accidents are obtained from Fedris, the Belgian federal agency for occupational risks. For The Netherlands, Storybuilder is used, which is a software tool developed for the Dutch Ministry of Social Affairs and Employment (Bellamy et al, 2008). Both agencies have provided data on accidents reported to and investigated by the labor inspectorate. The databases also contain information on types of accident scenarios, root causes, and failing safety barriers.
Thirdly, documents and data concerning pallet mover safety available at the Belgian plant (and by extension at all European plants if available) were analyzed (such as material of the pallet mover training, minutes of monthly safety meetings, safety notifications regarding pallet movers in the incident registration system). During 2015-2016, 127 safety notifications regarding pallet movers were available at the Belgian plant comprising information on accidents (n=9), near-misses (n=9), unsafe conditions (n=93) and positive feedback to the operators (n=16). All available accident analyses performed after a recordable accident with a pallet mover were also taken into account.
Fourthly, at the Belgian plant, observations were being held at the workplaces of the pallet mover operators. A personal introduction of the researchers and the purpose of the study were given before the observations, and an introduction was given to the contractors during their daily team meetings. Observations were complemented with interviews with operators (n=25), team leaders (n=5), the HSEQ staff (n=3) and management (n=2). The staff of the external company that provides the training of the pallet mover operators was also interviewed.

3. The bow-tie model

The safety metaphor used in this study is the so-called bow-tie (Figure 2). The bow-tie metaphor illustrates an accident process, starting with a hazard on the left hand side. A hazard (or energy) is a source or a condition with the potential for causing harm. Various accident scenarios, pictured as left-right arrows, can migrate to the center point of the metaphor, the central event. This central event represents a state where the hazard (energy) has become uncontrollable, and thus becomes an undesirable event with potential for harm or damage. The central event proceeds to the consequences at the right hand side of the metaphor, being harm to people or damage to assets or environment.
The strength of the metaphor is its relationship between accident scenarios, technical safety barriers, non-technical safety barriers and management delivery systems. A scenario is a sequence of events and conditions necessary for an accident to occur. Looking at the scenarios, two types of events can be distinguished. There are pre-event accident scenarios presented at the left hand side of the central event (leading to the central event), and there are post-event accident scenarios depicted at the right hand side of the central event (leading to the consequences). The technical safety barriers, represented as the black boxes in the scenarios, are technical entities that can interrupt the accident scenario. An example of a technical safety barrier is an emergency stop on a pallet mover. The non-technical (or organizational and human) safety barriers are represented as the white boxes in the scenarios, being non-technical entities that can interrupt the accident scenario. An example of a non-technical safety barrier is the removal of leaking cubitainers (which interrupts the pre-event accident scenario of losing control over the pallet mover due to leaked products on the

floor). The upwards arrows in Figure 2 represent the influence of management delivery systems. Management delivery systems influence the quality (in terms of reliability and availability) of the technical and non-technical safety barriers. For example, maintenance of the emergency stop on the pallet mover does not interrupt the accident scenario in a direct way, but is a management delivery system influencing the reliability of the technical safety barrier ‘emergency stop on pallet mover’. Another example of a management delivery system is the training of pallet mover operators on removing leaking cubitainers, which influences the reliability of the non-technical safety barrier ‘removal of leaking cubitainers’.
A more detailed explanation of the bow-tie method can be found in the paper of Swuste et al. entitled "Process safety indicators, how solid is the concept?", which is also published in the LP2019 conference proceedings.

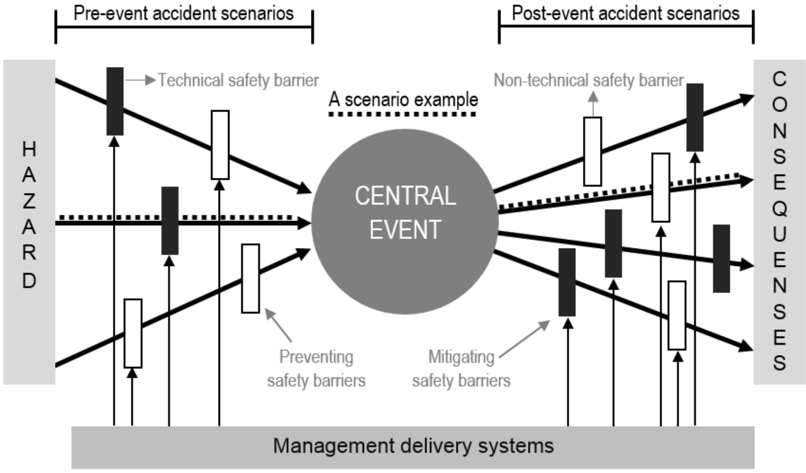


Figure2: The bow-tie model

After bow-ties are developed, the next step is to identify indicators and to link them with the safety barriers and the management delivery systems (Swuste et al, 2016). Indicators are able to visualize possibilities for improvement, to indicate safety improvement or safety decline over time, and create benchmarking (e.g. between different plants). Once indicators are developed, targets and limits should be assigned to every indicator (what is acceptable or inacceptable as a result or for instance tolerable with leeway for improvement). Also, responsibilities have to be set up in order to achieve goals and to define actions when targets are not met. According to the needs of the company, indicators can be prioritized (which indicators are for instance more important or more feasible to implement).

4. Bow-ties of accident processes with pallet movers

Based on the findings of the literature study, information available through Belgian and Dutch national accident databases, the analysis of documents and data regarding pallet movers available at the Belgian plant, and the results of the fieldwork (observations and interviews), bow-ties of accident processes with pallet movers were composed. Seven hazards could be identified: load, speed of the pallet mover, acceleration of the pallet mover, design of the workplace, condition of the workplace, condition of materials (load and pallet mover), and operating the pallet mover. Through several identified pre-event accident scenarios, these hazards can lead to central events: instability of load, loss of control of pallet mover, and breakdown of pallet mover. At their turn, these central events can lead through several identified post-accident scenarios to different consequences: injury, damage, or economic loss (because of a stop of the production process). Several safety barriers (both technical as organisational and human) and management delivery systems to prevent or mitigate the central event could be linked to the accident scenarios.

5. Assigning indicators to the bow-ties

Once bow-ties are composed, they are an excellent point of departure to assign indicators to the technical and non-technical safety barriers and to the management delivery systems in order to control (i.e. prevent or mitigate) the accident scenarios. Indicators can support a company’s safety management, and provide information on a preferred safety goal. It is important that indicators focus on aspects that are applicable to the operating environment. For instance, it could be an improvement to replace all present pallet movers by new, less heavy equipment. However, in the context of the company, it is possible that this is not feasible due to

budgetary constraints. Another example is reorganization of the lay-out of the floors, which is an important aspect in order to create more maneuvering space. However, in the plant under investigation, installations are integrated in an existing space which was initially not designed for that purpose, leading to space constraints. Also, in the past years, several improvements have already been made regarding the lay-out of the working space and the work floor, and there is of course a limitation to the possibilities in creating more maneuvering space. A question arising from this space constraint is whether pallet movers are the best equipment to use at particular spaces in a production facility with limited maneuvering space, and if it would not be better to search for an alternative way to transport the material. This is related to the inherent safety of a company (Kletz, 1991), which will be discussed at the end of this section.
Besides the applicability of indicators in the company environment, the focus of the indicators can also be chosen based on the presence of management delivery systems. For instance, when composing the bow-ties of accident processes with pallet movers, certain management delivery systems are present in multiple scenarios. It concerns the management delivery systems ‘training of pallet mover operators’, ‘sensitization and communication’, ‘guidelines and procedures’, and ‘planning of production and staffing’. Indicators assigned to these management delivery systems can be considered as general indicators, as they are linked to multiple accident scenarios. As an example, the management delivery systems ‘training of pallet mover operators’ is further elaborated below.
Next to general indicators, also scenario-specific indicators can be developed. Decisions on what scenarios should be focused on, can be based on the plant-specific risks regarding pallet mover use. As an example, the company-specific pre-scenario ‘leaking cubitainers’ will be further elaborated below.

5.1 General indicators: training of pallet mover operators

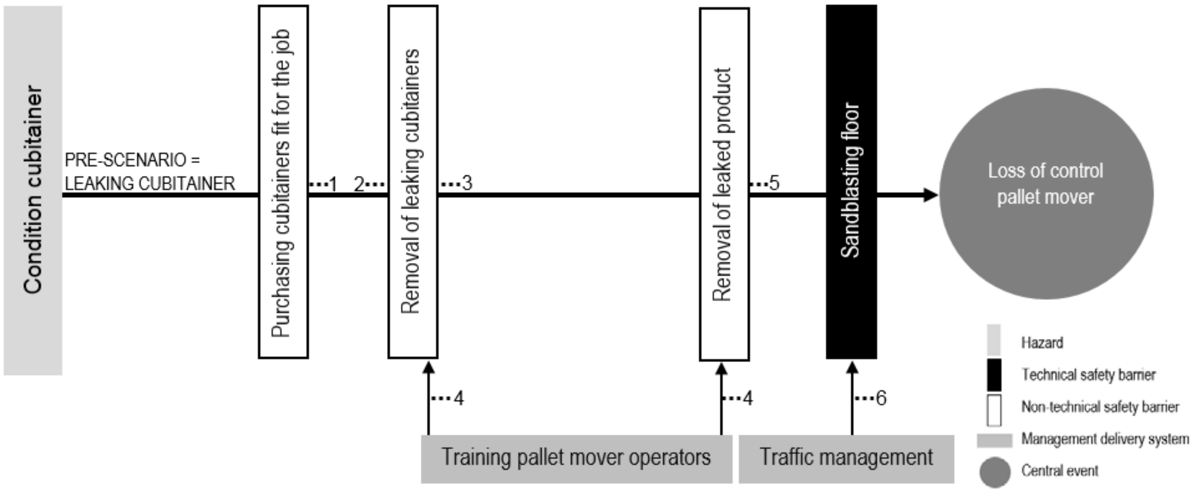
In Figure 3, possible indicators for the frequently occurring management delivery system ‘training of pallet mover operators’ have been elaborated. An indicator on the content of the (re)training is proposed, and an indicator on the quality control of the (re)training. Also, there are indicators regarding the coverage ratio of the training and the retraining. It should be noted that a certain sequentiality is present in the follow-up of the indicators. For instance, a high coverage ratio of the (re)training is negligible if the content of the (re)training is not tailored at the needs of the company and if the quality of the (re)training is evaluated as substandard.

Sequentiality in follow-up ↓		
	Content (re)training	Evaluation of the content of the (re)training every two years: is the (re)training completely tailored at the needs of the company? (yes/no) Aspects to take into consideration: - Use of examples of specific risks & possible accident scenarios at the company? E.g. narrow manoeuvring spaces, wet floors, too crowded buffers,… - Sufficient rules and guidelines for the target audience?
	Quality control (re)training	Yearly evaluation of the percentage of participants of the (re)training evaluating the training as positively (i.e. a score of 7 out of 10 or higher)
	Coverage ratio training	Monthly evaluation of percentage of starting pallet mover operators that is trained for pallet mover use
	Coverage ratio retraining	Yearly evaluation of percentage pallet mover operators receiving a retraining every five years

Figure 3: Possible indicators for the management delivery system ‘training of pallet mover operators’

5.2 Scenario-specific indicators: leaking cubitainer

A specific risk at the plant under investigation is the worn drain valves of cubitainers, leading to spills of liquid content. Products on floors lead to a longer breaking distance and a higher chance of losing control over the pallet mover. Figure 4 presents the bow-tie of the pre-event accident scenario of damaged loads, and more specific leaking cubitainers, complemented with possible indicators for this specific scenario. Only a selection of possible safety barriers and management delivery systems has been included in the bow-tie, namely the non-technical safety barriers ‘purchasing cubitainers fit for the job’, ‘removal of leaking cubitainers’, and ‘removal of leaked product’, the technical safety barrier ‘sandblasting floor’, and the management delivery systems ‘training pallet mover operators’ and ‘traffic management’.



	Content to evaluate	Frequency of evaluation	Outcome of the evaluation
1.	Evaluation of the supplier(s) of the cubitainers: Number of newly purchased cubitainers that leak / Number of newly purchased cubitainers	Once every year	%
2.	Number of cubitainers that leak / Number of cubitainers	Once every month	%
3.	Number of leaking cubitainers that are removed immediately / Number of leaking cubitainers	Once every month	%
4.	Evaluation content training pallet mover operators: Is the following included in the training? - Not using leaking cubitainers - Signalizing leaking cubitainers - Immediately cleaning leaked product on the floor	Once every two years	Yes / No
5.	Observation during a specific time period (e.g. two hours): Compliance with immediately cleaning leaked product on the floor	Once every month	Number of non-compliances
6.	Number of transportation routes with cubitainers that is sandblasted / Number of transportation routes with cubitainers	Once every two years	%

Figure 4: Possible indicators for the pre-scenario of ‘leaking cubitainer’

5.3 Evaluation of the indicators

Once indicators have been determined, they have to be evaluated. Based on the specificity of the indicator and the needs of the company, this evaluation can take place on a yearly basis, or if needed with a lower or a higher frequency. Also, after the development of the indicators, targets and limits have to be linked to every indicator. This means that the company has to decide what is acceptable as a result and what is not. In the example of the coverage ratio of the training, a target could be that 100% of all pallet mover operators should be trained for pallet mover use. In the example of the number of leaking cubitainers, a target could be that <5% of the cubitainers is leaking.

An important aspect is that responsibilities have to be indicated: who does what and when in order to reach the goals of the indicators. In the example of the (re)training, a responsible has to be indicated for the subscriptions for the (re)training. The same applies for responsibilities to take actions when a target is not achieved.

In order to facilitate an adequate monitoring of the indicators, a system should be set up to report and to collect the required data. Such systems are often already (partly) present in a company.

To be complete, something should be said on the necessity of the indicators, which is a reflection that should be made before developing the indicators. After all, it firstly should be analyzed if the processes that are present in the company are as inherently safe as possible (Kletz, 1991). In the given example regarding the narrow maneuvering spaces, it should be considered if a pallet mover is the safest equipment to use at these places (and by extension at all places). In the example of the leaking cubitainers, it should be considered if cubitainers are necessary and if the process cannot be designed in such a way that transportation of the liquid is minimalized. The article of Kletz (1978) entitled “what you don’t have, can’t leak” is a good resume of this matter.

6. Discussion and conclusion

The bow-tie method is chosen in order to address pallet mover safety at a Belgian manufacturing plant. The bow-tie was chosen for several reasons. Firstly, the bow-ties were composed using a multi-method design. This multi-method design leads to a better comprehensiveness of the entire accident process of pallet mover use, and gives a detailed overview of what could possibly go wrong with a pallet mover. In the bow-ties, the possible causes and consequences of potential accidents are identified. Also, the bow-tie includes the influence of safety measures (safety barriers and management delivery systems) on the evolution of accident scenarios (De Dianous et al, 2006). Because a multi-method design was used to compose the bow-ties, not only company specific data were included, but also generic data sources such as literature and national accident data. This leads to information on the entire accident process, including aspects that have not (yet) occurred at a specific plant.

Because of the comprehensive character of the bow-tie method, the results are easily transferable to other production facilities where pallet movers are used for internal transport, assuming that the hazards are the same. This means that, if this study was conducted in another production facility with similar hazards and working environment, composition of the bow-ties would have led to a similar outcome (this does not mean that the process of linking indicators to the bow-ties is the same, as this is very company specific). In other words, the bow-tie method leads to a general model that is transferable and applicable in every setting where, in this case, pallet movers are being used. However, the indicators may be different.

Another advantage of the bow-tie method is that it allows to make a clear distinction between preventing and mitigating safety barriers and management delivery systems.

Seven hazards regarding pallet mover use could be identified based on the composition of the bow-ties: load, speed of the pallet mover, acceleration of the pallet mover, design of the workplace, condition of the workplace, condition of materials (load and pallet mover), and operating the pallet mover. Through several identified pre-event accident scenarios, these hazards can lead to a central event: instability of the load, loss of control over the pallet mover, and a breakdown of the pallet mover. At their turn, these central events can lead through several post-accident scenarios to different consequences: injury, damage, or economic loss. Several technical and non-technical safety barriers and management delivery systems to prevent or mitigate the central event could be linked to the accident scenarios.

Once bow-ties are composed and safety barriers and management delivery systems have been identified, indicators should be developed and monitored consequently. These indicators should be composed based on their applicability in the company, meaning what is possible given a specific company environment. When developing indicators, an important distinction can be made. Firstly, there are general indicators. In the bow-ties, certain management delivery systems can be linked to many of the accident scenarios. When indicators are developed for frequently occurring management delivery systems, these indicators can be considered as general, because they are not linked to only one scenario. Secondly, there are scenario-specific indicators. This means that indicators are linked to specific scenarios that require attention in a plant. With both the general and the scenario-specific indicators, a certain sequentiality should be acknowledged in the follow-up of the indicators. For all indicators, it is therefore important to set priorities.

To conclude, indicators are an important result of a bow-tie analysis. When a company reaches consensus on a set of indicators to be monitored, a unique insight is obtained on the status and development of potential accident scenarios. The management can intervene adequately to ensure a safe production.

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