System Safety Assessment of the Warehouse Operation Using Functional Resonance Analysis Method and Resilience Analysis Grid

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Abstract

This study applied the perspective of Safety-II using the Functional Resonance Analysis Method (FRAM) and the Resilience Analysis Grid (RAG) to analyze safety in warehouse operations from a system perspective. FRAM was used to emphasize what caused things to go right, with the findings highlighting higher performance and safety variability occurring in activities that require multiple individual or group efforts. RAG was used to assess the organization's potential to handle unexpected occurrences, identify the potential resilience of the warehouse in its daily activities, and evaluate the ability to maintain flow and worker safety based on four pillars of resilience. The assessment resulted in a value of 3.50 in the ability to respond, 2.84 in the ability to monitor, 3.88 in the ability to learn, and 3.21 in the ability to anticipate. Combining FRAM and RAG enhances the depth of a new perspective of safety analysis and addresses resilience factors in daily operations.

Keywords: Functional Resonance Analysis Method, Resilience Analysis Grid, resilience engineering, Safety-II, system safety

Introduction

Ensuring that tasks are completed with a minimal amount of problems is desirable in every line of work, particularly jobs that require repeated activities. Accidents or categorized hazards that may lead to risk are sometimes examined to avoid having a repeat of the same accident. This approach is known as Safety-I.[1] However, recent developments in the concept of safety have shifted how people view the work process. Rather than focusing on accidents, the approach aims to understand the right ways of accomplishing work. This new perspective has emerged as the concept of Safety-II.[1,2] The perspective of focusing on what makes things go right can improve our understanding of how a system works.[3] An advantage of using this new perspective is that the amount of work done right always outnumbers the amount of work done wrong (e.g., accidents).[4] Having a large amount of correctly done work to observe enables more activities to be reviewed, and these activities can serve as a basis for learning.

In the attempt to get things done correctly, having resilience in adjusting to the different working conditions on any given day is key to maintaining safe and desirable working conditions. According to Hollnagel, the causes of acceptable and unacceptable outcomes are similar.[1] Moreover, some effort should be made to keep performance at an acceptable outcome state, known as the concept of resilience.[5] Higher resilience means the increased likelihood for an activity to remain safe.[6] Good resilience in an organization can help shape and improve its safety culture.[2,7] Ideally, the level of resilience is the same throughout the entire system. However, modern systems, often referred to as socio-technical systems, are highly complex and contain multiple interacting factors within the system, both socially and technically.[8] Hence, resilience can vary between these various factors.[8]

The Functional Resonance Analysis Method (FRAM) can be used to understand the work activities of a system by illustrating and analyzing the complex interaction of components in a socio-technical system.[8] This method has been researched and used for a wide variety of purposes, such as breaking down accidents that happened in the past,[9-12] analyzing day-to-day operation activities,[13-17] portraying possible undesirable outcomes as risk assessment,[18,19] and modeling a system before its implementation.[20,21] These previous uses of this method have

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shown that FRAM can illustrate a wide array of systems, clarify the interaction between system factors, and point out problems that might have to be addressed within a system.

Despite the wide potential for using FRAM, this method has scarcely been used to assess problems with supply chain systems.[22] Problems in any part of a supply chain system often occur with a relatively low impact but with high frequency,[23] particularly in day-to-day operations, such as warehouse activities. In the long term, this high frequency of problems potentially aggravates and lowers the overall ability of the warehouse to deliver products. FRAM can help analyze the system by pointing out where the performance variability in the system lies. Findings on performance variability can then help determine whether the system has the resilience to handle the constantly changing situations in the everyday work environment.[24]

The Resilience Analysis Grid (RAG) is used to measure the potential resilience capabilities of the system based on four pillars of resilience (respond, monitor, learn, and anticipate).[25,26] The RAG method has been used to measure potential resilience in the medical field,[27] air traffic management,[28] and heavy vehicle transport.[29] This study discussed the breakdown of the warehouse system as part of the supply chain using FRAM, the results of which could point out the function with the highest possible performance variability. Further analysis entailed the use of the RAG method to measure the potential resilience of the organization against vari-

ability. This study also exhibited the application of the perspective of Safety-II in the logistics industry, which has been rarely observed.

Method

This study was conducted from October to November 2021 in one of the Fast-Moving Consumer Goods (FMCG) distribution companies in Surabaya, Indonesia. First, three types of data gathering were conducted: direct observation, non-structured interviews, and structured questionnaires. FRAM was then used to model the flow of daily activities within the warehouse operation to find the possible aggregation of performance variability. This step resulted in a FRAM model that provided detailed information on the functions with high safety performance variability. A further analysis was conducted where RAG was used to measure the potential resilience level against the performance variability found in several functions based on the FRAM model. Findings were then mapped into a spider chart and interpreted and analyzed before the concluding remarks were given. Figure 1 exhibits the schematic structure of this study.

Data were collected in late October 2021. First, direct observation of the warehouse condition was conducted with the manager's permission, and any occurrences observed were noted. The purpose of the observation was to gain a better understanding of the process inside the warehouse. This included any step of the process according to six nodes in the tools and categorizing each process into connected nodes to represent the warehouse system.
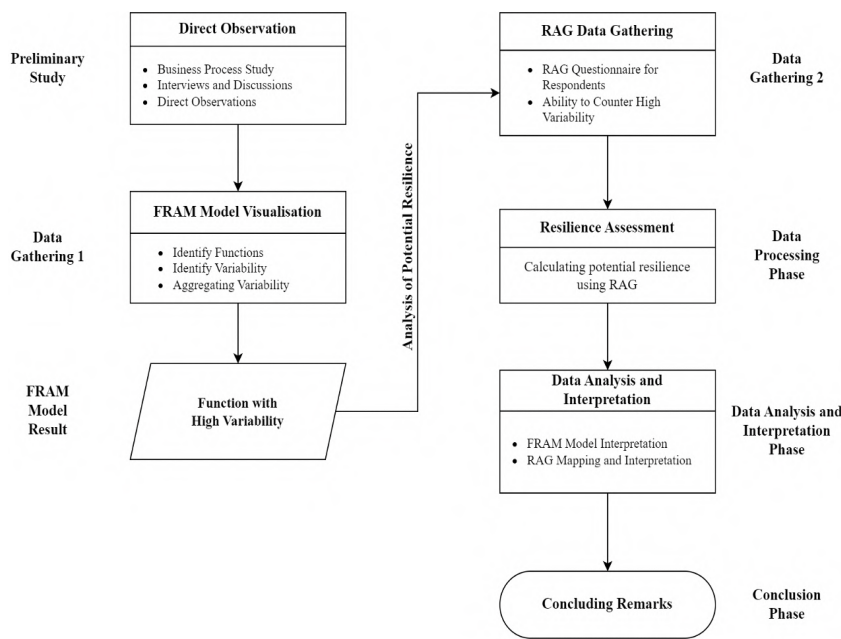

Figure 1. Structured Schematic of the Study

The observation began the moment the products arrived at the warehouse and continued until they were placed on the truck for delivery. Non-structured interviews accompanied the observation. The combination of observation and interviews helped to provide a more in-depth understanding of the ideal functioning within the system and facilitated the construction of the model. The collected data were analyzed using FRAM to visualize the overall activities inside the warehouse based on all the information derived from the observation and interviews. Each activity was analyzed into a function in the FRAM visualizer, and the factors affecting each function were described to identify the connection between the functions.

The critical functions that were deemed to contribute to system irregularities were analyzed with RAG to rate the potential resilience to deal with the constantly changing conditions. The questionnaire consisted of 20 question items, with 20 variables: the ability to respond (8), monitor (4), learn (5), and anticipate (3). These question items represented 20 variables chosen and suited to the warehousing activities. In total, 33 participants from the FMCG central warehouse completed the structured questionnaire. The participants ranged in age from 25 to 51 years, and the length of their work experience in the warehouse ranged from 3 to 31 years. The sampling was made possible by the manager, who provided access to the warehouse, and the willingness of operators and pickers/packers to participate during their scheduled work hours. The responses given by the participants were then calculated and mapped using a radar chart to represent the average score of each variable within each of the four abilities and the overall score of potential resilience.

Results

Functional Resonance Analysis Method Model Visualization

The FRAM model was created through four steps: identifying functions, identifying variability, aggregating variability, and model constructions. The steps and their results are described below.

a) Identifying Functions

The tasks related to the daily operation activities of the warehouse were observed, identified, and then put into functions in the model. Details of the observation activity have been described in the Method section. Observation included receiving products from manufacturers, loading the products into trucks for delivery, and handling returned items. The listed activities were classified into 14 foreground functions, 6 background functions, and 3 functions for completeness of the model. An overview of the functions is presented in Table 1. The classification was divided into three categories: 1) whether the activity changed the status of the input dur-

ing the process (foreground functions), 2) the activity that did not change the status of the input (background functions), and 3) listed processes that needed to connect with other functions (function for completeness).

b) Identifying Variability

Several foreground functions had different inputs that needed to be coordinated to accomplish a successful operation. This was especially true for the functions that took longer to complete. Functions that were mostly run by humans were key as they entailed a higher potential for imprecise output variability. Human functions combined with organizational aspects could also influence variability as the interaction went further, leading to the aggregation of variability inside the system.

c) Aggregating Variability

Ideally, the aggregation of variability would be found in downstream activities because such activities are performed by humans. Moreover, these activities require a great deal of coordination and communication in order for the function to be performed seamlessly. Functions that usually take longer to finish, combined with the need for a large group, would result in wider variability and more aggregated variability, which would result in a step/function with the wave sign of resonance in the background of the function hexagon in the model.

d) Model Construction

The functions listed in Table 1 built into the model were color-coded to display the different function performers. Blue represented the unloading material handling team, green represented the picker/packer loading team, and red represented the returned items handling team. The complete visualized model can be seen in Figure 2, where aggregated performance variability was found in the functions of item placement on the rack, the picking of items, and the delivery process.

Resilience Analysis Grid Assessment Results

According to the model, a possible performance variability was detected in the functions carried out by the material handler and picker/packer in the warehouse. This made it appropriate to focus on the potential resilience of the material handler and picker/packer. RAG assessed the average score of each variable of the four abilities and the overall score regarding potential resilience.

a) Ability to Respond

This ability showed how well the organization responds to undesired or unusual occurrences. Eight variables were fitted to measure the ability to respond. The result was 3.09 in event list, 4.09 in background, 2.61 in threshold, 3.58 in response capability, 2.61 in speed, 3.55

Table 1. Overview of Functions in Warehouse Operations

| Foreground Function	Background Function	Function for Completeness of Model
• Items input to the system • Rack placement labeling of item • Unloading item • Item placement to rack • Making goods pickup document • Allocating delivery order • Issuing dispatch report • Listing items in picking slip • Printing loading sheet • Delivery process • Item drop off at bad stock warehouse • Item repacking • Issue to the central warehouse • Item transfer • Returned items registered to the system	• Truck entering the loading dock • Checking of goods receipt • Item transfer from bin to bin • Register bin to bin • Items selection • Invoice deletion	• Warehouse system • Warehouse rack • Items burning
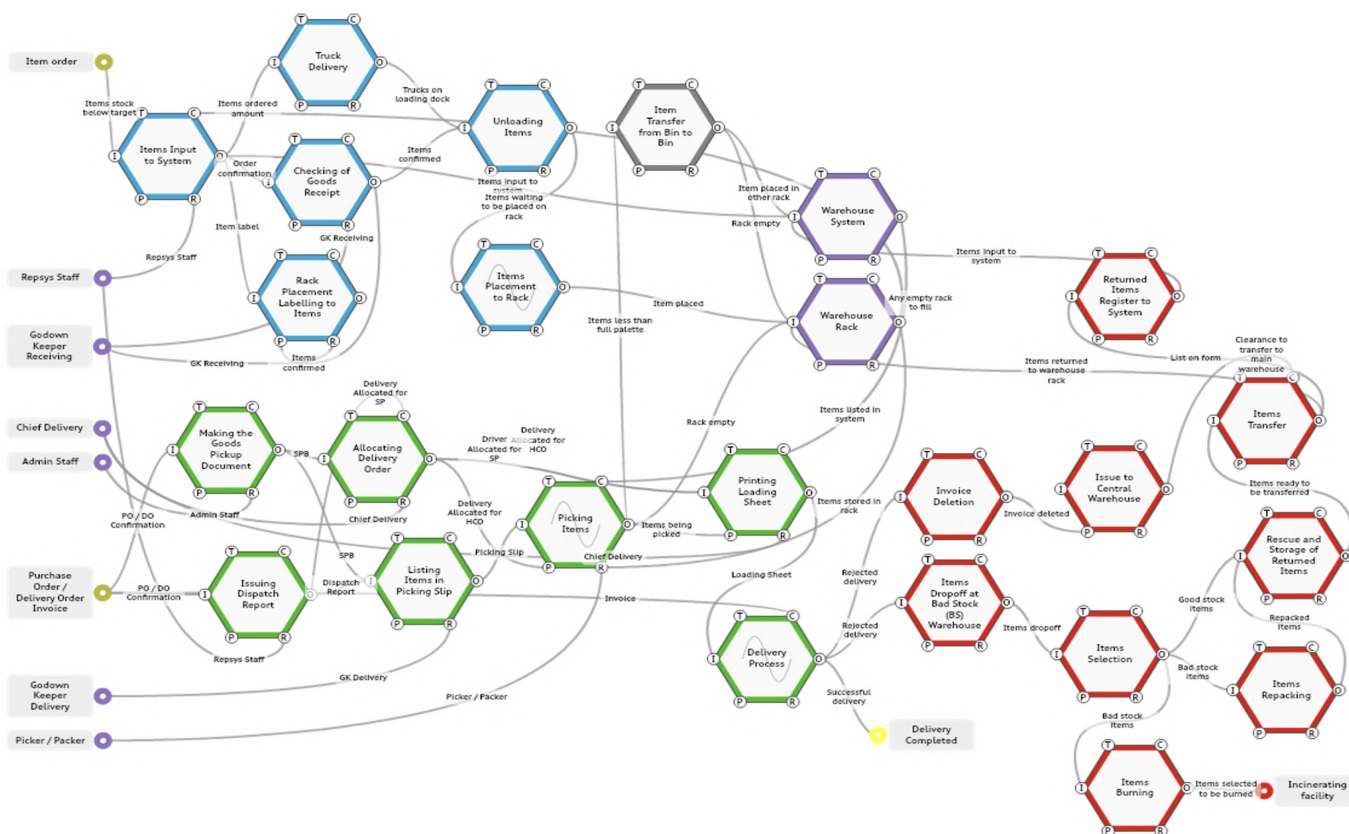
Figure 2. Functional Resonance Analysis Method Model Visualization of Warehouse Activity

in stop rule, 4.10 in duration, and 3.82 in relevance. The mapping of the average score of each variable is illustrated in Figure 3a.

b) Ability to Monitor
This ability showed how well the organization can

spot the signs of any possible difficulties. Four variables were used to measure the ability to monitor. The result was 3.04 in the indicator list, 2.92 in measurement type, 2.84 in measurement frequency, and 2.54 in relevance. A mapping of the average score of each variable can be seen in Figure 3b. This result showed that while there were
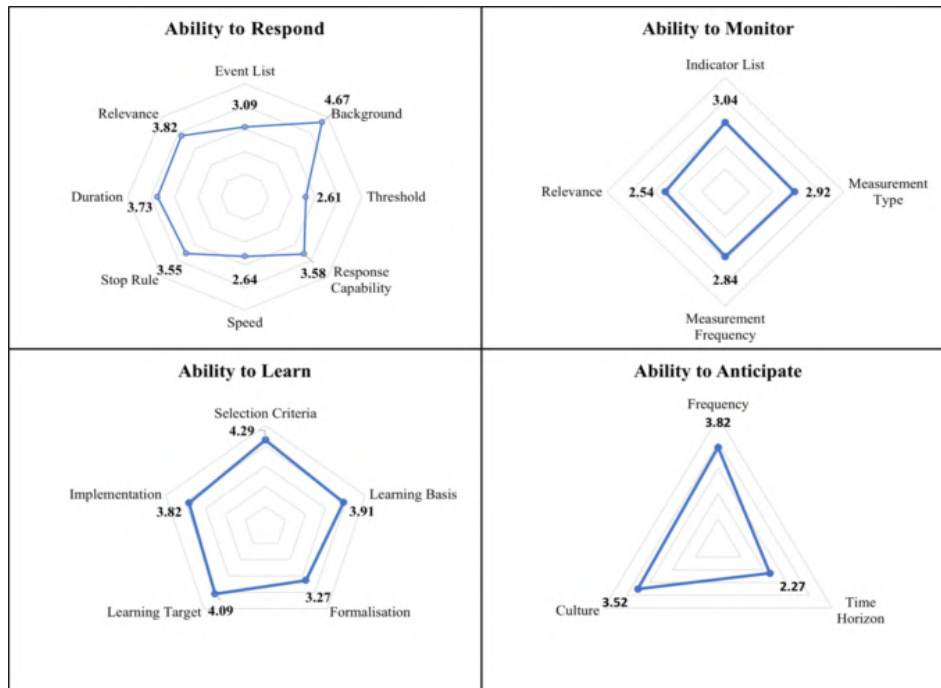
Figure 3. Mapping of the Average Score of Each Variable Regarding Resilience Ability; (3a) Ability to Respond; (3b) Ability to Monitor; (3c) Ability to Learn; and (3d) Ability to Anticipate

available measurement indicators to compare the usual capability with the increasing number of orders, the use of the indicator lists of performance was not perceived as optimal by the workers, resulting in the average value of the measurement type sub-variable. The measurement indicator was also used infrequently (only yearly monitoring), resulting in a low value of the frequency sub-variable. The performance indicator was also infrequently updated with the recent historical data of the total orders because the lists were only updated every 2-5 years and did not consider trends, seasonal demands, etc., resulting in a low relevance value sub-variable.

c) Ability to Learn

This ability showed how well the organization selects and learns from previous events and better understands how to succeed under various conditions. Five variables were used to measure the ability to learn. The result was 4.29 in selection criteria, 3.91 in learning basis, 3.27 in formalization, 4.09 in learning target, and 3.82 in implementation. A mapping of the average score of each variable can be seen in Figure 3c. The company had an excellent score in the ability to learn, with a value of 3.88. This means that in some cases, workers in the warehouse had a relatively good ability to learn from the previous adverse events, as evidenced in the selection criteria

(4.29), indicating that almost all near misses, incidents, and accidents were investigated and managed. The score of the learning target (4.09) showed that any efforts at improvement based on the investigation of an accident were applied to a wide range of targets (e.g., all personnel inside the warehouse).

d) Ability to Anticipate

This ability showed how well the organization uses its knowledge to anticipate future difficulties and hence give better responses in the future. Three variables were considered suitable to measure the ability to anticipate. The result was 3.82 in frequency, 2.27 in time horizon, and 3.52 in culture. A mapping of the average score of each variable can be seen in Figure 3d. The score of the ability to anticipate (3.21) indicated that the workers believe that management could anticipate when the orders will increase regularly, despite the short time horizon of anticipating a surge of orders (e.g., one week, one month, three months). This means that the frequency of anticipating orders was still not in line with the expected time horizon, with the frequency of increasing effort being done more often. This was caused by a disparity between a possible increase in orders and the anticipative action to counter it. The workers and the delivery dispatch were often forced to adjust the delivery to be earlier than

Figure 4. Average Score of the Four Abilities of Potential Resilience

planned. This means that the organization was likely to respond rather than anticipate.

e) Overall Potential Resilience

The final step was to average all values of the variables that formed the ability into a single radar chart containing the average value of each of the four abilities. The final chart results were 3.50 in the ability to respond, 2.84 in the ability to monitor, 3.88 in the ability to learn, and 3.21 in the ability to anticipate. Figure 4 illustrates the result.

Discussion

Functional Resonance Analysis Method Model Result

Performance variability was found in one or many functions that could lead to the bottlenecking of the orders and thus delay delivery. Performance variability was more aggravated in three functions (item placement to the rack, picking items, and delivery process). The effect of bottlenecking could be amplified due to the instability of the work needed in coupling activities.[14] A similar result could also be found in the daily activities of warehouse operations. Occasionally, an escalation of orders would occur at a particular time. The increasing number of products being sent to the warehouses and the number of items loaded into trucks also delayed the time for the delivery process to be finished. This meant that the cycles in the system intensified due to more frequent cycles being sequenced together, possibly simultaneously, with the performance variability cumulated from each cycle, which would amplify the performance variability.[12]

A higher effort would be needed by the material handler and picker/packer of the warehouse. If the effort remains unchanged, the palettes of products will pile up at certain crucial places (e.g., the receiving gate or loading dock), hindering the product loading/unloading process.

Hence, a potential hazard is created in which unsafe conditions could lead to unsafe action and the possibility of misses, incidents, or even accidents.[9] This potential hazard was applied to the material handler and picker/packer inside the warehouse.

In the delivery process, performance variability was found due to the diverse number of orders during the day, added to the postponement from the preceding day. The urgent delivery also aggravated this situation, as resources were allocated to prioritize these orders. This meant that normal delivery orders usually scheduled regularly would be postponed until the next one or after. This postponement intensified at times when the number of orders increased. This showed that a great deal of effort is required of the current resources to meet the escalated demands. Hence, it is important to understand the system and identify where humans are positioned as their role is key.[30]

It is worth noting that the FRAM method is proven to be beneficial in understanding the complexity of a system more deeply,[13] as there are one or more factors that might contribute directly or indirectly to the ability of performers to do their tasks. In the case of warehouse activity, its risk is aggregation from multiple low-risk events. However, any further analysis should be done to bolster the result of the analysis, as FRAM is meant to be used as the initial process of understanding complexity and pointing out the tasks where resilience is needed,[9] due to the large performance variability that can affect not only the tangible but also the intangible result.[10]

Resilience Analysis Grid Assessment Result

Measuring potential resilience shows the level of knowledge, competence, focus of resources, and time of the organization.[31] Dynamic developments in the environment force the system to adapt or respond based on the organization's resources and capabilities.[32] The ability to respond is an important aspect and is the first pillar of resilience for the organization to deal with undesirable or unanticipated events.[33] In this study, the average score of the potential ability to respond was 3.50, which indicated that the organization already had several ways to deal with certain situations. As an organization increases its ability to manage more situations, the likelihood of the organization succeeding in unexpected outcomes increases. Therefore, fewer things would go wrong, which would improve the safety of the whole system at an organizational level.

The ability to monitor showed a value of 2.84, which was relatively low, particularly in 3 out of 4 variables. The lack of the ability to monitor prevents the maximization of the potential ability to learn. On the other hand, the workers showed that they were able to learn from previous events, resulting in the workers being more ex-

perienced in performing the activity. While this was a good sign, it would be beneficial to provide additional training to workers to improve their knowledge, particularly in monitoring potential near-misses or accidents.[34]

Potential resilience measures an organization's ability to recover from both usual and unusual events that may occur during working hours.[35,36] If any undesirable outcome occurs, it does not effectively mean that the system lacks safety.[5] Undesirable outcomes test the ability of the organization to rebound and maintain the natural flow of the work. While it does not happen all the time, the effort needed for an organization to stay "normal" may differ from time to time in the repetition of the same sequence of activities.

It is also important to note that despite the need for various types of organizations to respond well as the initial step towards resilience, the path towards resilience may also differ from industry to industry. For example, the supply chain industry needs to develop the ability to anticipate rather than the ability to monitor or learn. In contrast, high-risk industries (chemical, oil, etc.) need to develop the ability to monitor rather than the ability to learn or anticipate.[37]

While resilience and safety seem to be two distinct aspects, they always coexist in the effort to achieve better operational excellence. Resilience could be considered as the shape of control for the system to keep delivering safe results,[3] as the greater the effort, the higher the likelihood of remaining in control of the system, regardless of both expected and unexpected outcomes, resulting in better safety enforcement, along with the goal of safety (freedom from unacceptable risk) that could be reached much easily.

Conclusion

This study shows the results of applying the FRAM in breaking down the complexity of a system where the interactions occurred between humans, machines, and groups. Possible performance and safety variabilities are found more often in activities requiring more than one person or a multiple group effort to finish a single task, resulting in a potential performance imbalance when unexpected events occur. Further assessment using RAG shows the ability of the organization to adjust its performance to counter unexpected occurrences. The warehouse shows a high ability to learn, but this is not maximized due to the relatively low ability to monitor. With the new perspective of Safety-II, both methods are used to analyze system safety, with FRAM pointing out safety performance variability and RAG measuring the ability to cope with the variability.

Abbreviations

FRAM: Functional Resonance Analysis Method; RAG: Resilience

Analysis Grid; FMCG: Fast-Moving Consumer Goods.

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