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Risk Assessment Due To Customs Delays In Supply Chains By Fuzzy Logic

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Abstract

Due to violations of existing trade relations, cargo flows between the European Union and Ukraine have been redistributed. As a result, new supply chains have been created that have increased the tension on ground transport, including road and rail. Unfortunately, this has caused significant delays when crossing the border, which has led to a greater increase in the total delivery time of goods. Therefore, to plan for effective delivery, it is important to consider risks associated with increased border passing time. A detailed study of the challenge revealed that these risks are caused by various hazards, which are often fuzzy. To address these risks, a modern mathematical approach is required. Fuzzy logic has proven to be successful in dealing with such research questions. According to the above, this study aims to design a fuzzy model that proactively assesses the risks of customs delays caused by operational, technical, human, and political hazards when crossing borders. The study identified four categories of hazards that can lead to delays or refusals in customs operations, resulting in increased border crossing times. These hazards are technical failures of the control system, border blocking due to human factors, formation of a queue for technological failures, and political influence. The proposed approach can take into account both quantitative and non-quantitative threats arising at the border. The study resulted in a decision support system that allows carriers to calculate possible risks and select the best alternative border crossing point in advance, reducing the risk of supply chain disruptions due to customs waivers.

Keywords: operational hazards, technichal hazards, human hazards, political hazards, sustainable gargo transportation, fuzzy model

1. Introduction

One of the "bottlenecks" (weaknesses) in supply chains is border crossings between countries. The reason is possible delays in the goods` passage through customs. This is especially noticeable on the border between countries that are part of the European Zone and are not members of the EU. One recent example of border delays affecting the supply chain for agri-food products is international routes between Ukraine and Poland. (Pavlenko et al., 2023a, 2023b). It should be noted that the reasons for customs delays may be different. Therefore, the decision to adequately assess risks in supply chains should be based on a systematic approach.

It should be noted that challenges regarding the impact of customs refusals on risks in supply chains become regularly the research subject. Researchers mainly utilized a probabilistic risk assessment to define how different hazards impact customs clearance duration. However, the customs context is seen as a multi-criteria problem affecting risks in supply chains (Hammadi et al., 2016). The risk management methodology needs to be based on a regulatory framework (Haidabrus et al., 2023), and for the decision support system structure to be integrated. (Tummala and Schoenherr, 2011.). This means that a multi-factor assessment should be used to determine risks, especially in supply chain "bottlenecks".

Recent studies in the supply chain risk assessment suggest that classical models, and other approaches, can be used for assessment. We are talking about neural network modelling (Muzylyov et al., 2021), special software

(Luściński and Ivanov, 2020) and applying mathematical toolkits of fuzzy logic (Aqlan et al., 2015; Omosa and Numfor, 2022; Koohathongsumrit and Chankham, 2023).

A team of scientists, Luo et al. (2023), has emphasized the ambiguous nature of risks involved in customs procedures. They have proposed using fuzzy models in combination with neural networks to enhance risk prediction in import and export enterprises. The proposed risk assessment models based on fuzzy logic and neural networks can process uncertain and vague data, thus increasing the effectiveness of risk assessment through adaptation and learning opportunities. However, it is important to note that the proposed models merely represent the risks and do not establish any correlation between hazards and the risks themselves.

Koohathongsumrit et al. (2022) suggest using a hybrid approach based on the incenter of centroid and MCDM to perform multimodal route selection based on risk assessment. The study includes a comprehensive assessment of risks at customs, which are evaluated as moderate.

Social networks are often used to gather initial information. One approach to assess risks is to use fuzzy logic based on data from Twitter, as demonstrated in a study conducted by Janjua et al. in 2023. The study's wide coverage of respondents was a significant benefit, but it is important to note that the risks were assessed for the sea border, which may differ from the risks for land transportation at the border (customs).

In 2020, Hammadi et al proposed a hybrid model to evaluate the risks associated with customs supply chains. The model is an extension of the Fuzzy Analytic Hierarchy Process (AHP) method and includes criticality analysis. The authors provide a detailed case study of Moroccan Customs where the approach was applied. The model helps in determining the significance of each risk and its importance in the overall supply chain. However, the model does not account for the impact of factors like border blocking and embargo for economic reasons.

The main lack of the existing approaches is that the such models are not directed to risk assessment due to customs delays. This aspect is because this issue was practically absent, especially for a single European space. Due to recent global shocks (COVID-19, Russia-Ukraine conflict, economic crisis), a new perspective is necessary for the challenge at hand. To solve such complex logistical issues, one cannot do without modern mathematical toolkits. This study is the first step in this direction to show how important it is to consider the extra time of customs procedures arising from hazards due to different natures

That's why, this study aims to design a fuzzy model that proactively assesses the risks of customs delays caused by operational, technical, human, and political hazards when crossing borders.

2. Definitions, methods and data

This section presented a risk definition, modeling framework, data sources, and method used due to research questions.

2.1. Risk definition

Based on the classic well-known definitions of risk (Aven, 2012), we understand the following definition in the study by risk: risk is uncertainty about and severity of the consequence of numerous hazards (operational, technical, human, political) due to customs delays with respect to custom procedure duration. In mathematical formulation, the definition is expressed as follows:

$$T_{cust}(\mathrm{RF}) \rightarrow \mathrm{RF}\left(H_{op}, H_{tech}, H_{hum}, H_{polit}\right), \quad (1)$$

where T_{cust}(RF) – extra custom procedure duration due to risk factors (RFs), [hour]; RF(H_{op}) – risk factor due to operational hazards occurring at customs; RF(H_{tech}) – risk factor due to technical hazards occurring at customs; RF(H_{hum}) – risk factor due to human aspects occurring at customs; RF(H_{polit}) – risk factor due to political hazards occurring at customs.

In the total border transit time structure, additional customs procedure duration attributable to risk factors can be represented in the following manner:

$$T_{cust} = T_{procedure} + T_{cust}(\mathrm{RF}), \quad (2)$$

where $T_{procedure}$ – average duration of customs procedures per 1 vehicle in the absence of failures (RFs), [hour]

Organizing international supply chains requires carriers to calculate the total border crossing time using the formula (2).

2.2. Modelling framework

The considered set of hazards that are selected to design a fuzzy model for assessing risks in the supply chain through customs delays allows a comprehensive (systematic) approach to the issue. Therefore, the framework for conducting a study on the development of a fuzzy risk assessment model can be depicted in Figure 1.

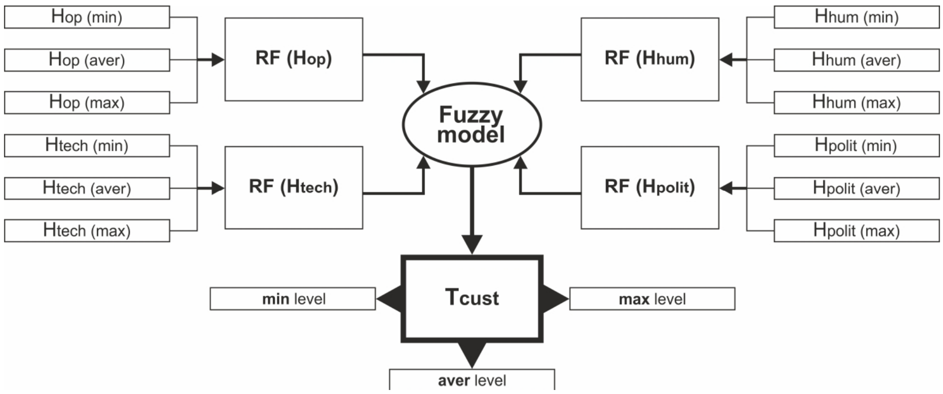


Fig. 1. Framework for modelling *Tcust*(RF) by Fuzzy Model.

Since the fuzzy model has four input factors, and each factor is characterized by three levels of variation, 81 causes were modelled during experimental studies. Such a set allows consideration of the possible risk situations due to the entire range. This number of causes corresponds to the full-factor experimental plan 3^4.

The proposed approach to assess customs risks would be useful for rationalising supply chain planning. The fuzzy model will become a tool for selecting the most appropriate border crossing checkpoint in terms of the minimum extra customs procedures arising from various hazards. Thus, the choice of the best checkpoint will be an adequate solution to optimize the delivery time of goods throughout the supply chain.

2.3. Data origin

The following data acquisition resources are used for the simulation:

- Data monitoring queues from trucks and their delay time at the border based on official Polish data (TaxFree. Border traffic, 2024) and Ukrainian customs (State Border Guard Service of Ukraine, 2024). Monitoring was carried out during December 2023.;
- Expert data on the duration of delays caused by technical failures in the customs control system were assembled due to customs inspectors and drivers of grain carriers who acted as experts.;
- This is an update on the duration of border closures caused by political reasons or human factors. The data has been gathered from open information resources, as well as social media platforms such as Twitter and Facebook (Janjua et al, 2023). Additionally, information from Telegram channels regarding the situation at the Ukrainian-Poland border has been considered. The monitoring has been ongoing since September 2023.

All types of data were used to determine the range of changes in incoming and outgoing risk factors. Numerical values for threats were applied to membership functions for their fuzzification.

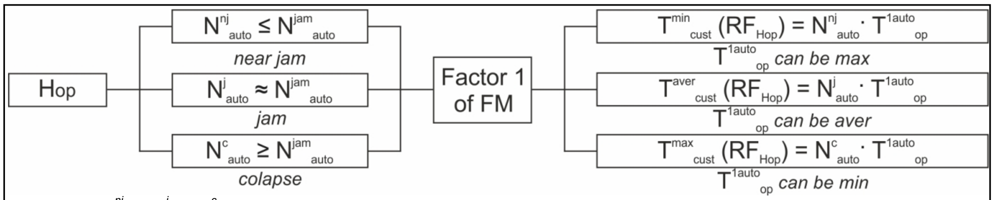
2.4. Methods

The study utilized several methods:

- Expert survey of grain truck drivers and customs officers to identify hazards that are most significant when crossing the border and affect the duration of customs procedures during cargo registration;
- Fuzzy logic for model designing in a Matlab simulation environment using a specialized Fuzzy Toolbox;
- Triangular and trapezoidal membership functions for fuzzification of hazards and extra time for customs operations (Popov et al, 2023; Kazan et al, 2015);
- Simulink simulation environment in which a fuzzy model is assembled for the experiment.

3. Modelling

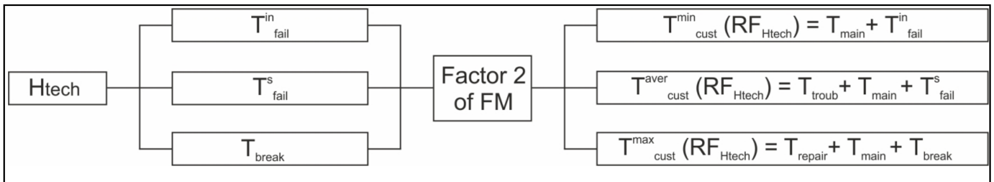
Experts have identified four hazard groups causing delays in cargo passing at land borders. The first factor is operational problems that may arise, leading to long queues of trucks at the border. To create a fuzzy model for these operational hazards, a logico-linguistic scheme depicted in Figure 2 was used.



Note: N^{nj}_{auto}, N^{j}_{auto}, N^{c}_{auto} - number of trucks corresponding to the following situations: near jam, jam, collapse, [auto]; N^{jam}_{auto} - number of trucks in check point, which can be considered as jam, [auto]; $T_{cust}(RF_{Hop})$ – extra custom procedure duration due to operational risk factors (RFs), [hour]; H_{op} – delays in customs servicing due to jam; N^{1auto}_{op} - standard time to customs servicing per one truck, [min/auto].

Fig. 2. A logico-linguistic scheme of fuzzy model using risk factors due to operational hazards occurring at customs.

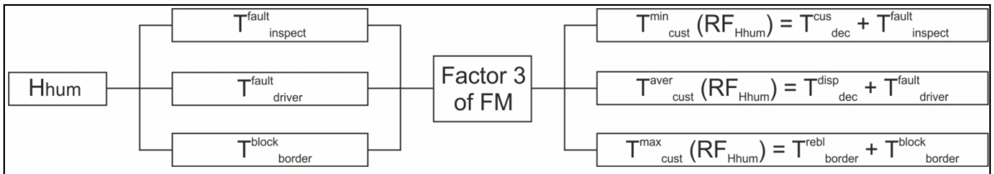
To improve the process of cargo processing at the border, carriers and foreign economic activity contract subjects are increasingly using an automated customs control system. To account for possible technical malfunctions of this system, a block has been added to the fuzzy model that considers technical failures in the operation of the automated system. The logical=linguistic scheme for this input factor is illustrated in Figure 3.



Note: T^{in}_{fail}, T^{s}_{fail}, T_{break} - duration due to the following situations: insignificantly failure, significantly failure, system breakdown, [min]; $T_{cust}(RF_{Hop})$ – extra custom procedure duration due to technical risk factors (RFs), [hour]; H_{texh} – delays in customs servicing due to failures in the customs automated; T_{main} – maintenance duration of the customs system, [min]; T_{troub}– duration of trouble due to customs automated system, [min]; T_{repair} – duration of customs automated system repair, [min].

Fig. 3. A logico-linguistic scheme of fuzzy model using risk factors due to technical hazards occurring at customs.

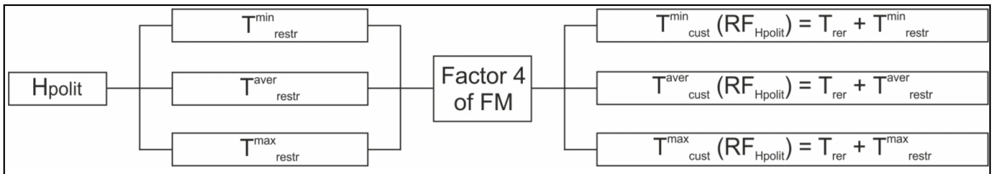
The influence of human activities on border crossings is an essential factor to consider when it comes to systems that involve people's participation. The risks associated with this impact are often uncertain and vague, making it challenging to predict their outcomes. Figure 4 illustrates how these human risks can affect customs procedures.



Note: $T^{fault}_{inspect}$, T^{fault}_{driver}, T^{block}_{border} - extra duration due to faults to the customs inspector, driver, or border blocking, [min]; $T_{cust}(RF_{Hhum})$ – extra custom procedure duration due to human risk factors (RFs), [hour]; H_{hum}– hazards on the border due to human influence; T^{cus}_{dec} – decision-making duration to resolve the fault of the customs inspector, [min]; T^{dis}_{dec} – decision-making duration to resolve the fault of the driver, [min]; T^{rebl}_{border} – time needed to fully unblock the check-point on the border, [min].

Fig. 4. A logico-linguistic scheme of fuzzy model using risk factors due to human hazards occurring at customs.

The political dimension often has a substantial impact on how the border operates. Typically, political disputes between countries can result in the border being closed for an extended period. The way in which our fuzzy model takes this into account is depicted in Figure 5.



Note: T^{min}_{restr}, T^{aver}_{restr}, T^{max}_{restr} - minimal, average, and maximal restrictions to border crossing, [day]; $T_{cust}(RF_{Hpolit})$ – extra custom procedure duration due to political risk factors (RFs), [hour]; H_{polit}– restrictions on border due to political aspects; T_{ren} – time needed to restart normal crossing through the border, [1 hour to several days].

Fig. 5. A logico-linguistic scheme of fuzzy model using risk factors due to political hazards occurring at customs.

Based on logico-linguistic schemes (Figures 2-5) and as described in "2.3. Data origin", Table 1 has data for the initial fuzzy model setting. Table 1 was used for incoming factors fuzzification (hazards) and output parameters (extra time for customs operations due to risks).

Table 1. Data for fuzzification.

Hazard	Linguistic variable	Level	Value	Estimated output value for response function, hrs
	N^{nj}_{auto}	Min (near jam)	50, [truck]	100
H_{op}	N^{j}_{auto}	Aver (jam)	200, [truck]	200
	N^{c}_{auto}	Max (collapse)	1000, [truck]	500
	T^{in}_{fail}	Min (insignificantly failure)	30, [min]	1
H_{tech}	T^{s}_{fail}	Aver (significantly failure)	60, [min]	3
	T_{break}	Max (system breakdown)	480, [min]	10
	$T^{fault}_{inspect}$	Min (customs)	60, [min]	2
H_{hum}	T^{fault}_{driver}	Aver (carrier))	240, [min]	9
	T^{block}_{border}	Max (society)	480, [min]	11
	T^{min}_{restr}	Min (1 day)	1, [day]	26
H_{polit}	T^{aver}_{restr}	Aver (1week)	7, [day]	192
	T^{max}_{restr}	Max (several week)	30, [day]	744

In Figures 2 to 5, there are three levels of variation for each risk factor. When only one hazard appears, the risk factor takes the minimum level. If two to three hazards occur, the risk factor is average. When four issues are present, the risk factor takes the maximum value.

The rules for a fuzzy model are designed based on a fuzzy inference that follows the Mamdani algorithm. The equation (3) expresses the general view of fuzzy inference in mathematical form.

$$IF\ \mathrm{RF}(H_{op})\ is\ \ldots AND\ \mathrm{RF}(H_{tech}) is\ \ldots AND\ \mathrm{RF}(H_{hum}) is\ \ldots AND\ \mathrm{RF}(H_{polit}) is\ \ldots THEN\ T_{cust}(\mathrm{RF})\mathrm{is}\ \ldots \quad (3)$$

A full-factor experiment 3^4 models each RF, was characterized by three variation levels or hazards. In total, the fuzzy model runs 81 study tests. The example of final model view is created using Simulink (see Figure 6).

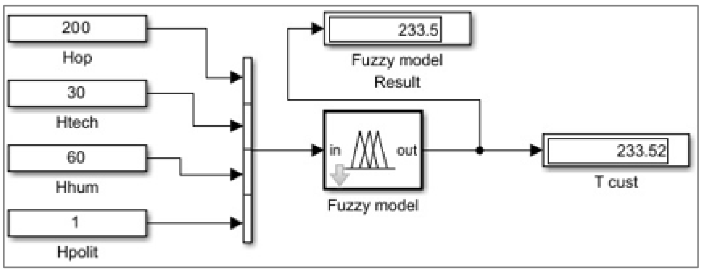


Fig. 6. The architecture of Fuzzy model assembled by Simulink.

The inputs for the model were determined based on the information provided in Table 1. This helped to establish the boundaries and intersection points of triangular and trapezoidal membership functions in the initial setup of a fuzzy model. Model, as shown in Figure 6, was executed for each of the 81 study tests. This helped to consider all possible combinations of threats arising at customs, considering the variability in the levels of values (minimum, maximum, and average).

4. Results and discussion

As a result, the final dependencies of fuzzy inference rules to determine the value of the output parameter from the inputs are visualized in Figure 7.

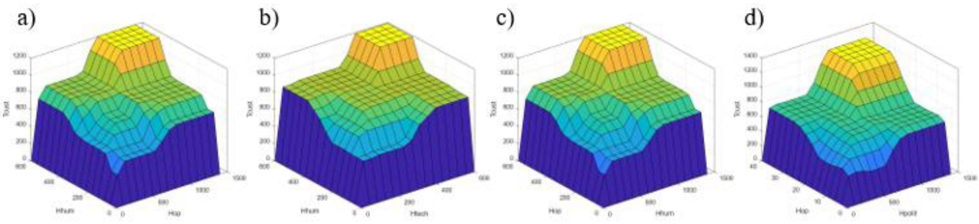


Fig. 7. Modelling Fuzzy Inference in MATLAB for extra custom procedure duration associated with: (a) human and operational hazards; (b) human and technical hazards; (c) operational and human hazards; (d) operational and political.

The surfaces presented in Figure 7 indicate that political and human factors are the main cause of delay in customs procedures. These failures can cause border passage times to increase from one day to several weeks. It is important to note that these issues can only be resolved through interstate agreements. On the other hand, technical failures and operational hazards have a lesser impact on the duration of customs clearance, resulting in delays that range from one hour to a day.

Figure 8 displays the outcome of applying a fuzzy model to simulate the impact of risks on the duration of customs operations. Additionally, it illustrates the basic decision support systems that rely on conditional categorization into levels to determine whether crossing the border via a specific checkpoint is feasible or not.

The graph depicted in Figure 8 shows the different input factor levels for each case study along the abscissa axis. This allows us to determine the management impact of specific hazards based on the variation level in input factors for each case.

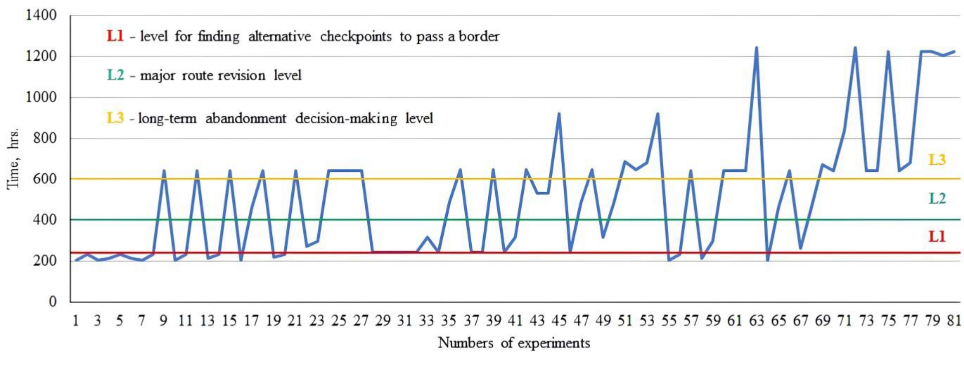


Fig. 8. Decision-making system according to result of extra customs time due to risk factors by fuzzy modeling.

After analyzing Figure 8, it is possible to identify four distinct levels of decision-making:

- The first unit has a range of 0 to 200 hours, indicated by the red horizontal line level L1. In such a scenario, it may be the most logical decision for the transport company to refrain from changing the border checkpoint and instead wait for the issue to be resolved;
- During the second unit, which occurs between 200 to 400 hours, the carrier may need to reconsider their route if there are delays during customs control when crossing the border with a particular country. In this scenario, the carrier may opt to choose an alternative crossing point to avoid any further delays. The

red horizontal line level L1 and green horizontal line level L2 are used to measure the duration of the unit.;

- Unit three has a range of 400 to 600 hours, indicated by the green horizontal line level L2 to the yellow horizontal line level L3. This range requires a complete overhaul of the supply chain. As a result, the carrier must either construct a new route that passes through another country or opt for sea transportation or piggybacking. By doing so, the time spent traveling along a detour over a longer route would be less than the time lost waiting at the border.;
- Fourth unit. It is necessary to avoid transporting in a specific direction above the yellow horizontal line level L3 in the long term until the situation stabilizes.

It is important to keep in mind that the criteria for assigning levels of service may vary between carriers. For instance, while one transport company might consider a delay of several hours as reasonable, another might find such a delay acceptable only if it lasts for several days. Consequently, the same management decision could lead to different outcomes for various waiting periods, such as whether or not to bypass the checkpoint and cross the border.

The proposed fuzzy model is universal. However, the following restrictions can be specified for it:

- When changing the range of factors, it's important to clarify fuzzification since FM is not self-leaning;
- Does not hierarchy factors screen out insignificant;
- Requires expert elicitation to correctly identify hazards;
- It is not supposed to use a zero rule that determines the situation of the occurrence or absence of a particular threat.

The above-mentioned limitation indicates that the fuzzy model proposed here can estimate the occurrence of all four associated risks simultaneously. This leads us to conclude that the resulting estimate of the increase in the time required to service a truck at customs is insignificant. This, in our opinion, is an essential factor to consider when evaluating the duration of downtime at the border for carriers.

In addition, it should be noted that comparing modeling results with other approaches is problematic. Previous studies consider customs risks as components of choosing a multimodal route. They do not focus on the reasons for this category of risks, which depend on hazards due to border passing.

6. Conclusions

The study aims to develop a model based on fuzzy logic that can help determine the time taken for customs processing, considering various factors such as operational, technical, human and political risks. With the proposed fuzzy model, carriers can predict the additional time required for customs clearance and plan their route accordingly, minimizing risks and ensuring smooth border passage.

A fuzzy model, assembled using Simulink, was used to model 81 case studies. A full-factor experiment assessed all possible risk situations.

As per the main finding, four decision ranges are obtained. The simulation results indicate that if the delay at a border crossing point does not exceed a few days, the carrier may not look for another point of crossing. However, if the checkpoint remains closed for an extended period, it is advisable to avoid transportation in that direction for a long time.

The proposed fuzzy model can be integrated into a neural network to create a hybrid model that can self-learn. It can be one of the further research directions.

Acknowledgements

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