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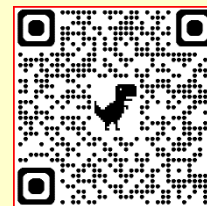
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Last-Mile Route Optimization Using FMEA at a Distribution Center in Pachuca: Diagnosis and Improvement Proposal

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ABSTRACT

This study diagnoses and prioritizes the operational failures that affect last-mile route planning in a distribution center in Pachuca, Hidalgo, using Failure Mode and Effects Analysis (FMEA) as a quality management tool. A quantitative, descriptive-applied and non-experimental case study was conducted. A 14-item closed questionnaire was answered by 15 employees directly involved in route planning, monitoring or execution. Descriptive frequencies were used to identify recurrent problems and support the assignment of severity, occurrence and detection ratings. The highest Risk Priority Number (RPN) values corresponded to incorrect or incomplete addresses and operational changes not updated (360), followed by lack of training (336), excess parcels per route (328) and traffic not considered (320). The findings show that route performance depends on sequencing, data quality, standardized procedures and adaptive planning. A prioritized improvement plan is proposed; a pilot implementation is still required to verify reductions in delays, failed deliveries and unnecessary mileage.

KEY WORDS: distribution center, FMEA, last-mile logistics, risk priority number, route planning.

INTRODUCTION

The growth of e-commerce has increased the demands placed on distribution operations, particularly in the last-mile stage, where an order leaves the local logistics center and must reach the consumer quickly, accurately, and with full traceability. In Mexico, ENDUTIH 2024 reported that 35.8% of Internet users made online purchases, while the Mexican Online Sales Association estimated 67.2 million digital buyers during 2024 [1], [2]. This environment places greater pressure on distribution centers because service levels depend not only on the product, but also on fulfillment of the delivery promise.

The last mile involves complex operational decisions: territorial

allocation, order consolidation, vehicle capacity, stop order, customer availability, traffic, addresses, and changes arising during the workday. The literature identifies routing and scheduling as central decisions at this stage and indicates that sequencing errors or poor information quality may result in repeat attempts, additional mileage, lost time, and higher costs [3], [4]. In urban areas, congestion and variable traffic conditions also make it difficult for a static route to remain efficient throughout the day [5].

At the distribution center analyzed in Pachuca de Soto, Hidalgo, conditions suggesting a partially reactive operation were observed: pending deliveries, simultaneous use of different navigation tools, uneven training, and failures associated with addresses or

operational changes. These situations affect the ability to execute a route as planned and make it necessary to determine which problems should be addressed first. Effective optimization does not consist solely of selecting the shortest path; it requires reliable data, balanced workloads, standardized work rules, and the ability to update routes when incidents occur.

Failure Mode and Effects Analysis (FMEA) was used to prioritize risks. This preventive tool identifies failure modes, analyzes their effects and causes, and rates them according to Severity (S), Occurrence (O), and Detection (D). The product of these three factors yields the Risk Priority Number (RPN), which establishes a relative order for action. This approach is consistent with quality management because it shifts the response from correcting an error after it occurs to preventing and controlling the conditions that may cause it [6].

The objective of the study was to analyze the assignment and sequencing of last-mile routes at a distribution center in Pachuca, identify and prioritize its main failure modes through FMEA, and formulate an improvement proposal aimed at reducing delays, failed deliveries, unnecessary travel, and operational variability. Because the proposed actions were not implemented during this stage, the scope of the study is an applied diagnosis and prioritization of improvements rather than a causal demonstration of reductions in time or costs.

RESEARCH METHODOLOGY AND DEVELOPMENT

Study design and unit of analysis

The research followed a quantitative, descriptive, and applied approach with a nonexperimental, cross-sectional design developed as a case study. The unit of analysis was a distribution center located in Pachuca de Soto, Hidalgo. The study focused on the planning, assignment, monitoring, and execution of last-mile routes.

Table 1. PRISMA process stage

PRISMA process stage	Number of records
Records identified in databases	1,085
Records after removing duplicates	813
Titles and abstracts screened	813
Potentially relevant records (full texts retrieved)	149
Articles assessed in full text	74
Articles excluded after full-text assessment	54
Articles included in the final review	20

Operational conditions were not manipulated, and no pilot intervention was conducted; therefore, the data represent the conditions observed during the data-collection period and provide support for an improvement proposal.

VARIABLES OF INTEREST

The independent variables were the application of Failure Mode and Effects Analysis (FMEA) and last-mile route optimization techniques (routing algorithms, order consolidation, and route reconfiguration). The dependent variables included average delivery time, the percentage of failed or delayed deliveries, kilometers

traveled per route, last-mile distribution costs, the number of priority failures identified, and the operational efficiency of the distribution center (INEGI, 2025; AMVO, 2025; last-mile logistics studies, 2018–2025).

APPLICATION OF THE PRISMA MODEL

The theoretical foundation was developed through a systematic literature review conducted in accordance with the PRISMA 2020 protocol. The Scopus, Web of Science, ScienceDirect, and Google Scholar databases and logistics repositories were searched for the 2016–2026 period. Combinations of terms such as “last mile logistics,” “last-mile delivery,” “route optimization,” “FMEA” OR “failure mode and effects analysis,” “distribution center,” and “e-commerce logistics,” as well as their Spanish equivalents, were used (Page et al., 2021; Ludeña, 2022).

The inclusion criteria were: (a) peer-reviewed articles or technical reports published between 2016 and 2026; (b) studies on last-mile logistics, route optimization, or distribution centers; (c) research applying FMEA to logistics or transportation processes; (d) studies evaluating effects on time, costs, or delivery failures; and (e) full-text documents available in English or Spanish. Studies published before 2016, articles without empirical evidence, and works unrelated to last-mile distribution were excluded (AMVO, 2025; INEGI, 2025).

PRISMA SELECTION FLOW AND ARTICLE REPORT

The selection process was documented as follows: 1,085 initial records were identified; after 272 duplicates were removed, 813 unique records remained; 813 titles and abstracts were screened, of which 149 were considered potentially relevant; 74 full-text articles were assessed, and 54 were excluded for not meeting the eligibility criteria. Finally, 20 key articles supporting the application of FMEA and last-mile route optimization were included (Page et al., 2021; Ludeña, 2022).

Participants and sampling

The effective sample consisted of 15 employees ($n = 15$) directly involved in distribution: operators and personnel associated with route planning or monitoring. Nonprobability convenience sampling was used, based on authorized access to the center and staff availability.

Direct participation in last-mile activities and practical knowledge of the process were established as inclusion criteria. Because the sample was small and nonprobabilistic, the results were interpreted descriptively and were not generalized to other distribution centers.

INSTRUMENT AND PROCEDURE

Data were collected through a survey. A structured Google Forms questionnaire consisting of 14 closed-ended multiple-choice questions was used. The instrument examined operating conditions, uncompleted deliveries, tools used to plan or monitor routes, training, and incidents affecting execution. Responses were organized using absolute frequencies and percentages. Where appropriate, percentages were cross-checked against the number of participants to maintain traceability; for example, 73.3% corresponds to 11 of 15 participants, and 46.7% to 7 of 15.

To evaluate the internal consistency of the instrument, the block of nine questions concerning the frequency of operational failure modes was analyzed. An approximate Cronbach's alpha coefficient of 0.90 was obtained from the 15 complete cases, indicating high internal consistency. This analysis was limited to the frequency block because data were missing from the impact-level section.

Application of FMEA

The survey results were used as evidence to identify the most relevant failure modes. Each mode was rated on a scale from 1 to 10 for Severity, Occurrence, and Detection; higher values represent greater impact, higher frequency, and a lower capacity for timely detection. The RPN was calculated as $RPN = S \times O \times D$. Ratings were based on the reported frequency, the associated operational effect, and the presence or absence of current controls. The RPN was used as a criterion for ranking risks and not as a probabilistic measure of loss.

Supplementary literature review

To strengthen the interpretive framework, studies on last-mile logistics, route optimization, urban transportation, and FMEA were reviewed, with priority given to recent literature and institutional sources. The review was organized according to the transparency and selection principles of PRISMA 2020 [7]. The literature review was used to compare the case findings with problems recognized in the literature; no meta-analysis was conducted.

Literature selection process

The literature search reported for the project identified 1,085 initial records. After duplicates were removed, 813 records remained for title and abstract screening; 149 documents were considered potentially relevant, 74 were reviewed in full, and 20 were retained as the final support for the reference framework. This procedure focused the discussion on studies of the last mile, urban distribution, routing technologies, logistics performance, and FMEA applications. The review contextualized the case and did not replace the primary evidence obtained through the survey.

Table 2: Complete report of the 20 articles included in the PRISMA systematic review (2016–2026)

#	Author(s) / Year	Title / Focus	Key Findings	Context	Relevance
1	Page et al. (2021)	PRISMA 2020 statement	Updated systematic review protocol	Global	Methodological basis
2	Ludeña (2022)	Last mile in logistics	Definition and criticality of the last mile	Logistics	Last-mile conceptual framework
3	INEGI (2025)	ENDUTIH 2024	35.8% of Internet users made online purchases	Mexico	Evidence of e-commerce growth
4	AMVO (2025)	E-commerce study in Mexico	67.2 million digital buyers in 2024	Mexico	National demand context
5	Last-Mile Logistics Studies (2018–2025)	Last-mile optimization	Reduced delivery costs and times	Global / e-commerce	Route optimization techniques
6	FMEA in logistics (2017–2025)	Failure mode analysis in logistics processes	Risk prioritization and preventive actions	Logistics and transportation	Application of FMEA
7	Route optimization algorithms (2018–2025)	Last-mile routing algorithms	VRP, genetic algorithms, and heuristics	Operations research	Route optimization methods
8	E-commerce distribution centers (2019–2025)	Distribution center management	Operational efficiency and order consolidation	E-commerce	Distribution center context
9	Last-mile delivery failures (2018–2024)	Causes of failed deliveries	Factors causing delays and non-deliveries	Global	Identification of priority failures
10	Urban last-mile challenges (2019–2025)	Urban last-mile challenges	Congestion, density, and costs	Cities	Applicability to Pachuca
11	Hernández-Sampieri et al. (2022)	Research methodology	Research approaches and designs	Methodology	Basis for experimental design
12	Creswell & Creswell (2018)	Research design	Experimental and mixed-method designs	Methodology	Pretest-posttest design
13	Sustainable last-mile (2020–2025)	Sustainable last mile	Emissions reduction and efficiency	Global	Optimization with a sustainability focus
14	Multi-criteria route	Multiobjective route	Balance among time,	Operations research	Optimization criteria

	optimization (2019-2025)	optimization	cost, and service		
15	FMEA applications in supply chain (2017-2024)	FMEA in the supply chain	Failure prevention and continuous improvement	Logistics	FMEA + improvement integration
16	Parcel delivery performance (2018-2025)	Parcel delivery performance	Timeliness and failure indicators	Parcel delivery	Performance indicators
17	GIS and route optimization (2019-2025)	Geographic information systems in routing	Use of maps and real-time data	Logistics technology	Technological tools
18	Crowdsourced / collaborative last-mile (2020-2025)	Collaborative last-mile models	Distribution alternatives	E-commerce	Improvement options
19	Cost structures in last-mile (2018-2024)	Last-mile cost structure	Cost components and drivers	Logistics	Distribution cost analysis
20	Case studies of distribution centers in Mexico / Latam (2020-2025)	Distribution centers in Mexico	Local practices and challenges	Mexico / Latin America	Applicability to the Pachuca context

Note. Prepared by the authors based on the PRISMA systematic review. Priority was given to studies on last-mile logistics, FMEA in logistics processes, and route optimization published between 2016 and 2026 (Page et al., 2021; Ludeña, 2022; INEGI, 2025; AMVO, 2025).

Proposed application of the study

Based on the findings of the systematic review and the growth of e-commerce in Mexico and Pachuca, the following experimental application is proposed:

1. Diagnosis (pretest): map the distribution center's last-mile processes, identify recurring failures (delays, failed deliveries, and inefficient routes), and apply FMEA to prioritize the highest-risk failure modes.
2. Intervention design: propose route optimization measures (routing algorithms, order consolidation, and route reconfiguration) and preventive actions derived from FMEA for priority failures.
3. Pilot implementation and posttest measurement: apply the improvements to a set of routes or a delivery area and measure their effect on delivery times, kilometers traveled, the percentage of failed deliveries, and distribution costs.
4. Analysis and continuous improvement: compare pretest and posttest indicators, validate the reduction of priority risks, and establish a monitoring cycle with an updated FMEA to sustain optimization (Page et al., 2021; Ludeña, 2022; last-mile studies, 2018–2025).

This pretest-posttest experimental design makes it possible to objectively demonstrate the contribution of FMEA and route optimization techniques to improving last-mile efficiency at a distribution center in Pachuca, Hidalgo, amid the rapid growth of e-commerce (INEGI, 2025; AMVO, 2025; Hernández-Sampieri et al., 2022).

Ethical considerations and data management

Participation was voluntary, and the information was used exclusively for academic purposes. The analysis focused on

aggregate trends rather than on identifying individual employees. The distribution center's commercial name was also withheld to protect sensitive operational information. This decision is relevant because the results describe internal processes, work tools, and incidents that could reveal specific organizational practices.

RESULTS AND FINDINGS

This section presents the empirical findings obtained from the survey administered to 15 employees directly involved in last-mile route planning, monitoring, or execution at the distribution center in Pachuca de Soto, Hidalgo. Results are organized into descriptive operational conditions, instrument reliability, and the prioritization of failure modes through Failure Mode and Effects Analysis (FMEA). All Risk Priority Numbers (RPNs) were recalculated for arithmetic consistency ($RPN = \text{Severity} \times \text{Occurrence} \times \text{Detection}$). The findings provide the diagnostic basis for the prioritized improvement proposal.

Sample Characteristics and Instrument Reliability

The effective sample consisted of 15 employees ($n = 15$) who met the inclusion criteria of direct participation in last-mile activities (route planning, monitoring, or execution). Non-probability convenience sampling was employed due to authorized access and staff availability. Because of the small sample size, results are interpreted descriptively and are not generalized beyond the case studied.

To evaluate the internal consistency of the instrument, the block of nine questions concerning the frequency of operational failure modes was analyzed. An approximate Cronbach's alpha coefficient of 0.90 was obtained from the 15 complete cases, indicating high internal consistency among the frequency items used to support the Occurrence ratings in the FMEA. This reliability analysis was limited to the frequency block; Severity and Detection ratings were assigned on the basis of reported operational impact and the presence or absence of current controls.

Incomplete deliveries

A total of 73.3% of participants (11 of 15) indicated that one or two deliveries normally remain uncompleted on an assigned route, while

13.3% (2 of 15) reported more than ten. The remaining responses were distributed between “not applicable” and “none.” Although one or two deliveries may appear to be a low-volume incident, their daily recurrence entails rescheduling, repeat attempts, changes in sequence, and additional use of time and fuel. The group reporting more than ten pending deliveries also suggests the existence of routes severely affected by capacity, information, or planning problems.

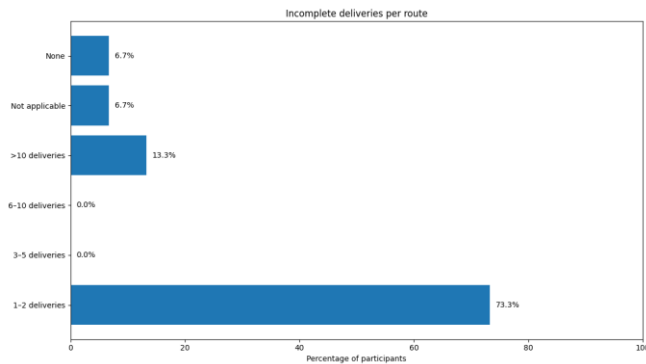


Figure 1. Frequency of uncompleted deliveries on an assigned route ($n = 15$).

Planning and monitoring tools

The company's internal application was the most widely used tool, at 46.7% (7 of 15). Another 20.0% (3 of 15) reported using Google Maps or another navigation application, while other participants reported manual planning, specialized software, or a combination of tools. The result shows that information is not always consulted from a single source. Navigation applications facilitate travel but do not replace a planning logic that considers workload, priorities, delivery windows, capacity, and operational changes. The coexistence of platforms increases the risk of differences between the planned and executed routes when information is not updated simultaneously.

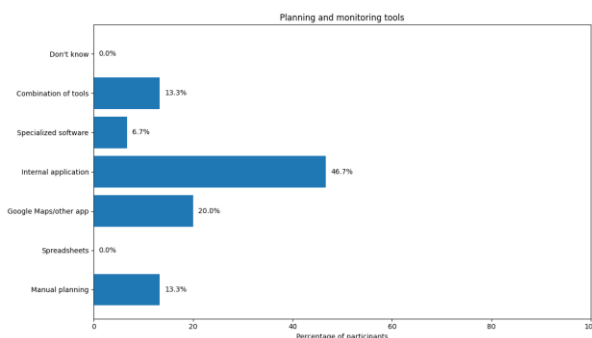


Figure 2. Tools used for route planning and monitoring ($n = 15$).

Personnel training

A total of 40.0% of participants (6 of 15) stated that they had received no training in route planning and execution, while another 40.0% reported training within the previous six months. This difference may lead to different criteria for validating addresses, arranging stops, recording incidents, or using the internal application. Training is interpreted as a preventive control: in addition to platform use, it should standardize data updates, workload distribution, and responses to traffic, road closures, or last-minute changes.

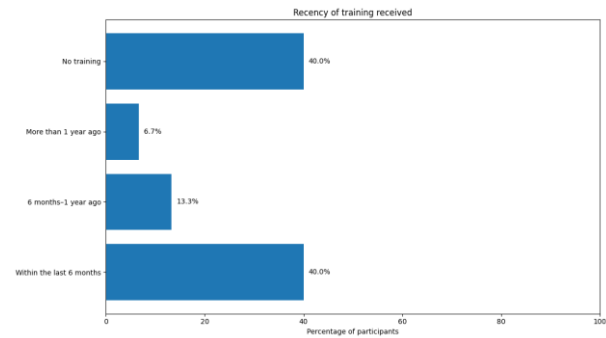


Figure 3. Recency of training reported by participants ($n = 15$).

This block of nine frequency questions showed high internal consistency. This result provides evidence of coherence among the responses used to describe failure occurrence. However, by itself it does not validate the Severity and Detection ratings or all the RPN values used in the FMEA.

Prioritization through FMEA

The highest RPN values corresponded to incorrect or incomplete addresses and operational changes not updated, both at 360. These were followed by lack of training (336), excess parcels per route (328), and traffic not considered during planning (320). To avoid inconsistencies arising from arbitrary qualitative categories, the risks are ranked directly by RPN: the higher the value, the greater the relative priority for intervention within the case studied.

Table 3. Initial prioritization of failure modes through FMEA.

Failure mode	S	O	D	RPN
Incorrect or incomplete addresses	9	8	5	360
Operational changes not updated	9	8	5	360
Lack of training	8	7	6	336
Excess parcels per route	8	6	6	228
Traffic not considered	8	8	5	320

Interpretation of priority risks

Incorrect or incomplete addresses and operational changes not updated share the maximum RPN of 360. Both risks have a common characteristic: they invalidate planning even when the stop order is reasonable. A deficient address may require calls, additional searches, or repeat attempts; a change that does not arrive on time makes the originally assigned sequence obsolete. Information quality should therefore be treated as an input requirement for the routing process rather than as an independent administrative activity.

Lack of training had an RPN of 336. Its relevance is associated with differences in the criteria used by individuals to interpret priorities, validate data, use the internal application, or respond to an incident. Excess parcels per route had an RPN of 328 and reduces the available margin for absorbing unforeseen events: a small delay can spread to the remaining deliveries when a route operates near its capacity limit. Finally, traffic not considered reached an RPN of 320, confirming that sequencing requires updating mechanisms throughout the day, especially in urban areas with changes in travel speeds and road closures.

Prioritized improvement proposal

The ranking obtained through FMEA directs the intervention toward

controls applied before and during route departure. First, address validation should become a prerequisite for dispatch, with mandatory fields and correction of inconsistent data. Second, operational changes require a single update channel with a timestamp and confirmation of receipt by the operator. Third, training should standardize planning, tool use, and incident management. Finally, workload assignment and sequencing should be reviewed using traffic information and capacity limits for each route.

Table 4. Improvement actions and monitoring indicators.

Risk	Priority action	Suggested indicator
Addresses	Prior validation and mandatory fields	Address incidents; first-attempt delivery
Changes	Single channel and time-stamped updates	Rescheduling; changes communicated on time
Training	Periodic program and operational checklist	Execution errors; protocol compliance
Workload	Route limits and balance across zones	Parcels/route; % of route completed
Traffic	Dynamic sequence review	Actual vs. planned time; km traveled

DISCUSSION

The results confirm that last-mile problems do not depend exclusively on the geometric layout of the route. Pending deliveries, the use of different platforms, a lack of updates, and uneven training show that information quality and process standardization condition execution. This interpretation is consistent with Boysen et al. [3], who identify routing and scheduling among the fundamental last-mile decisions and note that complexity increases when operational constraints and variability are present during delivery.

Ranieri et al. [4] emphasize the role of information technologies and travel efficiency in reducing last-mile externalities. In the case analyzed, technology appears to be a necessary but insufficient resource: if an address is incorrect or a change is not communicated, even a technically sound sequence may lose its validity. The first layer of optimization should therefore be data reliability and update discipline; more advanced routing tools can then be incorporated on that foundation.

Urban congestion and variations in travel time also support the need for adaptive planning. Savelsbergh and Van Woensel [5] note that city logistics must balance operational efficiency with actual urban conditions. The RPN of 320 obtained for “traffic not considered” shows that a static route may become inefficient during execution. However, the highest RPN values were associated with address information and change updates, so the initial investment should prioritize data and communication controls before attributing the problem solely to traffic.

The sample size and nonexperimental design limit the scope of inference. The responses of 15 employees make it possible to construct a contextualized diagnosis, but they do not demonstrate that the proposed actions causally reduce time, mileage, or costs. The next stage should apply a pilot and compare equivalent periods before and after the intervention. The minimum recommended indicators are the percentage of on-time deliveries, successful first-

attempt deliveries, average time per route, parcels delivered per driver, failed deliveries, planned versus actual mileage, and address-related incidents. The RPN should then be recalculated to verify whether the controls reduce occurrence or improve detection.

Management implications

From a business management perspective, the main contribution of FMEA is to transform an extensive list of incidents into an order for intervention. This allows resources to be allocated according to a preventive logic: first ensuring that input information is reliable, then standardizing communication and training, and subsequently strengthening workload balance and adaptation to traffic. This sequence is important because investment in routing software may yield limited benefits if address data or operational changes remain inconsistent.

The proposal also supports the development of verifiable controls. Each action can be associated with an indicator and an operational target: a lower rate of address-related incidents, a higher percentage of changes communicated before departure, fewer rescheduled deliveries, a higher proportion of completed routes, and a smaller difference between planned and actual time. This approach moves improvement from general recommendations to a monitoring cycle that can be reviewed by operations and quality managers.

LIMITATIONS AND FUTURE WORK

The study has four main limitations. First, the number of participants was small ($n = 15$), and convenience sampling was used. Second, the research was conducted at a single distribution center, so the organizational context may influence the results. Third, the failure modes were identified primarily from personnel perceptions rather than through the complete integration of GPS, fuel, stop-time, or actual visit-sequence records. Fourth, the proposed actions were not implemented during the period analyzed.

As a continuation, a pilot test should be conducted on comparable routes, using baseline and post-intervention periods of equal duration and evaluating at least on-time deliveries, first-attempt deliveries, average time, kilometers traveled, repeat attempts, and parcels per route. The FMEA should be updated after the controls are introduced because effective improvement should be reflected in lower Occurrence ratings or a greater Detection capability. The future incorporation of georeferenced records and sequencing algorithms would make it possible to compare employee perceptions with objective operational data.

IMPLEMENTATION RECOMMENDATIONS

Implementation of the proposal can be organized into three phases. The first involves data preparation and control. Before modifying algorithms or routes, the center should clean address data, define mandatory fields, establish a master information source, and assign personnel responsible for authorizing changes. A predeparture checklist should also be prepared to confirm the address, zone, workload, vehicle capacity, and the existence of open incidents. This phase seeks to reduce the two failure modes with an RPN of 360 before intervening in the sequence.

The second phase consists of an operational pilot. A set of routes with comparable characteristics should be selected, and a baseline should be recorded over a defined period. The priority controls should then be applied: address validation, a single update channel, brief operator training, workload balancing, and traffic review before departure and during the workday. The comparison should

use consistent indicators and avoid combining periods with substantially different demand levels so that observed changes can be more clearly associated with the intervention.

The third phase involves standardization and continuous improvement. If the pilot shows reductions in incidents, repeat attempts, or time deviations, the controls should be documented as standard operating procedures and gradually extended. The FMEA should be reviewed using the new data, and the RPN should be recalculated. A risk may decrease because it occurs less frequently or because it is detected before affecting the route. This update turns FMEA into a monitoring mechanism and prevents the matrix from remaining a static diagnosis disconnected from daily decisions.

CONCLUSIONS

The study identified that last-mile deficiencies at the distribution center do not arise from a single cause, but from a combination of unreliable logistics information, operational changes not updated, uneven training, overloaded routes, and planning that does not always incorporate traffic. Based on the questionnaire administered to 15 participants and the FMEA evaluation, an order for action supported by the RPN was established.

Incorrect or incomplete addresses and operational changes not updated reached the highest RPN (360), followed by lack of training (336), excess parcels per route (328), and traffic not considered (320). These values show that last-mile optimization requires action on data quality and operational discipline, in addition to better sequencing. The proposal prioritizes address validation, immediate updating of changes, periodic training, workload balancing, and dynamic planning.

The objective was achieved in its diagnostic and prioritization components, but it cannot be stated that the routes have already been optimized. No pilot test or pretest-posttest comparison of time, mileage, or failed deliveries was performed. The main recommendation is therefore to implement the actions on a controlled set of routes, measure indicators before and after implementation, and recalculate the RPN. The principal limitation is that the evidence comes from a single distribution center and a nonprobability sample of 15 employees; the results should be interpreted as case evidence and should not be automatically generalized to other operations.

ACKNOWLEDGMENT

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