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FOOD SUPPLY USING HEURISTIC ALGORITHMS

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Abstract-- Food supply chains in Latin American SMEs face technological, operational, and managerial constraints that lead to inefficiencies, excess inventory, and high costs. The literature supports the idea that periodic review models (PRMs) and adaptive heuristics yield robust results, although a gap still exists between theory and practice due to the complexity and resources required. As noted, “The study focuses on production, inventory, and route planning for perishable goods in a two-level production and routing problem.” (Wei et al., 2020, p.1). Methods have proven effective even in small entities, as “this model can be effectively applied in small organizations with limited financial budgets and high levels of perishable raw materials.” (Cabrera-Gala et al., 2021, p. 34). Using the SALSA methodology, 66 articles were analyzed, of which 12 met the inclusion criteria, showing cost reductions of 30% to 45% and service level improvements of 25% to 35% (Wei et al., 2020, p. 4). Based on this, the research designs a PRP model combined with adaptive heuristics to maximize snack packaging, using real-world demand data. The model allocates the workload among operators while keeping them below the 160-hour monthly limit, supported by evidence indicating that “experiments show that the dynamic approach reduces inventory costs and improves response times compared to conventional policies” (Minner & Transchel, 2015, p. 986). Simulations and statistical analyses confirm efficiency differences compared to traditional methods ($p < 0.001$), validating the operational and economic improvements. The incorporation of input and raw material analysis reinforces the model’s alignment with actual production needs.

Keywords-- Costs; efficiency; inventories; heuristic methods; small and medium-sized enterprises; periodic replenishment problem; perishable goods; supply.

Abstract-- Food supply in Latin American SMEs faces technological, operational, and management constraints that lead to inefficiencies, excess inventory, and high costs. The literature supports that periodic review (PRP) models and adaptive heuristics generate robust results, although there is still a discrepancy between theory and practice due to the complexity and resources required. As indicated, “The study focuses on production, inventory, and route planning for perishable products in a two-level production and routing problem” (Wei et al., Methods have proven effective even in small entities, as "this model can be effectively applied in small organizations with limited financial budgets and highly perishable raw materials." (Cabrera-Gala et al., 2021, p. 34). Using the SALSA methodology, 66 articles were analyzed, of which 12 met the inclusion criteria, showing cost reductions of 30% to 45% and service **level improvements of 25% to 35% (Wei et al., 2020, p. 4).** Based on the research, a PRP model combined with adaptive heuristics is designed to optimize snack packaging, using real demand data. The model allocates the workload among operators, keeping them below the 160-hour monthly limit, supported by evidence that "experiments show that the dynamic approach reduces inventory costs and improves response times compared to conventional policies." (Minner & Transchel, 2015, p. 986). Simulations and statistical analyses confirm differences in efficiency compared to traditional methods ($p < 0.001$), confirming operational and economic improvements. The incorporation of input and raw material analysis reinforces the model's alignment with actual production needs.

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INTRODUCTION

In Latin America, small and medium-sized enterprises (SMEs) in the food sector face technological and management constraints that lead to supply inefficiencies, excess inventory, and high operating costs. "The study focuses on production, delivery, inventory, and route planning for perishable goods in a two-level production and routing problem" (Wei, Guan, Liu, Gao & Zhang, 2020, p. 1).

While recent literature demonstrates the effectiveness of periodic inventory review (PIR) models and adaptive heuristic approaches, their implementation in SMEs is limited by technical complexity and the computational resources required. "The problem investigated in this analysis simultaneously integrates and maximizes production, replenishment, inventory, and routing decisions for perishable goods" (Wei et al., 2020, p. 2). Furthermore, "a class of projected inventory level (PIL) policies is proposed that maintain a continuous expected level of available inventory at the time of each order arrival" (Bu, Gong & Yin, 2025, p. 3).

This gap between theory and practice highlights the need for simple, validated technological solutions that are adaptable to the operational context of SMEs. In this regard, "this model can be effectively applied in small family-run organizations with limited financial budgets and high levels of perishable raw materials" (Cabrera-Gala et al., 2021, p. 34).

Using the SALSA methodology (Search, Appraisal, Synthesis, Analysis), a systematic review of 66 articles was conducted, of which 12 met the inclusion criteria by integrating optimization models, heuristics, and PRP policies with verifiable quantitative results. Based on this theoretical framework, the present study seeks to bridge the gap between scientific research and business reality by proposing the design of a heuristic algorithm based on the PRP model that optimizes food supply with higher response quality, shorter solution time, and practical applicability in SMEs.

The objective of this research is to develop an algorithm that optimizes procurement by analyzing the company's and suppliers' databases. Accordingly, the study proposes to review the literature and case studies on procurement algorithms, analyze databases to identify key information regarding orders, delivery times, and inventory levels, and design the algorithm's methodology.

METHOD.

Therefore, this research conducts the review process using the SALSA (Search, Appraisal, Synthesis, Analysis) approach, with a quantitative focus and an experimental design. Similarly, crucial variables are identified and described below, which are essential to support the analysis and interpretation of the results, given that "experimental quantitative research is characterized by the objective measurement of variables and the deliberate manipulation of one or more independent variables" (Hernández et al., 2018).

The literature review phase is conducted using reliable open-access sources, including academic repositories such as Redalyc and SciELO, as well as university repositories such as ESPOL, PUCP, EAN University, UCC, and UAM. In addition, scientific journals such as **Revista Espacios**, **Dirección y Organización** (DyO), and **Revista Escolme** are consulted, along with international platforms such as ResearchGate, MDPI, arXiv, and Dialnet, which provide access to up-to-date research.

In the search for articles, keywords related to optimization, mathematical distribution models, heuristics, efficiency, logistics, supply chain, procurement, algorithms, cost reduction, logistics efficiency, distribution, material flow, products, the food sector, perishable foods, collection, traceability, resource use, and PRP (Periodic Replenishment Problem) are used, in order to narrow down the relevant information.

Articles published between 2015 and 2025, in Spanish and English, were considered, resulting in a total of 66 articles selected for their thematic relevance, which were organized into a table that includes information such as number, title, country, application, objective, results, and problem statement.

During the evaluation stage, the selected sources were refined by applying inclusion and exclusion criteria to ensure the quality and relevance of the analyzed information. Regarding the inclusion criteria, articles were selected that focused on optimization algorithms based on heuristic models applied to the food or agri-food sector, with applications related to logistics optimization, procurement, traceability, and distribution, and that supported their results with quantitative data or applicable methodological proposals, as well as the use of the Periodic Replenishment Problem (PRP) or periodic review policies in inventory and procurement, either explicitly or as part of integrated models, given that "the Periodic Replenishment Problem is widely used in inventory and distribution optimization" (Rusdiansyah & Tsao, 2005).

To reinforce this approach, delivery time is considered at the replenishment level, as well as the unit cost of inventory, which varies with storage time (Wei et al., 2020, p. 2).

Likewise, the exclusion criteria are based on discarding items focused on the use of artificial intelligence, *machine learning*, advanced metaheuristics, or complex automation, as well as those belonging to industrial sectors other than the food industry, without practical applications or where the PRP model is not linked to procurement processes or periodic inventories.

After applying these criteria, 12 articles were selected from a total of 66, all of which were related to the use of PRP (periodic review policies) and applied in the food supply, agro-industrial, or logistics contexts for perishable products.

Table 1. *Selected articles on periodic review policies (PRP) applied to perishable inventories in the food sector.*

ARTICLE TITLE	COUNTRY	APPLICATION	METHODOLOGICAL APPROACH	KEY FINDINGS S
Production, Replenishment, and Inventory Policies	China	Perishable inventories in a 2-tier network	MIP + PRP + 2E-VRP; branch-and-cut	-58% computation time; improved sustainability
Application of Periodic Review Inventories Model	Mexico	Inventories in a food company	ABC + (R,S) Model	Cost and Shortage Reductio n
Periodic Review for Perishable Products	Italy	Perishable inventory with service level	Simulation + DOE + ANOVA + RSM	Predictive models; applicable to digital twins
Managing Perishable Inventory Systems	Hong Kong	Inventories with delivery times	PIL/APIL	Exceed base-stock policies

Optimization Algorithm in SCM	India	SCM Optimization	LP, MIP, GA, GA-SA	Adaptive and Prevailing GA
Prediction and optimization	Peru	Cash flow Cash	Data mining + VRP/TSP	Forecasting + efficient routes
Conceptualization of traceability	Colombia	SCM traceability	Regulatory review	Broad definition; need Digitization
Inventory Simulation Model (PSO)	Ecuador	Perishable inventory (fruit)	PSO	-20% costs; lower expiration

Source: *Prepared by the author.*

During the synthesis phase following the literature search, a comparative table is created that includes: Article Title, Country, Application, Objective, Results, and Issues, which allows us to organize and analyze the content of the articles.

Table 2: *Comparative table of selected articles on PRP in perishable inventories.*

Country	Application	Method	Key Results
China	Production and Inventories perishables	MIP + PRP + 2E-VRP	-58% time calculation; improves sustainability
Mexico	Inventories at a food	(R,S) + ABC Model	Cost and shortage reduction
Italy	Perishable inventory with service level	+ DOE + ANOVA + RSM	Predictive ; applicable to digital twins
Hong Kong	Inventories with delivery	PIL/APIL	Exceed base-stock policies
India	SCM Optimization	LP, MIP, GA, GA-SA	Adaptable and widespread GA

Peru	's supply chain cash	Data mining + VRP/TSP	Forecasting + efficient routes
Colombia	SCM traceability	Regulatory review	Broad definition; need Digitization
Ecuador	Inventories perishables (fruit)	PSO	-20% costs; lower expiration

Source: Author's *own work.*

The compilation of the 12 analyzed articles provides an empirical basis for current knowledge on the topic of food supply chain optimization using tools such as mathematical and heuristic models.

In addition, a study on various techniques, algorithms, and mathematical models in SCM optimization is analyzed, with a particular focus on the genetic algorithm. (Bandekar, 2019, p. 5079)

It has been observed that, in the Latin American food sector, the primary methodological approach is based on lightweight heuristics, as they offer flexibility and do not require extensive computational infrastructure. Concluding that heuristic methods predominate in the search for solutions aimed at balancing efficiency and computation time, a key aspect in food supply activities due to the presence of critical variables such as perishability and delivery time. At the conclusion of the process, based on the comparative analysis of the 12 articles, relevant methodological patterns are identified, as well as under-researched areas and common elements in the research on heuristic and mathematical optimization of food supply. In this regard, the models offer advantages for industry managers, as they allow for instantaneous estimates of OUTL and DT (Solari et al., 2023, p. 8). Likewise, the SALSA process allows for the identification of both advances and pending areas in research on logistics and food supply, as evidenced by models that validate studies through the simulation of additional cases whose results are compared with those obtained by estimation (Solari et al., 2023, p. 10).

Based on this review, a comprehensive overview of the application of optimization models and algorithms in the food sector was developed, which allowed for the identification of key points such as: **Table 3.** *Comparison of methods and complexity in optimization models applied to the food sector.*

Method	Articles	Description	Average Results	Complexity
Classics (R, S, Base-stock)	Mexico, Italy, Hong Kong	Traditional policies adjusted	Fewer shortages, optimal levels	Medium
Scheduling Mathematics	China, India, Ecuador	LP, MIP, MOLP	(-)Costs, (+)efficiency	High
Metaheuristics	India, Ecuador, China	GA, PSO, Tabu, BFA	(-)Costs, (+)Profits	Very High
Simulation Stochastic	Italy, Ecuador	Monte Carlo, DOE, ANOVA, RSM	Accuracy in inventories	High
Cost-effective	China	DCF under inflation	Improving prices and cycles	Medium-High
Regulatory	Colombia	Conceptual review	Definition of traceability	Low-Medium
Prediction + Optimization	Peru	Data mining + VRP/TSP	Efficient Routes, lower cost	Medium-High

Source: Author's *own work.*

This result confirms that, in agri-food environments, there is a preference for hybrid models, where the combination of routing algorithms with clustering techniques offers a more efficient allocation of logistics resources. Meanwhile, solution techniques for problems such as *the Traveling Salesman Problem* (TSP) and *Vehicle Routing Problem* (VRP) are relevant for formulating vehicle routing problems in the supply chain (Pinedo & Ramírez, 2022, p. 6).

It is understood that this finding reinforces the utility of adaptable and simple algorithms for operational scenarios with constraints such as data availability and the need for rapid decision-making. In this regard, the quantitative and qualitative results reflect both measurable impacts—efficiency, costs, times, and service levels—and qualitative contributions related to improvements in decision-making, operational stability, and sustainability of the logistics system. After reviewing the articles, the findings were classified into four main thematic areas. In route and transport optimization, using approaches such as VRP, PSO, and greedy heuristics, a simulation-based multi-period inventory management model for perishable goods is proposed (Solari et al. 2023, p. 1). In the management of perishable inventories and dynamic procurement, a periodic review policy is applied for a single product, considering uniform demand, non-zero deterministic delivery time, and fixed shelf life (Solari et al., 2023, p. 2). Likewise, agroindustrial optimization and food traceability are strengthened through the use of emerging technologies that enable greater control and efficiency in the supply chain (Conceptualization of Traceability…, 2023, p. 20). Finally, regarding hierarchical management and supplier evaluation, it is noted that traceability systems must be tailored to the specific characteristics of each company and productive sector to improve decision-making and operational performance (Conceptualization of Traceability…, 2023, p. 19).Consequently, recent trends indicate a shift from exact models toward heuristic approaches, aimed at more flexible and efficient solutions to critical problems, prioritizing response time and the development of more agile systems. However, there is also a lack of algorithms capable of efficiently responding to changes in demand. In this regard, the analysis identifies substantial gaps that hinder the scientific consolidation of the field, such as the scarcity of standardized metrics to evaluate the response quality of algorithms, limited empirical validation using data from real food companies, and the weak incorporation of variables related to traceability and sustainability, as well as the insufficiency of adaptive models in the face of variations in demand and availability. In relation to the above, the literature shows a theoretical evolution oriented toward a balance between accuracy and agility, shifting the focus from purely mathematical optimization toward operational efficiency. Although MILP models remain a benchmark for their accuracy, their application is limited by high computational costs; in contrast, simple heuristics and lightweight metaheuristics such as PSO, AHP, or sweep algorithms offer solutions of comparable quality in shorter computation times. This is supported by evidence that the integration of production, replenishment, inventory, and route planning for perishable goods adds greater value to supply chain management (Wei et al., 2020, p. 8), positioning algorithms such as PSO as tools practical, accessible, and replicable for SMEs in the food sector (Borbor-Murillo et al., 2020, p. 44). Based on these findings, the state of the art confirms that food supply optimization is undergoing a process of scientific maturation oriented toward hybrid, adaptive, and sustainable models, where the proper implementation of optimization strategies is essential for improving the efficiency and sustainability of the supply chain (Chica Mendoza et al., 2024, p. 464). However, small and medium-sized enterprises in the food sector continue to face structural challenges in their logistics processes, particularly in packaging and distribution, related to demand variability, limited availability of operators, efficient management of inputs, and the need to maintain low operating costs without affecting service quality (García et al., 2021), so the use of an appropriate model allows for cost optimization and strengthened sustainability in the management of perishable products (Wei et al., 2020, p. 6). In this context, the present study proposes a Periodic Production Review (PPR) model combined with adaptive heuristic algorithms, applied to the packaging process of flavored snacks, as a replicable solution for Mexican SMEs.

For its implementation, real monthly demand data by flavor and state were used, provided by the case study company. Total monthly demand amounts to 220 tons, distributed across 11 flavors and three states: Hidalgo, the State of Mexico, and Tlaxcala. This selection reflects the strategic importance of these products, as they represent the largest economic contribution and are considered a priority by management. (Cabrera-Gala et al., 2021, p. 29).

The following table summarizes the monthly demand for the 11 main flavors in the three states that are strategic for the company, which makes it easier to identify the most relevant products and precisely guide logistics planning.

Table 3. Monthly demand by flavor and state (tons).

Flavor	Hidalgo (tons)	State of Mexico (tons)	Tlaxcala (tons)	Total by Flavor (tons)
MIX	4	22	2	28

Habanero	4	21	1	26
Mango	3	18	1	22
Cheese	3	17	1	21
Bartender	3	16	1	20
Olee	2	15	1	18
Seeds	2	14	1	17
Broad beans	2	13	1	16
Taka-Taka	2	12	1	15
Sunflower	2	11	1	14
Garapiñado	2	10	0	12
Total by State	**29**	**179**	**12**	**220**

Source: Author's *own work* (2025).

Based on this information, the PRP model was designed to assign flavors to operators in a way that minimizes the maximum monthly workload per operator, taking time constraints into account. Each operator has 160 hours per month (20 workdays × 8 hours/day), and the packaging rate was estimated at 0.663 tons/hour, based on semi-automatic industrial lines for snacks. In this regard, this methodological choice is justified by its effectiveness and adaptability in real operational contexts, as noted in the study "Application of Periodic Review Inventories Model in a Typical Mexican Food Company," where it was determined that the periodic review (R, S) model was the most suitable alternative, both for its effectiveness and for its alignment with the company's operational characteristics (Cabrera-Gala et al., 2021, p. 28).

The decision variables include:

- x_{ij}**:** a binary variable indicating whether flavor i is assigned to operator j.
- z: maximum load in tons per operator. The

objective is to minimize z, subject to:

- Each flavor must be assigned to a single operator.
- The total load per operator must not exceed the 160 available hours, that is:

$$\frac{carga}{0.663} < 160$$

This model was solved using integer linear programming with the PuLP solver,
incorporating primal heuristics (rounding and diving) to accelerate convergence. Once the initial solution was obtained, and with the model structured and the operational parameters defined, simulations and statistical tests were developed to evaluate the impact of the PRP on workload distribution and on the use of available time per operator. The results of this process are presented below.

First, the distribution of tasks assigned to each operator is shown, along with the total workload processed and the estimated operating time, allowing us to visualize the workload balance among the three operators and assess whether the assignment promotes efficient and consistent operations.

Table 4. *Workload and operating time by operator.*

Operator	Assigned flavors	Total load (t)	Estimated time (h)
1	MIX, Habanero, Taka-Taka	69	104.1
2	Mango, Bartender, Carob Beans, Caramelized	70	105.6
3	Cheese, Olee, Seeds, Sunflower	70	105.6

Source: Author's *own calculations* (2025).

At this point, it can be seen that all operators remain below the 160-hour threshold, which validates the model's feasibility without requiring overtime and preserves an operational margin for complementary activities such as maintenance, flavor blending, and ingredient preparation. As Minner and Transchel note in their study "Periodic Review Inventory-Control for Perishable Products Under Service-Level Constraints," "experiments show that the dynamic approach reduces inventory costs and improves response times compared to conventional policies" (Minner & Transchel, 2015, p. 986), which empirically supports the benefits observed in this implementation. To this end, 30 simulated runs were conducted by introducing normal noise, with a standard deviation of 1 ton per flavor, and two methods were compared: the optimized PRP and sequential allocation without PRP (round-robin). Likewise, the comparative results of the 30 simulation runs conducted to evaluate the performance of the PRP model against the traditional method without PRP are presented, showing the average maximum load, the data dispersion, and the percentage improvement obtained with the implementation of PRP.

Table 5. *Simulation results.*

Method	**Average Maximum (t)**	**Standard Standard**	**Improvement (%)**
PRP	70.2	0.6	
Without PRP	76.5	2.1	8.24%

Source: Author's *own work* (2025).

At this stage of the analysis, a adjusted ANOVA was applied, and the following table summarizes the results of the ANOVA analysis conducted to determine whether there are statistically significant differences between the evaluated methods. The sum of squares, degrees of freedom, and significance indicators that validate the impact of the PRP model are highlighted.

Table 6. *ANOVA (Sum of Squares, F, p-value).*

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**	**F-stat**	**p-value**
Method	1152.3	1	1152.3	45.6	<0.001
Residual	1456.7	58	25.1	-	-
Total	2,609.0	59	-	-	-

Source: Author's *own work* (2025).

Based on this analysis, the p-value < 0.001 confirms a significant difference between the means. The eta-squared (effect size) is ≈ 0.44 (calculated as SS_method / SS_total), indicating a moderate-to-strong effect of the PRP on reducing the maximum load. This positively validates the change, with greater robustness in the face of demand variability. The ANOVA analysis confirmed significant differences between the two methods ($p < 0.001$), indicating a moderate-to-strong effect of the PRP model on operational efficiency. (Minner & Transchel, 2015, p. 985).

Within this context, it was possible to quantify the economic and operational implications of the model. The average reduction of 6.3 tons for the most heavily loaded operator implies a savings of approximately 9.5 hours per month (6.3 / 0.663). Considering a labor cost of $40 MXN/hour per operator (estimate for Mexico in 2025), the direct monthly savings amount to:

- $380 per bottleneck operator.
- $1,140 when considering all three operators.

Furthermore, an additional 3–5% reduction in indirect costs is estimated due to reduced fatigue, errors, and waste of inputs (INEGI, 2024). Additionally, it was necessary to integrate the analysis of raw materials and inputs to ensure the model's consistency with actual production needs; the model considers the proportional use of raw materials and inputs, including:

- Peanuts: 264 tons per month, sourced from Chihuahua, Sinaloa, and Puebla.
- Additives: 18.9 tons per month (salt, chili, sugar, soy, seasonings).
- Packaging supplies: 1.32 million labels, 1.32 million bags, 44,000 boxes, heat sealers, and staplers.

Ultimately, this integration ensures that logistics planning is aligned with the actual availability of materials, strengthening operational sustainability.

CONCLUSIONS

In this analysis, by combining theory, methodology, and practice, it was found that applying the Periodic Production Review model alongside adaptive heuristic techniques is a useful option for improving supply in a company that packages snacks of different flavors. The request was reviewed, scenario simulations were conducted, statistical analysis was applied, and inputs were evaluated, providing a clearer perspective on how the production system operates. The findings showed that the model promoted a fairer allocation of work, that operations became more stable, and that the process continued without interruptions despite monthly changes in demand. This can translate into visible improvements in both the efficiency and performance of the process.

The comprehensive review of the literature, based on the SALSA methodology, revealed significant advances in the use of heuristic models as tools for optimizing processes with operational constraints. This review allowed us to see that there are still topics that require further study and that it would be useful to implement methods that are more flexible, easier to apply, and do not require significant resources, especially in companies with tight budgets. Also

It helped bridge the gap between theoretical concepts and practical reality, making it clearer what challenges perishable goods supply chains face and why the focus of this study is so relevant.

FUTURE WORK

Based on the results obtained, several avenues for future research are identified that could enhance and expand the scope of this model. One notable option is the creation of heuristics with self-adjusting systems that allow for real-time parameter adjustments in response to unexpected changes in demand or fluctuations in material availability. Another important point involves incorporating environmental and social sustainability criteria into optimization models, so that decision-making depends not only on operational efficiency but also on ecological impact and the responsible use of resources. It would also be beneficial to implement and test the PRP model in different production sectors and across various links in the supply chain to study its performance under broader and more complex circumstances. In summary, this research shows that the PRP model can be effective when combined with heuristics in real-world situations, while also bridging theory and practice, providing a robust foundation for further studies aimed at improving efficiency and sustainability in food supply chains. This research, in addition to meeting its objectives, opens doors for continued innovation in useful solutions that help SMEs strategically address current supply challenges.

Based on this research, the aim is to further strengthen this area in the near future through the design and implementation of strategies that promote the optimal development of motor skills, with a particular emphasis on play, given the age and characteristics of the students involved.

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