Prototype of an Automatic Pothole Repair System for Public Roads

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This paper presents the development of equipment designed to support emergency corrective maintenance on public roads, guided by a product development methodology. The central issue addressed is the formation of potholes, which can cause accidents, damage vehicles, slow traffic, and create legal liabilities for public authorities. Potholes result from various factors, including poor-quality asphalt, heavy traffic loads, adverse weather conditions, and a lack of preventive maintenance. The proposed solution investigates efficient methods for rapid pothole repair to enhance road safety, reduce maintenance costs, contribute to environmental sustainability, and improve urban quality of life.
Keywords: Public Roads. Maintenance. Product Development. Potholes.

Public roads are vital components of urban infrastructure, enabling the movement of people and goods and fostering cities' social and economic integration. However, poor road conditions—particularly the prevalence of potholes—pose a persistent challenge in Brazil, leading to a wide array of negative social and economic consequences. Potholes arise from a complex interplay of factors, including intense traffic, unfavorable weather, and using substandard materials in road construction and repair. These issues complicate the timely and effective detection and remediation of surface damage [1]. Figure 1 illustrates the type of pothole targeted by the proposed equipment.

This situation goes beyond mere inconvenience for road users—it also entails significant economic losses and safety risks. Increased travel time, accelerated vehicle wear, and the heightened risk of traffic accidents are among the key consequences. These outcomes can lead to material damage, serious injuries, and even fatalities.

The core issue is the frequent occurrence of potholes on public roads, which, according to Silva [2], may incur legal liability for the responsible authorities. Therefore, enhancing the methods and materials used for road maintenance is of considerable importance to public agencies. According to Romeiro and colleagues [3], the knowledge to generate ideas, assess concepts, and structure the design process are essential components for successful project development. Furthermore, as emphasized in [3,4], project development can be viewed as a progression of sequential phases in which abstract ideas evolve into detailed product specifications. This study seeks to develop a solution to address the pothole problem by applying early-stage product development tools, such as QFD (Quality Function Deployment), morphological matrices, and TRIZ (Theory of Inventive Problem Solving).These tools are essential for professionals engaged in product design, providing opportunities to refine both practical and theoretical competencies.

If further developed and validated, the implementation of the solution proposed in this work could generate significant societal benefits. These include substantially reducing pothole occurrence, improved road safety and user comfort, lower maintenance costs for public infrastructure, enhanced environmental sustainability, and a better quality of life for the general population.

Materials and Methods

This study adopted a systematic approach to developing an innovative machine capable of

Received on 18 January 2025; revised 17 March 2025.
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J Bioeng. Tech. Health 2025;8(2):175-179

Figure 1. Public road pothole representation.

repairing potholes more rapidly, efficiently, and with superior quality tailored to the specific conditions of Brazilian public roads. The methodology followed is outlined in Figure 2, which illustrates the sequential steps taken to achieve the project's objectives.

The method was structured in two phases. In the first phase, the problem targeted by the project, stakeholder needs, and the technical requirements necessary to meet those needs were defined. This phase also included an analysis of the market, end users, lifecycle considerations for pothole maintenance solutions, and a review of existing patents and business models. Due to challenges involving public administrators, the design team identified stakeholder needs based on official reports and accumulated experience and then independently prioritized them.

The second phase focused on creating and selecting the optimal machine concept. The design team translated user needs into technical specifications and applied the Quality Function Deployment (QFD) method for analysis. Subsequently, the machine's primary functions were defined, potential solutions were generated using a morphological matrix, and the most suitable concept was selected using the Pugh decision matrix method [5,6].

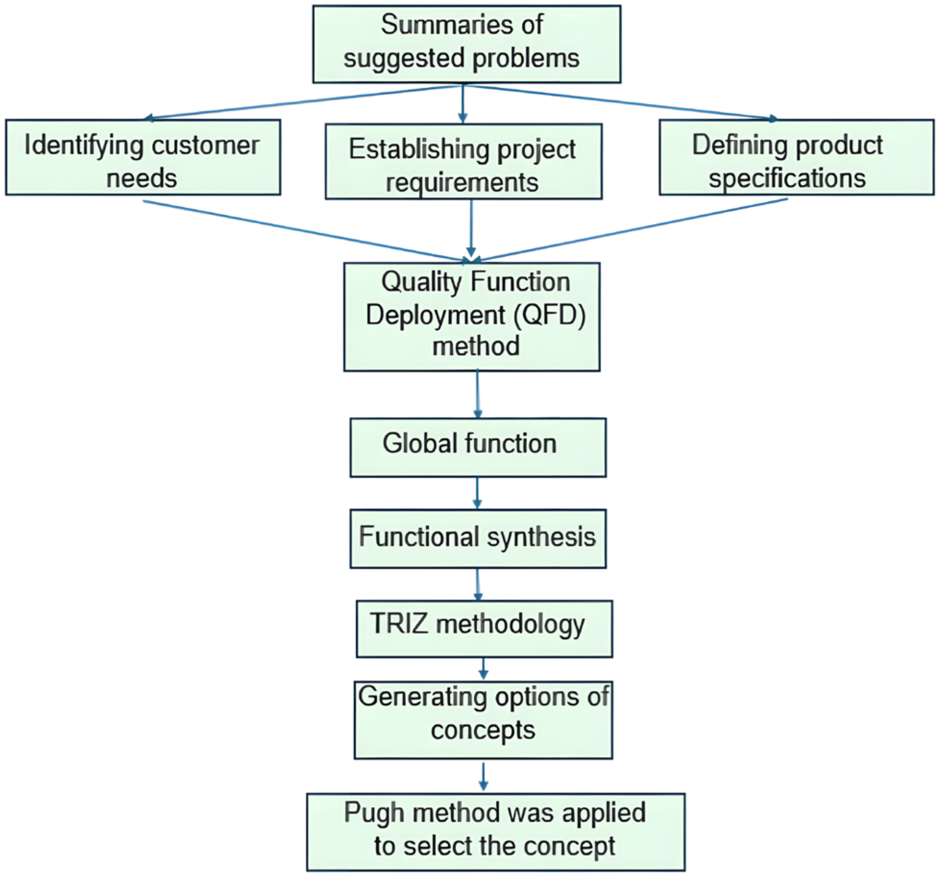
Results and Discussion

This section presents the decisions and outcomes of each step in the previously described methodology, along with the project's final product. The project began by thoroughly analyzing the problem and the market context. Government entities were identified as the primary potential customers, as they are chiefly responsible for managing and maintaining urban road infrastructure.Additional stakeholders include suppliers of raw materials and other inputs for the proposed solution. The direct users—contracted companies and their personnel—will operate the solution in the field.

Ultimately, the primary beneficiaries of the solution are road users, including drivers and passengers. The analysis of similar products and existing patents revealed numerous solutions that partially addressed the problem. Some featured a compact design or covered all required processes, while others were tailored to conditions outside the scope of this project. After identifying and translating customer needs into technical requirements, the QFD analysis was conducted. Table 1 illustrates the resulting matrix with the corresponding weights and stakeholder evaluations. The scores reflect the impact level of each requirement on fulfilling the related need without assessing the qualitative effect (positive or negative). The scale adopted was 0 for no impact, 1 for low impact, 3 for moderate impact, and 6 for high impact. Based on these values and stakeholder-assigned weights, it was possible to determine the most critical requirements for the project.

After analyzing the market, interfaces, lifecycle solutions, and stakeholders involved in the pothole maintenance scenario, a potential business model was proposed using the Business Model Canvas tool combined with functional synthesis. Based on this analysis, the route of filling potholes with precast plates was selected, as the team determined that this approach best addressed the project requirements. A morphological matrix was employed alongside the

Figure 2. The methodology applied in this work.



TRIZ methodology to support concept generation and selection.

The selected concept, illustrated in Figure 2, centers on integrating all necessary tools into a single piece of equipment capable of executing all stages of the maintenance process. The design includes a modular structure enabling automated tool replacement, storage of precast plates and bonding materials, and a dumping system. Furthermore, the equipment is designed to be self-propelled for short-distance operation and transportable over longer distances using a standard Munck truck.

Figure 4 presents the eight sequential steps defined during concept generation and solution development and the specific functions performed in each stage. The proposed machine incorporates a storage compartment for joint materials and debris, a forklift mechanism at the base for positioning precast elements, and a frontal tool alternating between an impact cutter and a vibrating compactor. It also features a vacuum for debris removal and a laser-guided marking system to delineate the cutting area. The machine is self-propelled and powered by a lithium-ion battery.

The proposed solution is considered technologically mature, integrating multiple well-established technologies in the market.

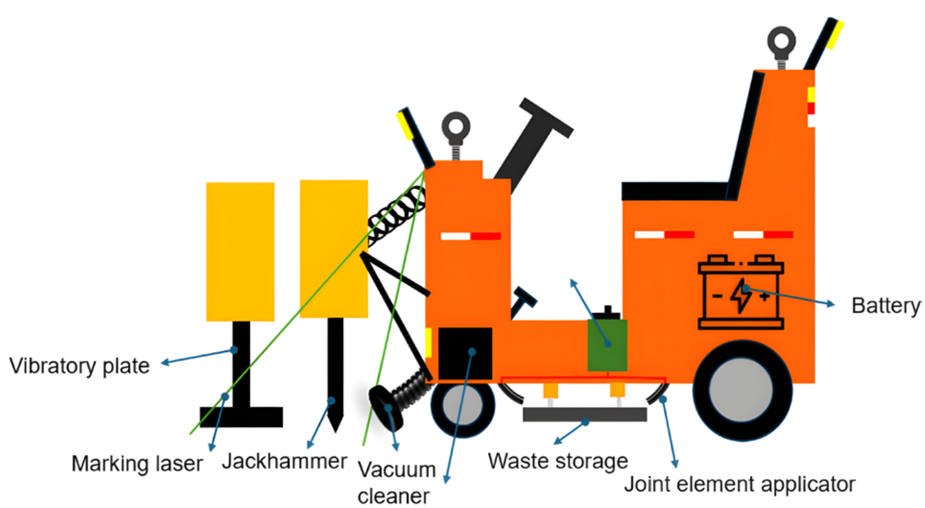
Conclusion

The methodology employed in this study proved robust and well-structured, fostering creativity among the team and enabling a comprehensive understanding of the problem addressed. The developed solution successfully met the identified functional requirements. The concept generation phase resulted in a design for equipment

Table 1. Needs and requirements of QFD.

#	Customer	Need	Customer's Weight	Customer's Rating	Intervention time	Daily productivity	Occupied area	Number of accidents	MTBF between interventions	Nº of operators	Nº of operations	Operation time	Solution volume	Solution mass	Acquisition cost	Operational cost
					min	#	m2	#	months	#	#	min	m3	kg	R$	R$
					↓	↑	↓	↓	↑	↓	↓	↓	↓	↓	↓	↓
N1	Driver	Reducing traffic congestion on roads	20%	7	6	3	6	3	0	3	3	6	6	0	1	1
N2		Avoiding risks for operators, drivers, and the population	20%	9	6	1	6	6	3	6	3	6	3	0	0	0
N3		To be long-lasting	20%	5	0	0	0	3	6	0	0	0	0	0	3	3
N4	Operator / User	Simplicity	30%	9	6	3	1	0	0	6	6	6	6	6	6	6
N5		Quick application time	30%	5	6	6	0	3	0	3	3	6	0	0	1	3
N6		Easy transportation	30%	7	3	6	1	1	0	6	0	3	6	6	3	3
N7	Public Authority	Reducing CAPEX and OPEX costs	50%	9	6	3	0	0	6	6	1	3	3	3	6	6

Figure 3. Sketch of the concept.

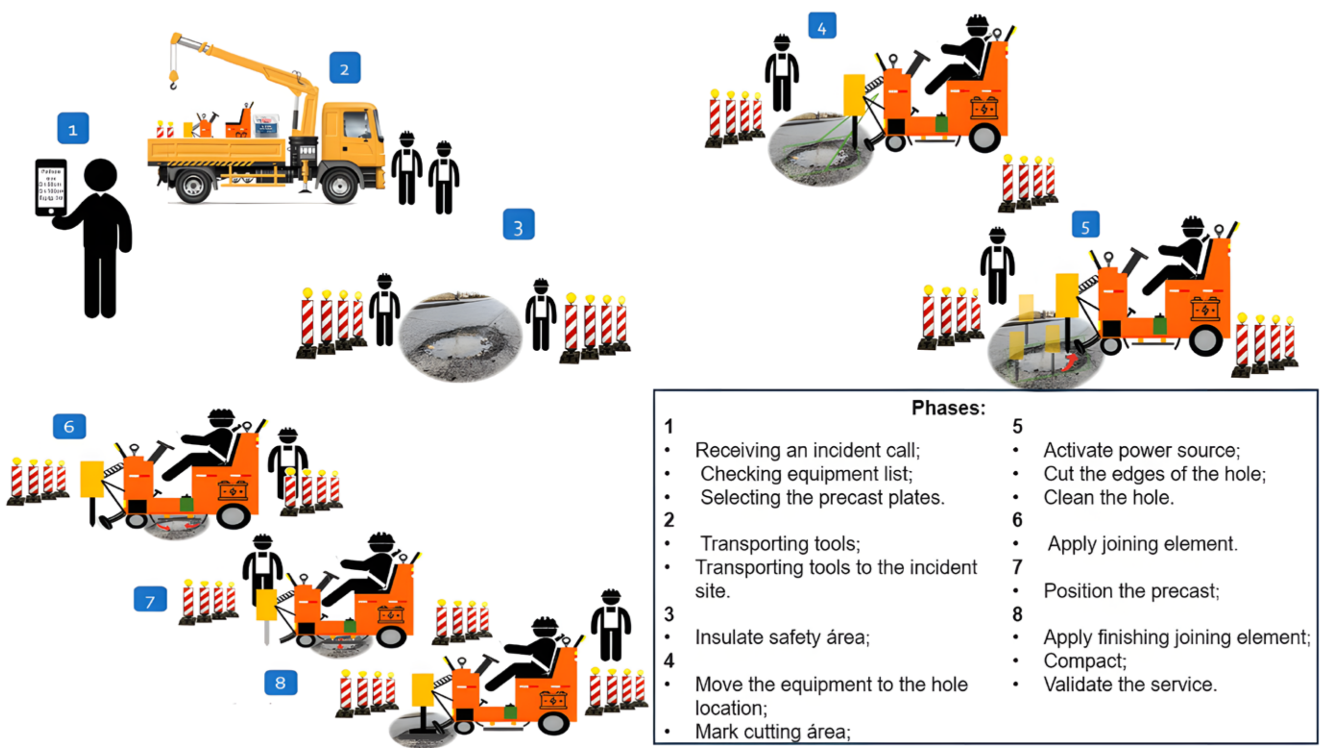


that promises reduced operation time, enhanced safety, minimized spatial footprint, and potentially lower costs. The proposed solution integrates multiple essential functionalities for pothole repair within a single, compact piece of equipment, demonstrating high technical feasibility and innovation.

Acknowledgments

The authors thank SENAI CIMATEC and the Postgraduate Program in Management and Industrial Technology for their support. Special thanks are extended to Professors Dr. Valter and Dr. Cristiano for their instruction and exemplary

Figure 4. Concept operation phases.



approach to methodologies in product development processes.

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