Product Development to Improve and Automate Orchard Fruit Handling

Gláucio Bessa Oliveira[1*], Bruno de Paulo Silva[1], Bruno Falcon Silveira[1], João Ricardo Lima de Oliveira[1], Priscila Coutinho Miranda[1,2], Valter Estevão Beal[1]

[1]SENAI CIMATECUniversity Center; [2]Bahia Federal Institute of Education, Science and Technology; Salvador, Bahia, Brazil

In transporting field fruits to the packing house, physical damage to the product can occur, especially if the facility is far from the orchard and needs proper traffic conditions. This study aimed to develop a solution to enhance the transportation of fruits from orchards to packing houses in the São Francisco Valley, Bahia properties. The method comprised the following steps: (1) System Definition; (2) Translation of Needs into Requirements; and (3) Generation and Detailing of Concepts. The proposed solution involves an innovative aerial transportation system utilizing high-strength cables and containers for moving fruits, eliminating the necessity for roads or other conventional means of transportation. This solution can potentially advance knowledge in the field and be implemented in similar contexts.

Keywords: Orchards. Fruit Handling. Concept Design. Automation.

In Brazil, it is estimated that up to 40% of fruits and vegetables produced are lost between harvest and reaching the consumer's table. These quantitative or qualitative losses lead to a decrease in their commercial value. Despite this, methods to reduce damages during fruit transportation remain uncommon and often ineffective [1].

Upon harvesting, fruits must be stored in shaded areas, kept off the ground, and transported swiftly to the packing house. Careful transportation is essential to prevent friction or injuries to the fruits. Typically, fruit transportation on farms is accomplished using trailers towed by tractors, animal labor, or manual handling to move fruit containers from the orchard. If the packing house is nearby, direct transport in these vehicles is feasible; otherwise, trucks are employed. However, in many orchards, there is limited access for tractors or trucks, necessitating more cautious handling to minimize physical damage to the fruits. Ideally, transportation should utilize vehicles with refrigeration systems, or measures must be taken to counter temperature increases. These measures include covering vehicles with light-colored tarps, leaving space between the tarp and containers for air circulation, optimizing container arrangement, reducing the time between harvest and transport, and stacking containers in no more than three layers to avoid fruit damage. Additionally, avoiding harvesting during peak heat hours is crucial, as heat accelerates fruit deterioration processes.

The challenges faced in Brazilian fruit farming make fruit movement a significant issue. Manual harvesting, followed by long-distance travel under harsh weather conditions, often damages fruits. A solution is needed to facilitate movement within the farm, saving time and preserving fruit quality.

This study aimed to identify and translate customer needs into well-defined requirements using quality techniques, functional analysis, and concept generation. The goal was to develop a solution to improving fruit movement from orchards to packing houses in the Vale do São Francisco region, Bahia.

Materials and Methods

This research presents an innovative system development approach aimed at addressing issues identified through primary data research with fruit

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Address for correspondence: Gláucio Bessa Oliveira. Avenida Orlando Gomes, 1845, Piatã. Salvador, Bahia, Brazil. Zipcode: 41650-010. E-mail: glaucio_bessa@hotmail.com.

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producers and the institutional ecosystem in the Vale do São Francisco region. The methodological proposal is structured into three stages: Stage 1 - System Definition; Stage 2 - Translation of Needs into Requirements; and Stage 3 - Generation and Detailing of Concepts.

The Product Development Process (PDP) is a complex activity that requires control and management for a new product to succeed in the competitive market. This complexity drives ongoing efforts to enhance and streamline the product development process, leading to various methodologies that offer theoretical support, recommend procedures, and provide valuable techniques and tools across project phases. Numerous methods, tools, and techniques support the Product Development Process (PDP), with Quality Function Deployment (QFD) being among the most commonly utilized. QFD enables measuring and translating customer needs through matrices that offer detailed insights. The advantages of applying QFD include reduced product development time, minimized design changes, cost savings, increased customer satisfaction, and more. Regarding information gathering about the target segment, various research tools were employed based on the target audience's profile.

A questionnaire was developed and administered using the Google Forms survey tool. Individual interviews were conducted with representatives of pre-selected companies, forming a "focus group" with the highest-scoring client in the evaluation. The interview and questionnaire participants identified themselves as consultants for agricultural companies or small, medium, and large fruit producers. A total of 11 participants were involved. Following team discussions and the collection of secondary data on fruit harvesting and post-harvest processes in the Vale do São Francisco region, customers (Table 1), along with their identified, translated, and valued needs, played a crucial role in developing equipment for fruit movement from orchard to packing house.

Results and Discussion

Results of Step 1 – System Definition

The results obtained from the questionnaire, market research, and patent analysis (of similar products) have allowed for identifying customer needs and a better understanding of the product that needs improvement. The main products identified include: Tobata tractors: These tractors are designed to operate in small areas and are commonly used for various agricultural tasks. They are characterized by their lightweight nature, relatively small size, and excellent maneuverability in tight spaces. Tractors with attached crates: These tractors come equipped with a body or platform capable of accommodating multiple fruit crates. The crates are designed to secure the fruits during transportation, and they are often stackable and easy to load and unload with the assistance of forklifts or winches. Further discussion will delve into the specific customer needs identified based on these products.

Results of Step 2 – Translation of Needs into Requirements

Each identified need was translated into measurable technical requirements, meaning they were converted into quantitative criteria that were collectively analyzed using Quality Function Deployment (QFD) (Table 2). This analysis considered the importance level of each requirement and their interrelationships. Requirements were categorized as functional or quality-related, depending on their connection to the expected functionality for addressing the identified problem. Upon analyzing the QFD matrix, it was noted that only one requirement does not exhibit conflict (Table 3). Consequently, the following analyses aim to elucidate some of the most critical conflicts: "Volume for fruits" with "transport volume," "weight," and "quantity of lost fruits": There are negative interactions here; a more significant volume required for fruits necessitates more volume for transportation, leading to increased weight in the

Table 1. Methodological details of the solution development for fruit movement from the orchard to the packing house.

Step 1: System Definition	Methods and Tools
The objective was to contextualize the proposed system, understanding the market and relevant interfaces.	The actors and customers involved in the fruit transportation system lifecycle, as well as competitors, similar products, and patents, were identified. Additionally, relevant standards and regulations were analyzed. The methodology included the application of the business CANVAS model to comprehensively map the key elements of the system.
Step 2: Translation of Needs into Requirements	**Methods and tools**
The customer needs identified in the previous stage were translated into clear and objective requirements.	The overall function of the system was defined, taking into consideration the requirements established through the Quality Function Deployment (QFD) technique. Conflicts between requirements were analyzed and resolved by ranking the relative importance of the requirements. Techniques such as functional synthesis and morphological matrix were used to explore various solution alternatives. The methodology included the application of the Theory of Inventive Problem Solving (TRIZ) to stimulate the generation of innovative concepts. The concepts were selected based on predefined criteria and subsequently detailed to develop a concrete proposal.
Step 3: Concept Generation and Detailing	**Methods and tools**
The overall function of the system was defined, considering the requirements established in the previous stage.	Functional synthesis and morphological matrix were used to explore various solution alternatives. The methodology included the application of the Theory of Inventive Problem Solving (TRIZ) to stimulate the generation of innovative concepts. The concepts were selected based on predefined criteria and then detailed to develop a concrete proposal. Additionally, a patent proposal was developed to highlight the originality of the proposed concepts.

solution, which in turn may result in higher fruit loss. "Product cost" and "MTBF" (Mean Time Between Failures): Lower product costs may lead to a higher likelihood of failures due to the potential use of lower-quality parts or components. "Quantity of lost fruits" and "product cost": There is an indirect relationship between the quantity of lost fruits and the product cost, as fruit losses impact production costs, potentially influencing the product's final price. "Reliability level" with "product cost": Highly reliable products less prone to failures are more expensive due to the high-quality materials and components necessary for achieving reliability. These conflict analyses help understand the trade-offs and considerations necessary for developing a practical solution that balances technical requirements with customer needs and market expectations.

Results of Step 3 – Concept Generation and Detailing

The Theory of Inventive Problem Solving (TRIZ) method was applied to develop the concept

Table 2. Correlation between needs and project requirements.

#	Client	Need	Customer's Impact	Customer's Rating	Standardized parts	Shipping Volume	Average distance from suppliers	Assembly time	Weight	Number of operations to use	Maintenance cost	MTBF	MTTR	Product cost	Amount of fruit lost	Degree of Reliability	Cost of use	Number of possible uses	Volume for fruits	Weight for fruits	Tipping angle	Speed	Number of sharp corners	Leave of absence
					#	L	km	hr	kg	#	$	dias	min	$	%	%	$/use	#	L	kg	°	m/s	#	#
					↑	↓	↓	↓	↓	↓	↓	↑	↓	↓	↓	↑	↓	↑	↑	↑	↑	↑	↓	↓
N1	Fruit growers	Not to degrade the fruit	50%	9					1					1	6		1		3	6	3	3	1	
N2	Fruit growers	To have low product cost	50%	9	6	3	3	3	3	3	6	1	3	6	3	6	3	3	3	3	3	3		
N3	Fruit growers	To have low maintenance cost	50%	6	6	1	3	3	1	3	6	6	6	3	1	6	3	3		3	3	3		
N4	Fruit growers	To have high capacity	50%	3		6		1	6		1	3	3	3	3		3	3	6	6	6	6		
N5	Fruit growers	To have stability	50%	3	1	3			3		1	1	1	3	6	1		1	3	6	6	6		3
N6	Fruit growers	To be robust	50%	9		1		3	3		6	6	3	6	1	6	3		1	3	1	3		1
N7	Fruit growers	To be efficient	50%	9		1			3	3	6	6	6	3	1	1	6	1	6	6		6		
N8	Fruit growers	To operate on different terrains	50%	3	1	3			3		3	3	3	3	1		1	6			6	6		
N9	Fruit growers	To be versatile	50%	6	1	1		1	1	3	3	3	3	6	1		1	6	3	3	6	3		
N10	Fruit growers	To be user-friendly	50%	3				3		6	3	3	3	1	1	3	1	3						6
N11	Fruit growers	To be fast	50%	3	1	3		1	3		3	3	3	3	3	3	3	3	3	6	6	6		3
N12	Operator	To be easy to handle	20%	9		3			3	6	3	3	3	3	3		3	3					3	3
N13	Operator	To be safe	20%	9		1			1	6	3	3	3	6	1	1	3	1		3	6	6	6	6
N14	Operator	To be ergonomic	20%	6	1				1	6	1	1	1	3	1	3	3	1		3	3	1		6
N15	Manufacturer	To use locally available raw materials	15%	6	3		6	3	1	1	3	3	3	6		6	3	3		1	1	3	3	1
N16	Manufacturer	To be easy to manufacture and assemble	15%	9	6		1	6	3	3	6	6	6	6		6	6	6		1	1	3	3	6
N17	Logistic operator	To have low liquid volume	15%	9	1	6		6		1	3	1	1	3	1	3	3	1		3	3	3		1
N18	Logistic operator	To have low weight	15%	9	1	6	1	6		1	3	1	1	3	1	3	3	1		3	3	1		1
		Ranking of Importance of Requirements:			67	74	31	74	87	90	155	131	126	160	88	114	116	91	86	145	119	146	27	58

Source: The authors, 2023.

Table 3. Roof of the house of quality matrix.

Roof Legend:

2	Strongly positive
1	Positive
	Neutral
-1	Negative
-2	Strongly negative

	Standardized parts	Shipping Volume	Average distance from suppliers	Assembly time	Weight	Number of operations to use	Maintenance cost	MTBF	MTTR	Product cost	Amount of fruit lost	Degree of Reliability	Cost of use	Number of possible uses	Volume for fruits	Weight for fruits	Tipping angle	Speed	Number of sharp corners	Leave of absence
Leave of absence																				
Number of sharp corners																				1
Speed																				-1
Tipping angle																		-1		1
Weight for fruits																	-1	-1		
Volume for fruits																2	-1	-1		
Number of possible uses																				
Cost of use															1	1		-1		
Degree of Reliability																	1			1
Amount of fruit lost															-2	-2		-1		
Product cost											-2	-2	-1	-1	-1	-1	-1	-1	-1	
MTTR										-1			1							
MTBF										-2		2	1				1			
Maintenance cost								2	2	-1		-1	2	-1						
Number of operations to use								1		-1			1	-1						1
Weight							1		1	1		-1	1	-1	-2	-2	1	1		1
Assembly time					1	-1	1		1	1	1									
Average distance from suppliers							1		1	1										
Shipping Volume					2					1			1	-1	-2	-2	1			
Standardized parts			2	1			1		1	2		1	1	-1					1	

Source: The authors, 2023.

of the solution. In this process, contradictions between prioritized requirements were listed to define engineering parameters corresponding to the respective requirements. Table 4 indicates some of the principles considered and their possible applications in the final solution (selected by the Pugh method, as shown in the following sections).

Thirteen concepts were generated in the Concept Generation stage. Using the Pugh Matrix and classified based on customer needs and weights. This analysis allowed for ranking the most promising concepts to meet customer needs. Table 5 shows the result of the concept evaluation, and Table 6 shows the concepts generated. In the qualitative evaluation, '-1' values were assigned when the concept performed worse in meeting the need, '0' when the performance was equal, and '+1' when the performance was more satisfactory than the chosen reference concept.

Table 7 briefly describes the respective concepts and gives an idea of the type of product, correlating them with the functions selected by a morphological matrix.

Concept 7 presents rail and cable equipment designed for fruit transportation within orchards. This solution utilizes a system of rails and cables to move fruit containers from one location to another within the orchard. The equipment incorporates a braking system to regulate the movement speed, ensuring the safe transportation of fruits. The transportation system comprises fixed rails and cables secured to poles or trees throughout the orchard. Fruit containers are placed on hooks that move along the cables. The speed of movement is adjustable through the braking system, which can be operated manually by a person pushing the containers along the rails or automated using electric or hydraulic motors in some instances.The manual braking mechanism allows the equipment operator to stop the movement of containers, preventing fruit damage smoothly. Implementing the rail and cable equipment can streamline fruit harvesting and transportation processes, reducing time and effort. It also minimizes the risk of fruit damage compared to manual handling. However, proper care and maintenance are crucial for the equipment's optimal performance and safety, and adhering to relevant standards and regulations for orchard equipment usage is essential. The rails and cables are constructed from corrosion-resistant materials like stainless steel, ensuring durability. They can be configured in various setups to accommodate specific orchard conditions. Overall, Concept 7 provides an innovative and secure solution for transporting fruits from orchards to packing houses, enhancing efficiency and reducing the potential for fruit damage or loss.

Conclusion

This study proposes an innovative air transport system for moving fruit, utilizing cables and high-resistance containers, thus eliminating the need for traditional road transport. The system's commercial and technical feasibility is highlighted, showcasing its potential applications across various sectors. Emphasis is placed on the systematic approach and collaboration among specialists to transition this concept into a market-ready product with significant ethical impacts, particularly regarding socio-environmental benefits for small to medium-sized producers and potentially at a larger scale.

The solution is designed for scalability and adaptability, making it suitable for fruit trees and other assets. The reduction in reliance on ground infrastructure and the consequent decrease in greenhouse gas emissions are critical factors contributing to the system's acceptance and commercial success. The focus on positive environmental impacts is a strategic advantage for the product, optimizing land use and promoting sustainability.

In conclusion, the innovative air transport system, utilizing cables and high-resistance containers, holds promise for enhancing logistics in transporting various agricultural products. Its adaptability makes it applicable in similar contexts, although the study focuses explicitly on tropical fruit cultivation in the Vale do São Francisco region. The successful implementation of this system will require collaborative efforts and a deep appreciation

Table 4. Inventive principles indicated by the TRIZ method.

Contradictions			Inventive principles indicated by TRIZ	
			Inventive Principles	Possible Applications in the Solution
Maintenance Cost	X	Product Cost	Prior action	Leave pre-assembled equipment to store more fruit
				Perform Set-up of tools to increase versatility
Product Cost	X	Speed	Inversion	Use a more powerful motor and mount it inverted to facilitate bolting
			Counterbalance	Use balloons / big bags to transport the fruits in rough terrain. Fill in the "empty spaces" of the cargo during transport.
Product Cost	X	Cost of use	Copy	Replace hard-to-obtain, fragile and/or expensive objects with cheaper parts
				Using alarms with infrared sensors
			Disposable objects	Use disposable boxes in the harvest to follow it to the market
Product Cost	X	Number of possible uses	Removal / Extraction	Remove unwanted parts or use the only parts you want
			Localized Quality	Boxes or trays with compartments suitable for home type of fruit
			Dynamization	Watering or throwing insecticide during storage and transport of fruits
Maintenance Cost	X	Number of possible uses	Alignment	Build the boxes or packages with fittings to be compact, decrease vibrations and decrease "dead" freight
			Asymmetry	More resistant tires or tracks on the outside due to contact with trees
			Partial or excessive action	Wash the fruits by immersion and drying during transport to anticipate washing in the later stage
Weight of fruits	X	Tipping angle	Use of inert atmospheres	Use of inerted cotton to reduce impact and friction of fruits
Weight of fruits	X	Amount of fruit lost	Joining or mixing	Use the same water in a reservoir to cushion the fruits, perform the first wash and irrigate the orchards on the return to the packing house

Table 5. Evaluation results of the concepts.

Needs	Customer's impact	Customer's rating	Equivalent grade/score	1	2	3	4	5	6	7	8	9	10	11	12	13	Tractor + Boxes
Not to degrade the fruit	50%	9	4,5	1	1	1	1	1	1	0	1	1	1	1	1	1	REFERENCE
To have low product cost	50%	9	4,5	-1	-1	0	-1	0	-1	-1	-1	0	0	-1	-1	-1	
To have low maintenance cost	50%	6	3	-1	-1	0	0	0	-1	1	0	0	0	-1	-1	-1	
To have high capacity	50%	3	1,5	1	1	0	1	1	-1	1	1	1	0	1	1	1	
To have stability	50%	3	1,5	1	1	0	1	1	1	1	1	1	0	1	1	1	
To be robust	50%	9	4,5	1	1	1	1	1	1	0	1	1	0	1	1	1	
To be efficient	50%	9	4,5	-1	-1	1	1	1	1	1	1	1	0	-1	1	1	
To operate on different terrains	50%	3	1,5	0	0	0	0	0	1	1	0	0	0	0	0	0	
To be versatile	50%	6	3	-1	-1	0	0	0	1	1	0	0	0	-1	0	0	
To be user-friendly	50%	3	1,5	0	0	0	0	0	0	1	0	0	0	-1	0	0	
To be fast	50%	3	1,5	0	0	0	0	0	-1	1	0	0	0	-1	0	0	
To be easy to handle	20%	9	1,8	0	0	0	1	0	0	1	0	0	1	-1	0	0	
To be safe	20%	9	1,8	1	1	0	1	1	-1	0	1	1	0	1	1	1	
To be ergonomic	20%	6	1,2	1	1	0	1	1	0	1	1	1	1	1	1	1	
To use locally available raw materials	15%	6	0,9	0	0	0	0	0	1	-1	0	0	0	-1	0	0	
To be easy to manufacture and assemble	15%	9	1,35	0	0	0	0	1	0	-1	0	1	0	-1	0	0	
To have low liquid volume	15%	9	1,35	-1	-1	0	-1	0	0	-1	0	-1	0	-1	-1	-1	
To have low weight	15%	9	1,35	0	0	-1	-1	0	0	-1	0	0	0	0	0	-1	
			TOTAL	-1,4	-1,4	12	14	21	8,1	12	15	20	7,5	-8,4	11	9,3	

Table 6. Generated concepts.

(C1) - Autonomous Refrigerated Cart	**(C8)** - Water Tank Transport in a Truck Bed
(C2) - Autonomous Refrigerated Cart	**(C9)** - Tractor-Powered Compartmentalized Water Tanker
(C3) - Autonomous Refrigerated Cart	**(C10)** - Tractor-Powered Cart
(C4) - Tractor-Powered Refrigerated trailer	**(C11)** - Solar-Powered Refrigerated Trailer
(C5) - Tractor with Compartmentalized Water Tanker	**(C12)** - Refrigerated Trailer with Biodigester
(C6) - Animal-Drawn Cart	**(C13)** - Tractor-Powered Water Tanker
(C7) - Transport via Suspended Rails	

Table 7. Brief description of the selected concept.

Product Concept 7 (C7) - Transport via Suspended Rails	
Product Concepts	**Transportation via suspended rails**
Advantages	- No need for an operator (Remote operation). - Reduced fruit degradation. - Increased safety. - Solar power generation. - Transportation of fruits in nets or in bulk (such as bananas).
Disadvantages	- Longer manufacturing time and larger volume. - Need to design and create trunk lines. - Lack of versatility. - Fruits exposed to adverse weather conditions.

for its environmental benefits, paving the way for a more efficient, sustainable, and promising future in freight transport and agricultural management.

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