

Modified Checkland Soft Systems Methodology and Functional Analysis (FAST) applied to aquaculture

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ABSTRACT

Objective: To represent the logical relationships between the functions of the Tilapia production process (*Oreochromis Niloticus*) using the Functional Analysis Diagram (FAST) and build a conceptual model based on the Modified Soft Systems Methodology that allows for improved management of an aquaculture farm.

Design/methodology/approach: The Functional Analysis Diagram (FAST) diagram is applied together with the Modified Soft Systems Methodology in the Tilapia (*Oreochromis Niloticus*) production process and the principles of process engineering.

Results: Production management indicators showed that only 28.57% achieved 100% of the results (SPF1, SUP1, SUP2, SUP3). Regarding STC1, 94.44% of the fry reached the target weight. The fattening period for the organisms took 25% longer than calculated (FAT1) and consumed 21.43% more feed (FAT2). Regarding the expected weight, 58.33% met it (HAR1, HAR2). 74.13% (HAP2) are sold live at medium wholesale prices, the rest are sold retail (HAP1). Finally, 86.67% of deliveries (HAP4) have an estimated delivery time between 1 and 5 hours.

Limitations and implications of the study: The study was limited to a semi-intensive Tilapia farm in southeastern Mexico, as a case study. The systemic approach employed includes activities already covered in some Mexican technical manuals but also considers a way to evaluate the management of aquaculture farms holistically.

Findings/Conclusions: A novel conceptual model for aquaculture farm management was presented. The modified Soft Systems Methodology and FAST were shown to be useful tools for designing a management system for aquaculture farms. The quantitative data from the 14 developed indicators complement the indicators generally used in aquaculture, thus enabling more efficient and effective farm performance evaluation.

Key words: *Oreochromis niloticus*, functional analysis, aquaculture indicators.

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INTRODUCTION

Tilapia accounts for 43% of Mexico's imports of aquaculture species (Secretaría de Agricultura y Desarrollo Rural, 2024), with a commercial value of 377,066 thousand dollars. On the other hand, the production of tilapia hatchlings, fingerlings, eggs, and



larvae in aquaculture centers of the Secretariat of Agriculture and Rural Development (SADER) as of 2024 was 2,236 thousand organisms; 80% were produced in Colima and the rest in Oaxaca, specifically in Temascal. Vázquez-Vera and Chávez-Carreño report 9230 aquaculture facilities in the national territory in 2022, noting that tilapia farming corresponds to 50% of all (Vázquez-Vera, Chávez-Carreño, 2022, p. 26). On the other hand, in 2025, López Téllez *et al.* indicate that the number of Aquaculture Production Units (UPAs) was 11,594 in 2023. With respect to tilapia farming, López Téllez *et al.* report that semi-intensive farming represents 31% of the UPA's dedicated to tilapia production and that 85% of the respondents in the study do not calculate the Feed Conversion Factor (FCA); they also indicate that 90% use suppliers for seed and that only 29% have a National Fishing and Aquaculture Registry (Registro Nacional de Pesca y Acuacultura, RNPA). These figures show deficiencies in technical management, use of indicators, and process control. On the other hand, based on the responses obtained, the study suggests that there are some threats to tilapia producers, such as the supply of low genetic quality hatchlings, increased costs of inputs and services, low production and low economic profits, low application of beneficial practices in the production process, poor water quality, as well as diseases and high mortality rates. López Téllez *et al.* (2025) found that 95% of the 20 states studied reported low application of Best Manufacturing Practices (BMP) as a weakness of the aquaculture production system.

In addition, there are problems in some semi-intensive aquaculture farms, such as the difficulty in obtaining and maintaining food safety certification, a high percentage of lack of knowledge of techniques and tools to increase efficiency, the lack of production management indicators for each of the processes, and the absence of criteria to evaluate suppliers of fry, feed, and pharmaceuticals (SENASICA, 2008; Betanzo-Torres *et al.*, 2020; COSAP, 2022).

The previous paragraphs state whether the combined use of FAST and the modified Soft Systems Methodology will allow the identification and prioritization of at least 80% of the critical management control points of the process (seeding, pre-fattening, fattening, harvesting and post-harvest, fry, feed, and pharmaceutical suppliers). Therefore, the objective of this work was to represent the logical relationships between the functions of the tilapia (*Oreochromis niloticus*) production process using the functional analysis diagram (FAST) and to build a conceptual model based on the Modified Soft Systems Methodology to improve the integrated management of an aquaculture farm.

Regarding the use of soft systems methodology and FAST, it was found as evidence that Nguyen *et al.* (2021) used it to improve rural aquaculture management in Mekong and identify viable solutions regarding water control, yield maintenance, and urgent investment needs. Paramita, *et al.* (2022) also analyzes with SSM the situation of blue crab fishermen in Java, finding a lack of standardized knowledge regarding how to fish and work.

Meanwhile, information was found about using FAST to analyze the functions of a pond oxygen controller during the pond design process (Buendía González *et al.*). On the other hand, Neven *et al.* (2025) examine the dynamics of aquaculture production chains, performance, and roles, proposing tools to improve sustainability and the way they work. Their joint application in aquaculture is incipient, which demonstrates a knowledge gap

due to the fact that other indicators are generally used in aquaculture farm management (Andersson *et al.*, 2025). Therefore, this work offers a replicable methodological tool to enhance the productive efficiency and sustainability of Mexican aquaculture farms.

MATERIALS AND METHODS

Study place

The Tierra Adentro aquaculture farm, whose corporate name is Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L., is located between 18° 39' 26" north latitude and 96° 17' 58" west longitude, at an altitude of 63 meters, in Joachin, Tierra Blanca, in the state of Veracruz. It has collaboration agreements with Tecnológico de Orizaba to increase aquaculture productivity. It is located in southeastern Mexico, between the Tropic of Cancer and the Tropic of Capricorn, an ideal geographical strip for the cultivation of the *Oreochromis niloticus* species. It is a medium-scale, semi-intensive farm, and it is also convenient for the application of this work due to its proximity, accessibility, and inter-institutional cooperation.

Participants

The participants were of two types: personnel belonging to the farm, with the experience and knowledge of more than 15 years of work, and professors and students of the technological school, who were doing their thesis work on different topics. The subsequent work dynamics involved teachers and students freely contributing based on their knowledge and observations. Subsequently, joint virtual sessions were held with the farm personnel, who listened, asked questions, evaluated the answers, and then added, adapted, or eliminated them as appropriate. This procedure was done at all stages of the project.

Phase 1. Development of the Functional (FAST)

Functional Analysis, also known as FAST Diagram (Functional Analysis of Systems Technique), emerged in the 1960s as part of Value Analysis (VA) and Value Engineering (VE) (Bartolomei & Smith, 2001). It is a technique that allows detecting the existing relationships between the functions of a system, based on the activities performed in it. The diagram answers two questions: how the function is performed and why it is necessary to perform it. By identifying all the functions, this method makes it possible to focus on those that generate the highest value, recognizing the essential ones and those derived from them, and thus structuring the functions through which value is added to the process or product. The FAST diagram is used to improve products, processes, and design systems, among other objectives, and is a technique that continues to be used in the development of new products today.

According to Paramita *et al.* (2022), the activities performed in one production unit may differ from those performed in others; however, their importance lies in the value they contribute to the final product. In this sense, it is essential to identify them, analyze their need, and determine to what extent they contribute to the added value in order to then implement actions aimed at their optimization.

The stages of phase 1 are:

1. Determine the main function.
2. Determine secondary and tertiary functions.
3. Determination of auxiliary functions.

The method followed at this point started with the structuring of the main system. The inputs are the fingerlings; the black box contains the value chain of the semi-intensive tilapia production process, and the outputs are the organisms for consumption. This system will be referred to as the first-level black box. The main functions within the first-level black box were established: seeding, pre-fattening, fattening, harvesting, and post-harvesting, creating different black boxes for each one. Secondary functions were determined for each one. The black box of the fry suppliers was also identified, which is not part of production but is essential for the correct functioning of the system as a whole.

Phase 2 involves the implementation of the modified soft systems methodology

The Soft Systems Methodology was proposed by Peter Checkland in 1970 as a response to the solution of unstructured problems through a systemic approach (Checkland & Shoales, 1994). Its application has been carried out in fields as diverse as health, agriculture, aquaculture, and management, among others (Sepehirad *et al.*, 2017; Fadhil *et al.*, 2021; Feili & Tavallaei, 2022). The act of transforming inputs (actions, methods, and operations) into outputs is called a process. A process is considered key when the transformation performed can affect outputs and resources. In addition, the Modified Checkland Soft Systems Methodology allows identifying the inputs and outputs of each activity, control points, and measurement parameters, as well as processes and sub-processes (Gurruchaga Rodriguez *et al.*, 2006).

The modified soft systems methodology comprises:

1. Determining the elements of the root definition (CATOWE).
2. Obtaining the root definition.
3. Determine the minimum activities required.
 - a. Brainstorming.
4. Structuring flowcharts.
5. Determination of decision nodes.
6. Development of indicators.
7. Determination of criteria.
 - a. Likert Scale

Work was done to obtain information on the unstructured problem, and the situation was expressed. The root definitions were obtained using the elements of the CATOWE acronym: C for customers of the system, A for actors of the system, T defines the transformation performed by the system, O owns the system, W, from the German term “Weltanschauung,” indicates the different points of view of the actors, and E indicates the

restrictions imposed by the environment in which the system is developed (Checkland & Schooles, 1994; Wilson, 2001).

According to Soft Systems Methodology proposed by Checkland in 1993 and later developed by Wilson in 2001, a conceptual model was created based on the main definition of each human activity system identified. To this end, a brainstorming session was held with the participants to identify the activities needed to achieve the transformation established in each root definition. Subsequently, the activities were grouped by affinity into the so-called minimum necessary or main activities, in a number no greater than nine (Wilson, 2001; Checkland, 1993, pp. 195-196), and were organized in a logical and sequential manner (Checkland, 1993, p. 196). The minimum necessary activity formed the main transformation process for each root definition. Based on their grouping, the secondary activities were defined, which were also arranged logically and sequentially. Finally, the corresponding flowcharts were drawn up to graphically represent the relationships between the activities and the overall transformation process.

To determine the points in the process where the decision nodes were placed that have an input and two or more outputs associated with a condition so that the flow within the activity is controlled by these conditions (Xiacong, 2015), the opinion of the farm experts was used, which has been validated as a method in some situations (Vázquez-Vera & Chávez Carreño, 2022; Vázquez-Quispesivana *et al.*, 2022).

Based on the decision nodes, the respective inputs and outputs were identified. Based on this information, performance indicators were determined, considering outputs as the numerator and inputs as the denominator. These indicators do not have units, since the relationship between the two terms cancels them out, so they are expressed as a percentage or as a fraction of the unit, as appropriate for each of the subsystems analyzed (Gurruchaga Rodríguez *et al.*, 2006).

Figure 1 shows the flow diagram of the methodology used; the main points of the method are shown in bright blue, and the steps involved in each of them are in light blue.

RESULTS AND DISCUSSION

Phase 1. Development of the Function Diagram (FAST)

Determine the main function

It began with identifying the main process to determine the value chain in Tilapia production, shown in Figure 2, which indicates the inputs and outputs of the entire process. The next stage determines the processes that occur within the “black box.”

Determination of secondary and tertiary functions

Figure 3 shows the secondary functions of the Tilapia production process from stocking with fry. The black box's inputs and outputs match the main function's (Figure 2).

From the secondary function (Figure 3), the tertiary function is obtained for each of the processes in the black box. Figure 4 shows the functions for the pre-fattening process, which are like those for the fattening process. In the production process, the pre-fattening stage is characterized by the introduction of fry, which remain under controlled conditions until they reach the appropriate size for transfer. At the end of this phase, the organisms

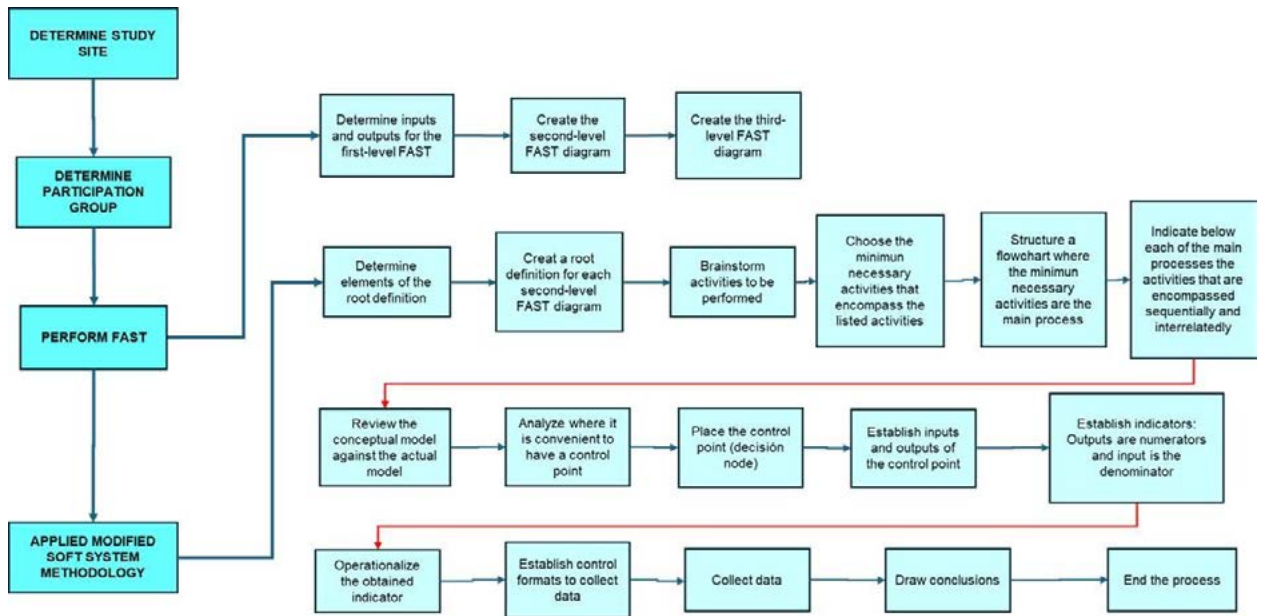


Figure 1. Method followed for the study.



Figure 2. Representation of the main Tilapia production process.

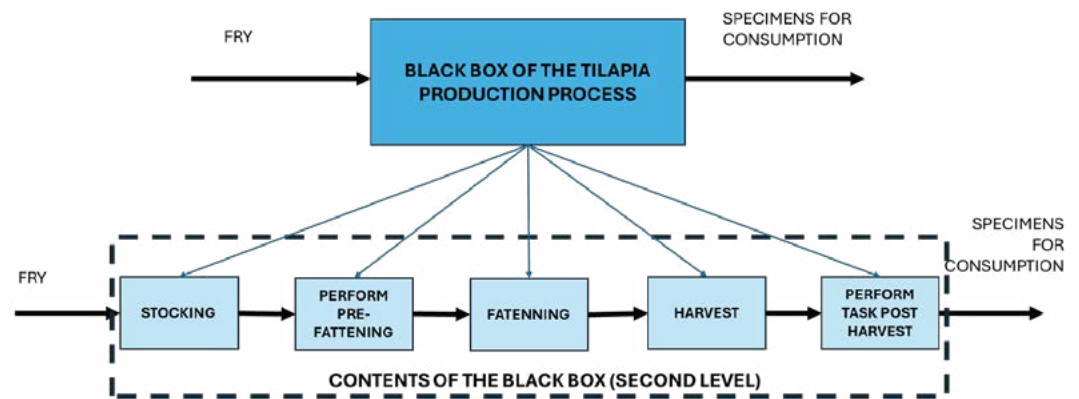


Figure 3. Representation of the secondary functions of the Tilapia production process.

leave to join the fattening process, where they continue to grow until they reach the weight and size required to be transferred to the harvesting process.

Figure 5 displays the third-level functions related to the harvest. When compared with the previous processes (Figure 4), two functions were added: obtaining the weight and size of the Tilapia and the separation of the Tilapia according to customer orders (Figure 5).

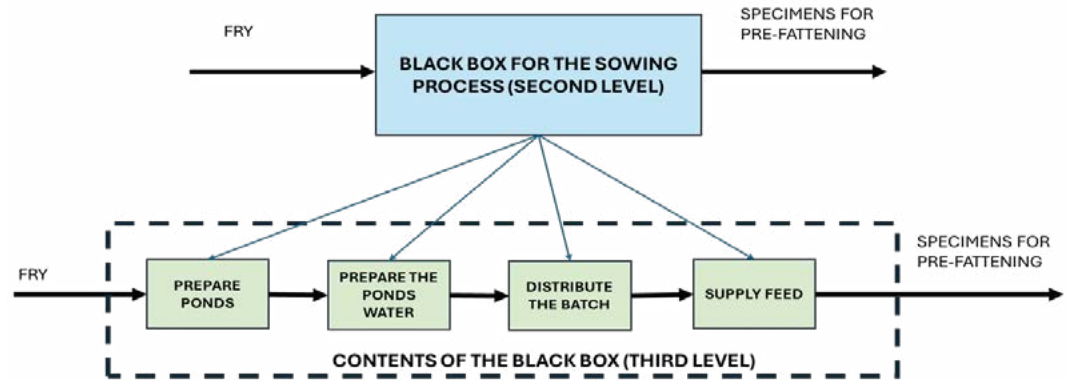


Figure 4. Functions derived from the pre-fattening process.

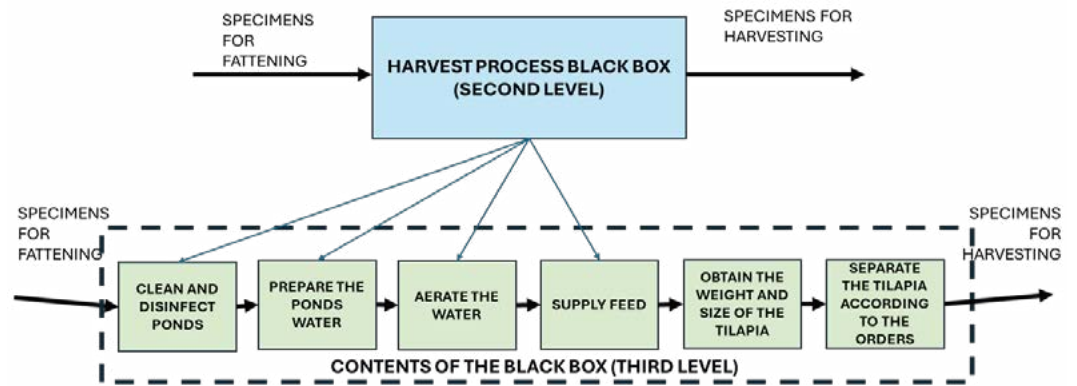


Figure 5. Harvest process black box (second and third level).

The last of the secondary functions for which tertiary functions were defined corresponded to the performance of post-harvest tasks. This function included the activities necessary for the sale of the specimens (Figure 6), which vary according to the destination of the product, whether for the transfer of live organisms to other sites or for their direct delivery to a distributor.

Determination of auxiliary functions

In the Tilapia production process, which begins with the purchase of fry, there are three auxiliary functions that must be considered but are generally not specified. Therefore, a functional analysis was conducted of these three functions: feed suppliers, pharmaceutical suppliers, and fingerling suppliers. One of the most important is the fingerling procurement process, which is critical to maintaining production quality. Figure 7 presents the process for selecting and evaluating domestic fry.

Phase 2. Application of the Modified Soft Systems Methodology

Determine the elements of the root definition (CATOWE)

Once the functional analysis was completed, the elements of each of the root definitions of the different subsystems shown in Table 1 were determined.

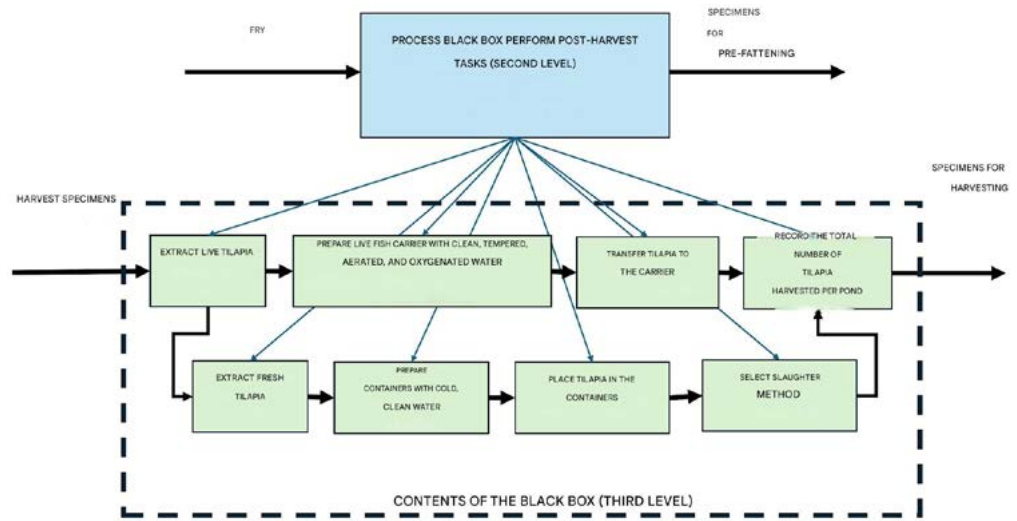


Figure 6. A black box contains the functions of post-harvest tasks for delivery to the customer, either live or in containers.

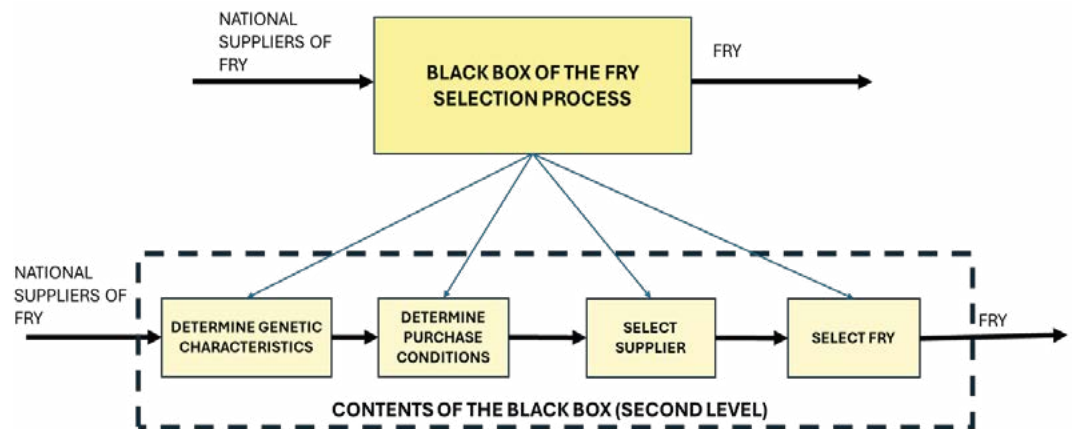


Figure 7. Selection and purchase process of fry prior to the Tilapia production system

Obtain the root definition

Once the elements of CATOWE were defined, 8 root definitions were structured, which are shown in Tables 2 and 3.

Table 3 presents the root definitions related to obtaining the inputs: fry, balanced feed and medicines.

Identify the minimum necessary activities

For each of the root definitions obtained, a brainstorming session was held to answer the question: What should have been done to achieve the defined transformation? In the case of the fry, the question is, what should have been done to select the best fry? This brainstorming session is shown in Table 4.

Table 1. Elements of the CATOWE analysis to perform the root definitions of the subsystems sowing, pre-fattening, fattening, harvesting, post-harvest work, selection of fry suppliers, balanced feed and drugs.

Proceso	C	A	T	O	W	E
Stocking	Buyers, end consumers	Farm, farm staff, COSAP	Achieving the best planting	Farm Manager	Ensuring safety, minimizing costs, optimizing infrastructure and environmental conditions, accurately counting fry, and assessing the physical characteristics of the fry are all essential factors.	Health regulations
Pre-fattening	Buyers, end consumers	Farm, farm staff, COSAP	Achieving the best pre-fattening	Farm Manager	The key factors for achieving the best pre-fattening are safety, minimizing costs, fish weight, stocking density, and water exchange rate.	Health regulations
It fattens	Buyers, end consumers	Farm, farm staff, COSAP	Achieving the best fattening	Farm Manager	Ensuring safety, minimizing costs, optimizing fish weight, utilizing aeration, managing feed supply, facilitating water exchange, and overseeing farm management are all essential factors.	Health regulations
Harvest	Buyers, end consumers	Farm, farm staff, COSAP	Get the best harvest	Farm Manager	Ensure safety, minimize costs, maintain commercial size, and prepare presentations	Health regulations
Post harvest	Buyers, end consumers	Farm, farm staff, COSAP	Obtain the best post-harvest	Farm Manager	Safety, lowest possible cost, best genetics, customer assurance	Health regulations
Selection of fry	Farm	Supplier of fry	Selecting the best fry	Farm Manager	The farm manager should prioritize good quality (food safety certification), the lowest possible cost, the highest utilization rate (conversion factor), and customer assurance.	Health regulations
Balanced Feed	Farm	Supplier, farm, COSAP, veterinarians, laboratories	Select the best balanced feed	Farm Manager	Good quality (food safety certification), lowest possible cost, highest utilization rate (conversion factor), customer assurance.	Health regulations
Drugs	Farm	Supplier, farm, COSAP, veterinarians, laboratories.	Selecting the best drugs	Farm Manager	Certifications, lowest possible cost, best quality, safety and reliability, customer assurance.	Health regulations

The minimum necessary activities were determined and ordered logically and sequentially, and the set of activities resulting from the brainstorming session was shown (Table 5). Subsequently, a flowchart was structured in which the control points for obtaining the indicators were located.

Structuring flowcharts

Figure 8 presents the flowchart obtained from the brainstorming of the activities to be carried out (light yellow), the minimum required activities (bright yellow) and the chosen control point (light green).

Table 2. Root definitions obtained from the elements of CATOWE for the sowing, pre-fattening, fattening, harvesting and post-harvest tasks (Amaro Guzmán, 2024).

Process	Root definition
Stocking	“The stocking system of ‘Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.’ seeks to achieve the best sowing of fry, which complies with existing regulations on safety, at the lowest possible cost, seeking to have optimal conditions in the infrastructure and the environment in which the fry will develop as well as having an accurate count of them and the identification of their physical characteristics to obtain the best product.”
Pre-fattening	“The pre-fattening system of “Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.” seeks to achieve the best pre-fattening of fry, which complies with existing regulations on safety, at the lowest possible cost, taking into account their weight, stocking density, and water exchange percentage to obtain the best product.”
Fattening	“The fattening system of ‘Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.’ seeks to achieve the best Tilapia fattening, which complies with existing regulations on safety, at the lowest possible cost, knowing the weight of the organisms using aeration, water replacement, supplying food, maintaining a good water temperature, and properly managing the farm to obtain the best product.”
Harvest	“The harvesting system of ‘Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.’ seeks to obtain the best Tilapia harvest, which complies with existing regulations on safety, at the lowest possible cost, and that the Tilapia meets the commercial size to obtain the best product.”
Post-harvest tasks	“The post-harvest system of ‘Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.’ aims to achieve the highest quality post-harvest Tilapia that complies with existing safety regulations, is produced at the lowest possible cost, and meets the commercial size requirements necessary for final sale procedures, whether live or fresh, ensuring the best product outcome.”

Table 3. Root definitions obtained from the elements of CATOWE for suppliers of fry, balanced feed and drugs (Amaro Guzmán, 2024).

Process	Root definition
Fry	“The fry system of “Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.” seeks to select the best fry that comply with existing regulations on food safety, at the lowest possible cost, with the best genetics, ensuring a long-term customer-supplier relationship.”
Balanced feed	“The balanced feed system of “Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.” seeks to select the best-balanced feed for Tilapia, which meets the expected quality standards (food safety certification), at the lowest possible cost, with the highest utilization rate (conversion factor), ensuring a long-term customer-supplier relationship.”
Drugs	“The pharmaceutical system of “Ingeniería Agropecuaria del Papaloapan S.P.R. de R.L.” aims to select the best medications for Tilapia that comply with relevant regulations and certifications, ensuring the lowest possible cost and highest quality while guaranteeing safety and reliability when supplying them to organizations as needed. This approach ensures a long-term client-supplier relationship.”

Table 4. Displays the outcomes of the brainstorming process that led to the fry selection.

Locate domestic suppliers of fry that have a food safety certificate.	Compare delivery punctuality.	Receive fry.
Compare genetic characteristics of the fry.	Compare customer service.	Verify that the order is correct in terms of quality and quantity.
Compare prices.	Select a primary supplier and a backup supplier.	Stock the fry.
Compare payment types.	Check availability of fry.	
Compare response time.	Track the shipment/transport of the order.	

Table 5. Result of the grouping of activities, the minimum necessary activities are in the first row, the secondary or grouped ones in the subsequent rows.

Minimum necessary activities	Locate domestic suppliers of fry that have a food safety certificate	Compare genetic characteristics of the fry	Place order	Stocking fry
Activities included		Compare prices.	Check availability of fry.	
		Compare payment types.	Track the shipment/transport of the order.	
		Compare response time.	Receive fry.	
		Compare delivery punctuality.	Verify that the order is correct in terms of quality and quantity.	
		Compare customer service.		
		Select a primary supplier and a backup supplier.		

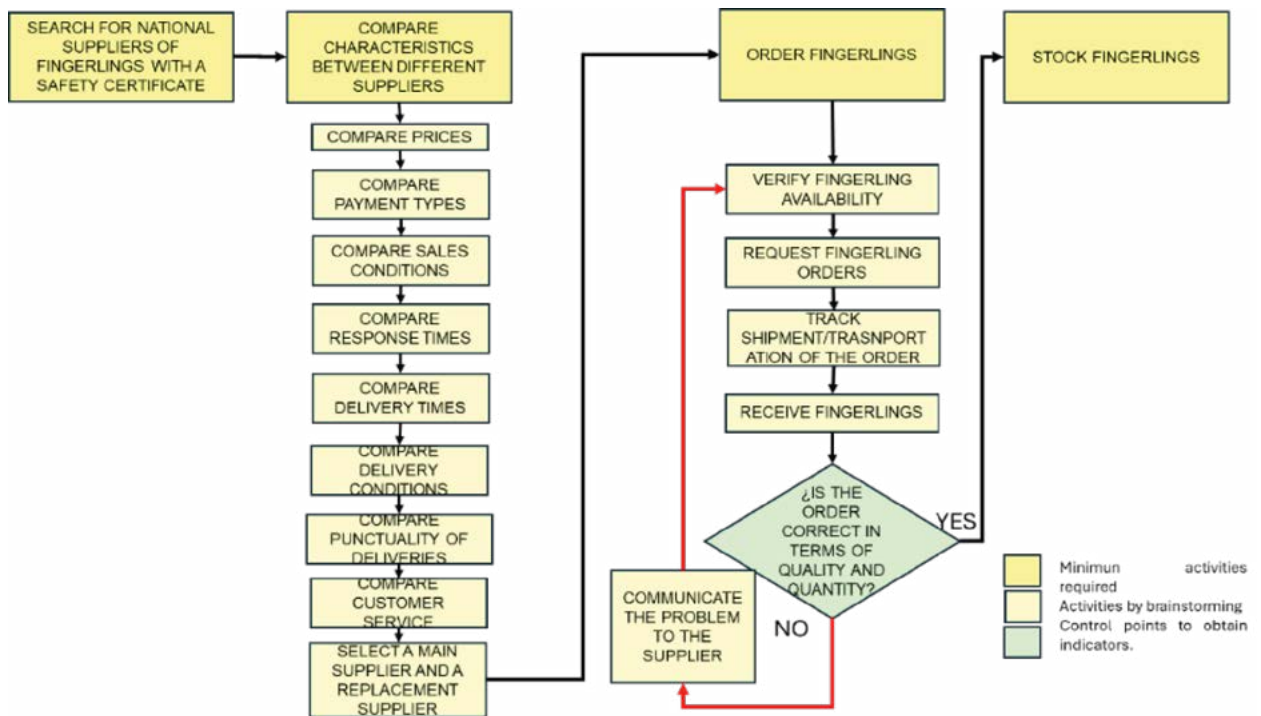


Figure 8. Fry System Flowchart.

Identify the decision nodes

A single decision node was considered for the fry supplier process

Obtain indicators

The remaining flowcharts were developed, and the control points were transformed into indicators, as shown in Table 6. Fourteen indicators were obtained for the different

secondary functions, primarily efficiency. These indicators are unitless because dividing outputs by inputs cancels the units and multiplying by one hundred results in a percentage.

During the stocking, pre-fattening, fattening, and harvesting processes, two indicators were measured: the percentage of compliance with the established conditions (SPF1) and the efficiency of compliance with the physi-cochemical parameters of the pond water (SPF2). This evaluation is not limited to verifying whether the control parameters are maintained within the specified ranges but also allows for determining the percentage of effective compliance, which constitutes a measure of the farm's operational efficiency in maintaining its processes within the technical specifications.

In the stocking process, a planting efficiency indicator (STC1) was determined, while in the fattening process, two additional indicators were defined: one that measures the efficiency of fattening time (FAT1) and the other that evaluates the feeding factor (FAT2).

Table 6. Management indicators obtained from the flowcharts.

Subsystem	Name	Indicator	Calculation method
Stocking, pre-fattening, fattening and harvesting	SPF1	Percentage of compliance with conditions of fry batches	= Batches that meet the conditions \times 100 / Batches purchased
	SPF2	Efficiency in pond water parameters	= (Total checks performed - Total corrections made) \times 100 / Total checks performed
Stocking	STC1	Efficiency of the stocking process	= Weight of fry obtained \times 100 / Expected weight of fry
Fattening	FAT1	Efficiency of the fattening process over time	= Number of days that compliance with size or weight is delayed \times 100 / Total days calculated
	FAT2	Efficiency of fattening process with respect to feed	= Amount of feed supplied due to delay \times 100 / Amount of feed calculated
Harvesting work	HAR1	Percentage of tilapia produced for individual rations	= Tilapia weighing less than 500 grams / Tilapia harvested
	HAR2	Percentage of tilapia produced for fillet	= Tilapia weighing more than 600 grams / Tilapia harvested.
Harvesting and post-harvest work	HAP1	Percentage of live product packaged	= Total de live product packaged \times 100 / Total product harvested
	HAP2	Percentage of fresh product packaged	= Total fresh product packaged \times 100 / Total product harvested
	HAP3	Percentage of trips less than 1 hour	= Trips less than 1 hour \times 100 / Total trips
	HAP4	Percentage of trips less than 5 hours	= Trips less than 5 hours \times 100 / Total trips
Suppliers of fry, feed and drugs	SUP1	Order efficiency and quality	= Number of correct orders \times 100 / Total orders placed
	SUP2	Order efficiency and quality	= Number of correct orders \times 100 / Total orders placed
	SUP3	Order efficiency and quality	= Number of correct orders \times 100 / Total orders placed

The identified harvest indicators (HAR1, HAR2) are primarily related to the percentage of Tilapia destined for individual portions or fillets. Both indicators are associated with the efficiency of the process in achieving the specified standard weight.

Four indicators were defined for the harvesting and post-harvest processes. Two of them are related to the percentage of live eviscerated product (HAP1) and fresh product (HAP2); these indicators allow identification of the market segment accessed (retail or semi-wholesale). The other two indicators (HAR3, HAR4) are associated with the transport and delivery time of the product.

An efficiency and quality indicator was defined as applicable to the three suppliers involved in the process: fry (SUP1), feed (SUP2), and medications (SUP3). This indicator serves to evaluate the suppliers comprehensively in relation to timely delivery and compliance with order specifications.

Table 7 presents the quantitative results of the developed production management indicators, showing that only 28.57% achieved 100% of the results (SPF1, SUP1, SUP2, SUP3). Regarding STC1, 94.44% of the fry reached the target weight. The fattening period for the organisms took 25% longer than calculated (FAT1) and consumed 21.43% more feed (FAT2).

Regarding the expected weight, 58.33% met it (HAR1, HAR2). 74.13% (HAP2) are sold live at medium wholesale prices, the rest are sold retail (HAP1). Finally, 86.67% of deliveries (HAP4) have an estimated delivery time between 1 and 5 hours.

Upon reviewing the flowcharts of suppliers for fry, feed, and pharmaceuticals, we found a total of 13 activities that serve as selection criteria. Each criterion was assigned a relative value using a Likert scale, where one indicates the worst performance in each area and five indicates the best. This criterion was determined based on the experience and knowledge of the farm staff, as well as the particular interests of the farm.

Table 7. Results of the application of the management indicators obtained from the flowcharts.

Subsystem	Name	Output	Input	Indicator
Stocking, pre-fattening, fattening and harvesting	SPF1	3.0	3.0	100.00%
	SPF2	957.0	1080.0	88.61%
Stocking	STC1	85000.0	90000.0	94.44%
Fattening	FAT1	150.0	120.0	125.00%
	FAT2	1.7	1.4	121.43%
Harvesting work	HAR1	1350.0	6000.0	22.50%
	HAR2	1156.0	6000.0	19.27%
Harvesting and post-harvest work	HAP1	1352.0	6000.0	22.53%
	HAP2	4448.0	6000.0	74.13%
	HAP3	8.0	60.0	13.33%
	HAP4	52.0	60.0	86.67%
Suppliers of fry, feed and drugs	SUP1	3.0	3.0	100.00%
	SUP2	10.0	10.0	100.00%
	SUP3	1.0	1.0	100.00%

Determine criteria

Figure 9 presents the criteria for evaluating the performance of fingerling suppliers and the results obtained from the evaluation. There are 11 criteria in total, which were applied to three suppliers. The results indicate that the third supplier is the most convenient and that the main differences between them are price, sales terms, payment method, and delivery timeliness. All three suppliers are located far from the farm and take three days to deliver an order once it is placed.

Figure 10 shows the criteria for evaluating feed suppliers. The difference compared to those established for fry is that it does not consider genetic characteristics but instead introduces two criteria: quality and feed conversion ratio.

The results favor food supplier No. 3. The criteria where there are significant differences compared to the other suppliers are conversion rate, price, punctuality, and payment terms, as they offer credit. One of the drawbacks is the response time, as it takes more than 3 days to deliver the food.

In the case of the drug suppliers (Figure 11), only 10 criteria were considered. The results of the evaluation of the three suppliers to the farm are similar.

The indicators found in manuals related to tilapia production (FONDEPES *et al.*, 2004; INCODER, 2006; Saavedra Martínez, 2006; SENASICA, 2008; OIRSA, 2017) cover technical aspects, biosecurity, traceability, and others. However, they do not cover administrative aspects beyond examples of how to calculate costs. In some of them,

FINGERLING SUPPLIER									
CRITERIA	RATING	1	2	3	4	5	Supplir 1	Supplier 2	Supplier 3
GENETIC CHARACTERISTICS		Terrible	Poor	Average	Good	Very good	3	3	3
PRICE		More than \$500/100 fingerlings	Between \$400 and \$499/100 fingerlings	Between \$300 and \$399/100 fingerlings	Between \$200 and \$299/100 fingerlings	Between \$100 and \$199/100 fingerlings	3	4	5
PAYMENT TYPE		Other	Cash	Card	Transfer	On credit	2	2	3
TERMS OF SALE		Terrible	Poor	Average	Good	Excellent	3	4	5
RESPONSE TIME		After 3 dias	Within 72 hours	Within 48 hours	Within 24 hours	In less than 24 hours	3	2	1
THE SUPPLIER DELIVERS TO THE FARM		Never	Almost never	Sometimes	Almost always	Always	5	5	5
DISTANCE BETWEEN THE SUPPLIER AND THE FARM		More than 120 km	From 91 to 120 km	From 61 to 90 km	From 31 to 60 km	From 0 to 30 km	1	1	1
DELIVERY TIME		After 3 dias	Within 72 hours	Within 48 hours	Within 24 hours	In less than 24 hours	1	1	1
DELIVERY CONDITIONS		Terrible	Poor	Average	Acceptable	Excellent	4	4	4
PUNCTUALITY IN DELIVERIES		Terrible	Poor	Average	Good	Very good	3	4	5
CUSTOMER SERVICE		Terrible	Poor	Average	Good	Excellent	5	5	5
							34	38	43

Figure 9. Criteria and evaluation carried out on three suppliers of fry.

FEED SUPPLIERS								
RATING CRITERIA	1	2	3	4	5	SUPPLIER 1	SUPPLIER 2	SUPPLIER 3
QUALITY	Terrible	Poor	Average	Good	Very good	3	3	3
CONVERSION FACTOR	Less than 1:1.4	1:1.4	1:1.5	1:1.6	Greater than 1:1.6	1	3	5
PRICE	More than \$60/kg	From \$51 to \$60/kg	From \$41 to \$50/kg	\$40/kg	Less than \$40/kg	3	4	5
PAYMENT TYPE	Other	Cash	Card	Transfer	On credit	2	2	3
TERMS OF SALE	Terrible	Poor	Average	Good	Excellent	3	4	5
RESPONSE TIME	After 3 días	Within 72 hours	Within 48 hours	Within 24 hours	In less than 24 hours	3	2	1
THE SUPPLIER DELIVERS TO THE FARM	Never	Almost never	Sometimes	Almost always	Always	5	5	5
DISTANCE BETWEEN THE SUPPLIER AND THE FARM	More than 120 km	From 91 to 120 km	From 61 to 90 km	From 31 to 60 km	From 0 to 30 km	1	1	1
DELIVERY TIME	After 3 días	Within 72 hours	Within 48 hours	Within 24 hours	In less than 24 hours	1	1	1
DELIVERY CONDITIONS	Terrible	Poor	Average	Acceptable	Excellent	4	4	4
PUNCTUALITY IN DELIVERIES	Terrible	Poor	Average	Good	Very good	3	4	5
CUSTOMER SERVICE	Terrible	Poor	Average	Good	Excellent	5	5	5
						34	38	43

Figure 10. Criteria for the selection of feed suppliers for an aquaculture farm.

DRUG SUPPLIERS								
RATING CRITERIA	1	2	3	4	5	SUPPLIER 1	SUPPLIER 2	SUPPLIER 3
Calidad	Terrible	Bad	Average	Good	Very good	3	3	3
PAYMENT TYPE	Other	Cash	Card	Transfer	On credit	2	2	2
TERMS OF SALE	Terrible	Bad	Average	Good	Excellent	3	3	3
RESPONSE TIME	After 3 días	Within 72 hours	Within 48 hours	Within 24 hours	In less than 24 hours	1	1	1
THE SUPPLIER DELIVERS TO THE FARM	Never	Almost never	Sometimes	Almost always	Always	1	1	1
DISTANCE BETWEEN THE SUPPLIER AND THE FARM	More than 120 km	From 91 to 120 km	From 61 to 90 km	From 31 to 60 km	From 0 to 30 km	1	1	1
DELIVERY TIME	After 3 días	Within 72 hours	Within 48 hours	Within 24 hours	In less than 24 hours	1	1	1
DELIVERY CONDITIONS	Terrible	Bad	Average	Acceptable	Excellent	5	5	5
PUNCTUALITY IN DELIVERIES	Terrible	Bad	Average	Good	Very good	5	5	5
CUSTOMER SERVICE	Terrible	Bad	Average	Good	Excellent	5	5	5
						27	27	27

Figure 11. Criteria for the qualification of drug suppliers.

there are annexes with formats that help in the process. They don't show flow charts, and while they show some indicators like % survival, size, and % shrinkage, they don't say what to do with them. No methods or suggestions were found for the evaluation of

suppliers of fry, drugs, and feed. The research by Anderson *et al.* (2025) on Aquaculture Performance Indicators (APIs) constitutes a relevant conceptual contribution to enrich the interpretation of the results obtained. The authors suggest a group of standardized indicators that help to measure the performance of aquaculture systems from three aspects: economic, social, and environmental. This method promotes a complete and comparative view of sustainability in aquaculture. From a theoretical perspective, the combination of methods used in this study (FAST and SSMM) fits the logic of APIs, as it converts complicated qualitative processes into quantitative performance indicators. This integration reinforces that sustainability should not only be seen in relation to biological productivity but also in terms of management efficiency, quality of governance, and ability to adapt to changing conditions (Anderson *et al.*, 2025; Gurruchaga Rodríguez *et al.*, 2006). Its practical usefulness lies in the indicators it provides. We can link farming efficiency, feed, suppliers, and logistic times to global APIs to compare semi-intensive tilapia farms in Mexico. This articulation allows Granja Tierra Adentro to advance in a comprehensive evaluation of productive and social sustainability, with international standards of aquaculture performance (Anderson *et al.*, 2025; López Téllez *et al.*, 2025). Bringing the two methodologies together forms a replicable model to increase competitiveness and improve control of tilapia production in semi-intensive systems in tropical climates. Anderson *et al.* (2025b) developed Aquaculture Performance Indicators (APIs) as a low-cost evaluation tool for data-limited contexts. APIs come from previous experience with Fisheries Performance Indicators and allow comparison of production systems, species, and technology scales through performance indicators and enabling factors. The study at the Tierra Adentro Farm uses a qualitative/quantitative approach based on FAST Analysis and MSSM to generate internal operational indicators. The systemic logic relates to the concept of APIs: turning complicated processes into verifiable indicators that show how production, management, and sustainability are connected (Delfín-Portela *et al.* 2023). The theoretical contribution of both approaches lies in the integration of systemic tools and performance assessment. This indicates that indicators not only represent technical productivity but also the adaptability, control, and resilience of the aquaculture system (Anderson *et al.*, 2025b; Gurruchaga Rodríguez *et al.*, 2006). This study represents a microanalytical application of APIs: its internal indicators, although based on local qualitative information, are comparable and scalable to a global assessment framework. The Tierra Adentro farm shows how semi-intensive tilapia systems in tropical areas are shifting towards methods that evaluate and improve their performance, following the international recommendations of Anderson *et al.* (2025b). To achieve scalability, it is proposed to: a) Select farms by type of system, product, and size; b) Bring stakeholders together; c) Train and raise awareness of the working method; d) Apply the method using the knowledge and experience of stakeholders to adjust it to different environmental, technological, and organizational conditions; e) Select a larger number of aquaculture farms; f) Replicate steps b to d; g) Evaluate reproducibility, impact, and sustainability; g) Integrate the method as a formal tool; h) Carry out dissemination and technology transfer.

CONCLUSIONS

The combined use of functional analysis (FAST) and the Modified Smooth Systematic Analysis Methodology (MSSM) made it possible to identify more than 80% of the critical management control points in the tilapia production process at the Tierra Adentro Aquaculture Farm. This process encompasses all stages from planting to post-harvest, including the evaluation of suppliers. The integration of methods demonstrated the clear and organized relationship between the system's functions. The process helped to prioritize functions and identify problems in the operation.

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