SYSTEMS ENGINEERING MANAGEMENT PLAN (SEMP)

FOR

FRUIT2U

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ASE 6001: Fundamentals of Modern Systems Engineering

Final Project

Table of Contents

List of Figures

List of Tables

1. SEMP / Project Overview (ASE 6001)

1.1 Need Statement

The mission of Fruit2U is to tackle rampant problems such as food wastage, food shortage and hunger, and global warming. Data from the USDA shows that even as recent as 2019, 10-12% of households in the United States faced food insecurity. [1] The other side of the coin is that grocery stores are major contributors to food wastage. RTS states that retail grocery stores waste approximately 30% of their produce, leading to around 16 billion pounds of food waste annually. [2][3] Most of this food waste ends up in landfills and decomposes to release greenhouse gases that further contribute to global warming. The cost incurred in generating this wasted food is estimated to be twice the profit from food sales and thus the concept of Fruit2U was further incentivized for retail grocers. [4] Thus, the primary customers for Fruit2U are retail grocers like Walmart or Kroger.

The objective would be to have a solution to bridge the gap between the existence of surplus food that is disposed of, and areas with widespread hunger. The major distribution challenge here is currently the spoilage time for food with Produce leading the list. Bananas are the leading contenders in produce due to their short spoilage time, volume, and popularity of the product. Moreover, the marketable window where users find the fruit aesthetically pleasing is quite small thus leading to large quantities of bananas being disposed to landfills.

This led to the generation of the problem statement: "Short spoilage time and perishability lead to bananas being major contributors to produce waste." The related solution for this was: "To develop an equipment to prepare, dehydrate and package surplus bananas for transport to food banks." The goal of the project is to develop a system that will process surplus bananas at retail grocery stores. The name of this system is Fruit2U. Fruit2U would convert the fresh fruits into dehydrated packs of bananas which have a longer shelf-life, thus alleviating the burden on the supply chain and minimizing food waste. The team would develop this equipment with funding from retail groceries to commission Fruit2U within their facility to process surplus bananas into ready-to-eat packages.

The Concept of Operations (ConOps) is described separately in an additional document that will be submitted with this SEMP document. From a system perspective, this SEMP document will highlight the details of Fruit2U. The scope of the system would lie from the bananas entering the system (surplus) to the bananas exiting the system (as boxes of sealed banana packs). The prescribed system's capabilities would lie in correctly peeling, cutting, dehydrating, and packaging bananas into its final form and these four comprise the major sub-systems of Fruit2U. Details of these sub-systems will be found in the Functional Analysis and Design Model section of this document. Key stakeholders are outlined in the ConOps document (see ConOps, section 5.1).

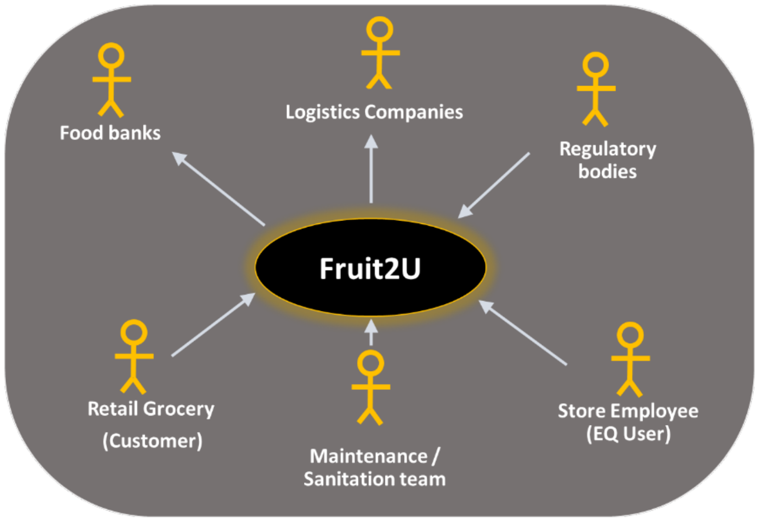

Figure 1: Context Diagram

The context diagram shown above was used to obtain a preliminary understanding of the customer needs. The various actors outlined above interact with the Fruit2U System in different ways:

- The **Retail Groceries** are the customer for the Fruit2U system and will house the Fruit2U system at their site. The Retail Grocery will provide the operational inputs for the Fruit2U system (viable bananas and energy considerations)
- The **Grocery Store Employee** is intended to be the main operator of the Fruit2U system. They will load the Fruit2U with unprocessed bananas and be responsible for moving the packaged banana chips from the packaging area to a temporary storage area.
- The **Logistic Company** is responsible for taking the packaged banana chips from the Retail Grocery Store and delivering it to the Food Banks.
- The **Food Bank** is the end recipient of packaged banana chips as it relates to the Fruit2U system.
- The **Regulatory Bodies** will be critical to the successful implementation of this system. This system must be approved to produce food that is fit for human consumption. Regulatory bodies exist at the local, state, and federal levels and each will be considered.

- The **Maintenance and Sanitation team** will be responsible for the preventative maintenance and cleaning of the machine.

1.2 Project Structure (N/A)

Section will be developed in later phase of program.

2. Business Case (N/A)

Section will be developed in later phase of program.

3. Customer Requirements

The table below outlines the high-level Customer Requirements.

Requirement ID	Requirement	Functional	Testable	Hazards	Stability	Criteria Mapping
Prepare_Req1000	The system shall detect Class I through Class VII ripe bananas autonomously	F	Y	N	High	Process Time
Cutting_Req2000	The system shall direct the flow of peeled bananas	F	Y	N	High	User Friendly
Dehydrate_Req3000	The system shall be able to desiccate a fixed mass of banana pieces within a single cycle	F	Y	N	High	Process Time
Package_Req4000	The system shall hermetically seal boxes of packaged banana	F	Y	Y	High	Safety
General_Req5000	The system shall be constructed using materials that meet regulatory requirements for food compatibility.	N	Y	Y	High	Safety

Table 1: Customer Requirements

The high-level Customer Requirements were developed after multiple consultations with the customer and considering their strategic goal to reduce operational wastage in the next five years.

4. Derived Requirements (ASE 6001)

The Customer Requirements were divided into five main buckets:

1) Prepare – Relates to the preparation of the raw banana pre-slicing
2) Cut – Relates to the slicing of the bananas into the shape of chips
3) Dehydrate - Relates to the desiccation of the banana slices
4) Package – Relates to the packaging to the dehydrated banana chips
5) General – Relates to overarching system-wide requirements

The Customer Requirements were further decomposed to provide a more comprehensive picture of all the detailed requirements involved to bring this system to fruition. The decomposition of the Customer Requirements served as the input for the Derived Requirements. All Derived Requirements are traceable to their parent Customer Requirements and were made to be independent, testable, specific, and valuable to the customer.

Requirement ID	Requirement	Functional	Testable	Hazards	Stability	Criteria Mapping
Prepare_Req1010	The system shall accept bananas packaged in a standard container.	N	Y	N	Low	User Friendly
Prepare_Req1020	The system shall dispose of Class VIII through Class XII from the system.	F	Y	Y	High	Safety
Prepare_Req1030	The system shall provide a 'Platform Overloaded' error if the weight is above 50 lbs.	F	Y	N	Medium	Maintainability
Prepare_Req1040	The system shall measure bananas within a tolerance of 10g.	N	Y	N	Low	Process Time
Cutting_Req2010	The system shall have peeled bananas loaded into a deep chamber.	F	Y	Y	Medium	Safety
Cutting_Req2020	The system shall operate in a 360-degree allowable access space.	N	Y	N	Medium	Maintainability
Cutting_Req2030	The system shall shut-off when high vibration causes a shift from installed position.	N	Y	Y	High	Safety
Dehydrate_Req3010	The system shall allow the operator to adjust heat settings for the device.	F	Y	N	Medium	Process Time
Package_Req4010	The system shall arrange sealed dried banana packages of a fixed mass.	N	Y	N	Low	User Friendly
Package_Req4020	The system shall screen incoming bananas for pathogens.	F	Y	Y	High	Safety
General_Req5010	The system shall use a standard North American electrical input.	N	Y	Y	Medium	User Friendly

Table 2: Derived Requirements

5. Use Case Model

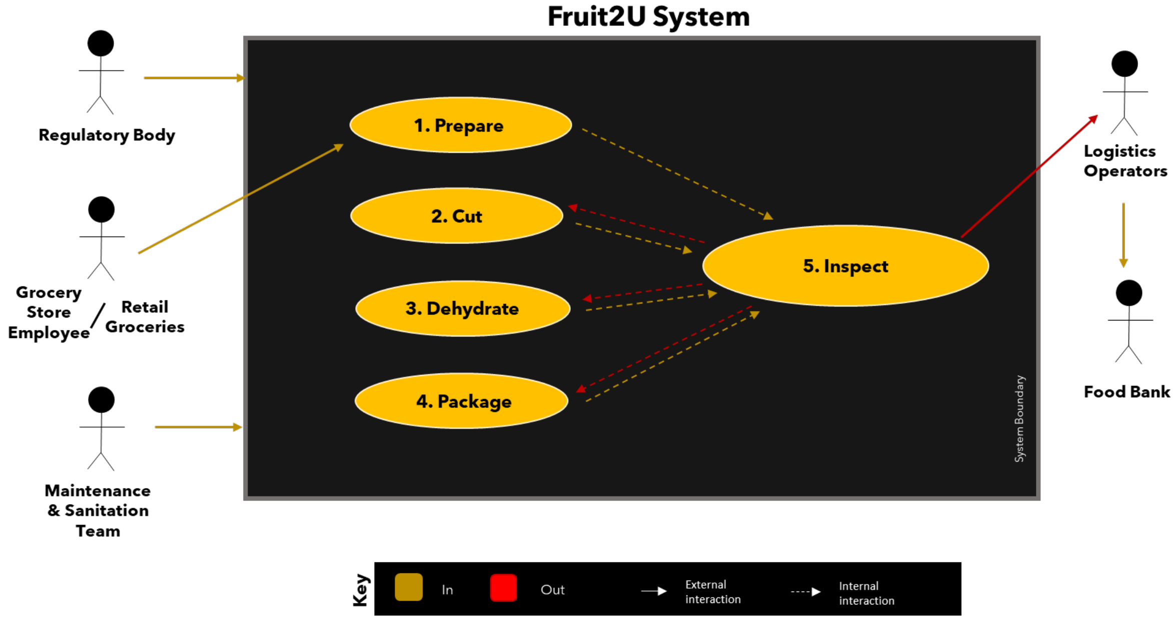

Figure 2: Use Case Model

The Use Case diagram illustrated above (Figure 2) helped to illustrate the interactions of the different actors with the Fruit2U system. It was used to refine the understanding of the system and what was necessary to achieve the goal of the primary actors (Grocery Store Employee, Retail Grocery and Food Bank). The flow of events is demonstrated by following the direction and order of the external and internal interactions.

There are four main functions, Load, Cut, Dehydrate and Package. The Inspection function of the system is central as inspection should occur after each function is performed. After the banana is prepared, there should be no peel left. Once cutting has concluded, the banana slices should be of a certain thickness. Once the Slices have been dehydrated, they need to have a specific moisture content before they can be deemed finished. Any packaging of the dried banana slices needs to be sterile and should protect the dried chips from external pathogens and other potential "bad actors".

The Grocery Store employee serves as the main operator of the Fruit2U system while the Retail Grocery is the customer of the Fruit2U system. The Retail Grocery houses the Fruit2U system and is responsible for providing its operational inputs. The Maintenance and Sanitation team will interact with the entire system which is why its arrow flows into the boundary of the system. The input from the Regulatory Bodies is critical as it will feed into the definition of Verification and Validation procedures necessary for further system development and implementation. The Fruit2U system needs to be able to generate a consumer good that is fit for human consumption.

6. System Verification and Validation

The verification and validation portion of the SEMP should include the following:

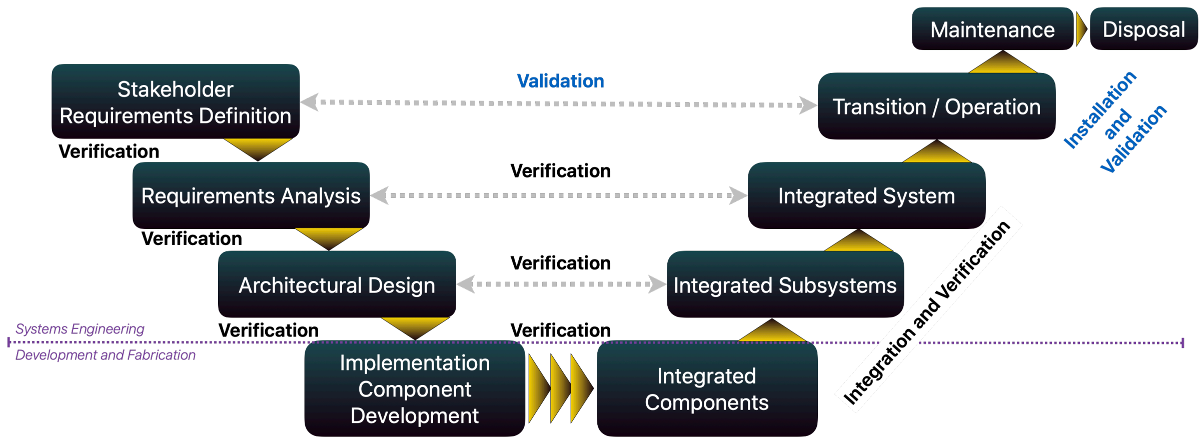

Figure 3: V-Model Diagram

The system Verification and Validation (V&V) diagram in Figure 3 is used to show the entire process flow of the systems engineering process. The highlights of the Vee-diagram are that the left side illustrates verification process, that is, the step that ensures whether the system is being built right. On the other hand, the right-side of the Vee highlights validation or the steps taken to ensure that the correct system is being built. Verification and Validation happens in every stage of the process and include both high level aspects (for example, within high level design or integrated full module) and low-level aspects (for example, within detailed design and sub-module integration steps).

This section would detail the Verification and Validation for requirements and the overall system.

Requirement verification proves that each requirement has been satisfied and is done using four major techniques: 1) test, 2) inspection, 3) analysis, and 4) demonstration. Table 3 shows the one-to-one mapping between the requirements and the test plan for each of the derived requirements.

Requirement ID	Requirement	Verification Method
Prepare_Req1010	The system shall accept bananas packaged in a standard container.	T - Testing of sub-system prototypes for banana container.
Prepare_Req1020	The system shall dispose of Class VIII through Class XII from the system.	D - Prototype demonstration of the sub-system showing reject and acceptance operation.
Prepare_Req1030	The system shall provide a 'Platform Overloaded' error if the weight is above 50 lbs.	T - Sample testing for evaluating error notice.
Prepare_Req1040	The system shall measure bananas within a tolerance of 10g.	T - Measurement of bananas to determine tolerance.
Cutting_Req2010	The system shall have peeled bananas loaded into a deep chamber.	A - CAD view of chamber model prior to fabrication.
Cutting_Req2020	The system shall operate in a 360-degree allowable access space.	A - Model simulation of tool in a virtual environment allowing customer to verify accessibility.
Cutting_Req2030	The system shall shut-off when high vibration causes a shift from installed position.	A - Simulation of vibration scenarios for sub-system.
Dehydrate_Req3010	The system shall allow the operator to adjust heat settings for the device.	A & T - Analysis followed by prototype testing.
Package_Req4010	The system shall arrange sealed dried banana packages of a fixed mass	I & D - Inspection and demo of banana packs.
Package_Req4020	The system shall screen incoming bananas for pathogens.	T - Testing of inspection systems to measure % of successful detections.
General_Req5010	The system shall use a standard North American electrical input.	I - Inspection of components used in fabrication.

T	I	D	A
Test	Inspection	Demonstration	Analysis

Table 3: Requirements and Verification Methods

Table 3 highlights the testing techniques used for each derived requirement. This level of granularity would be visible to the systems engineers and the customers to understand the link between the systems being developed and the requirements thus enabling better decision-making and direction.

System verification ensures that the system complies with its requirements and ensures conformance to its design. To check if the 'system is being built right', each system would need to be understood in some more detail. Figure 4 shows Level 1 and 2 items within Fruit2U.

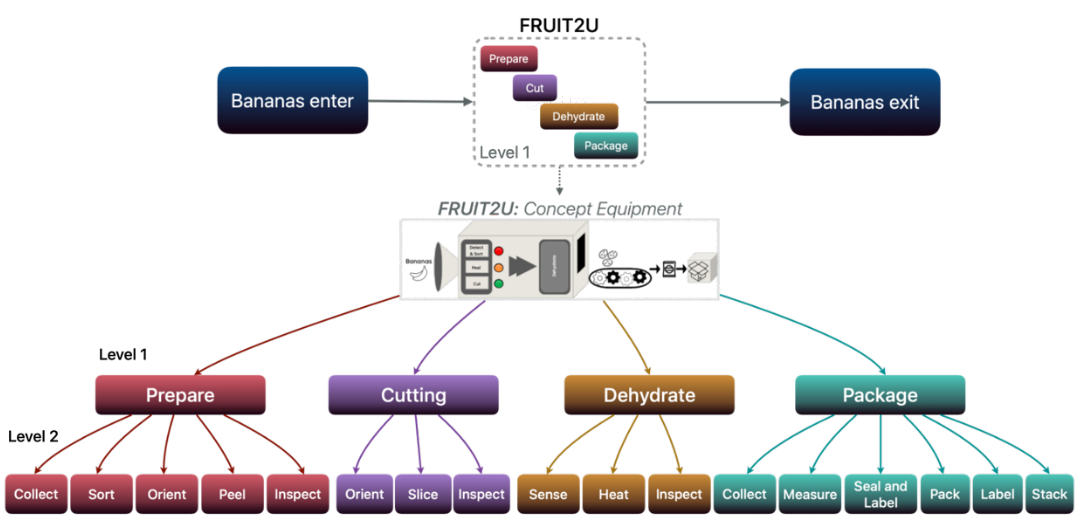

Figure 4: Functional Tree Diagram

For system verification Table 4 below captures each Level 2 item and details the verification steps used to ensure that the right system is being built.

Systems		Verification Method	Requirements Addressed
Level 1	Level 2	Items	
Prepare	Collect	T - Testing of sub-system prototypes for banana container.	Prepare_Req1010
	Sort	D - Prototype demonstration of the sub-system showing reject and acceptance operation.	Prepare_Req1030, Prepare_Req1040
	Orient	A - Analysis of banana variants (shapes and sizes) through the orientation sub-system.	Prepare_Req1010
	Peel	T - Prototype peeling sub-system to test peel acceptance and function limitations.	Cutting_Req2010
	Inspect	D - Demo the inspection system to understand acceptance performance.	Prepare_Req1020
Cut	Orient	A - Analysis of banana variants (shapes and sizes) through the orientation sub-system.	Cutting_Req2010
	Slice	T - Prototype slicing sub-system to test efficiency and throughput. Also testing would reveal any functional limitations.	Cutting_Req2010, Cutting_Req2020
	Inspect	D - Demo the inspection system to understand acceptance performance.	Prepare_Req1020
Dehydrate	Sense	A - Modeling the temperature	Dehydrate_Req3010
	Heat	A & T - Analysis followed by prototype testing of heating module.	Dehydrate_Req3010
	Inspect	D - Demo the inspection system to understand acceptance performance.	Dehydrate_Req3010, Prepare_Req1020
Package	Collect	T - Testing of sub-system prototypes for collecting cut and dehydrated bananas.	Package_Req4010
	Measure	T - Measurement of banana packs to determine weight boundaries for packs.	Package_Req4010
	Seal and Label	D - Working-level prototype to verify the seal quality and label process.	Package_Req4020
	Pack	I - Inspection of packages to test quality of hermetic seal.	Package_Req4010
	Label	I - Inspection of labels for conformance to standards.	Package_Req4010
	Stack	T & D - Testing of pack stacking and demo of sample to customer.	Package_Req4010

T	I	D	A
Test	Inspection	Demonstration	Analysis

Table 4: System Verification Details

Requirement validation ensures that the set of requirements is correct, complete, and consistent and that a model can be created that satisfies the requirements. This would also mean that a real-world solution can be built to satisfy the requirements and testing can be done on it. For Fruit2U, the customer (Kroger or Walmart) would be frequently updated with the progress of the systems.

This is primarily validated through to reviewing and updating the ConOps with the customer, reviews of Customer Requirements and mapping to functional requirements, prototypes reviews and real-world demonstrations with the customer, including customer on integration testing, discussions during monthly status meetings, and customer gate reviews during design development. This is the latter section (right half) of the Vee-diagram. Key items for customer requirements validation are described in the final column in Figure 4 above. This helps with mapping back the sub-system development process with the requirements to be addressed.

System validation ensures that the system performs what it is supposed to do. During the integration phase of sub-systems for the Fruit2U system, the key validation steps need to be conducted. For example, within the dehydration system the sub-system would be tested using metrics such as temperature range, performance, moisture removal etc. This would be carried out using techniques as described in Tables 3 and 4. This way the dehydrate sub-system would be verified quantitatively.

At the sub-module integration phase for Fruit2U, the validation items would be verified through customer review compared to the metrics for acceptance. This would include functioning videos of the prepare system including a sub-system level prototype. For the cut system, the evaluation of the slicing sections would be critical. This would be validated through customer on-site demonstration of the working module using test bananas from grades I through VII. Additional bananas outside this ripeness class would also be considered to evaluate the functioning of other sub-systems like rejection and inspection. Dehydrate sub-system would be validated with temperature metrics from the customer measured using thermocouples. Packaging lines would also be evaluated through customer visits to ensure operation meets their expectations.

Once each sub-system is evaluated in a similar manner, the module system integration begins. The system validation at this level ensures the seamless functioning of each sub-module with each other. This would be done with multiple site visits for a full demo prototype or a site commissioning on a small scale to confirm customer acceptance. At the sub-module integration phase for Fruit2U, the validation items would be verified through customer review comparing to the metrics for acceptance. This would include functioning videos of the prepare system including a sub-system level prototype. For the cut system, the evaluation of the slicing sections would be critical. This would be validated through customer on-site demonstration of the working module using test bananas from grades I through VII. Additional bananas would outside this ripeness class would also be considered to evaluate the functioning of other sub-systems like rejection and inspection. Dehydrate sub-system would be validated with temperature metrics and from the customer

7. Concept Exploration

For the Concept Exploration the operational requirements were analyzed, the performance requirements were formulated, then a range of feasible implementation technologies and concepts were explored.

For the problem of banana food waste, there were several options that could be considered:

Competition: There is no automated banana or fruit processing system available.

Do-nothing: The do-nothing approach would be to have commercial services rely on using commercially available dehydrators. This process would be very manually intensive and would not minimize power efficiency. Companies do not perform this activity and will not do this because of the labor resources needed. Bananas would continue to be wasted because of environmental impacts and not improving food availability.

Do-something: The Fruit2U would perform all tasks needed to dehydrate bananas. This would include identifying if the banana can be dehydrated based on ripeness, peeling, cutting, dehydrating, and packaging. This concept would be much more likely to be implemented at retail grocery stores as this minimizes labor required while salvaging overripe bananas.

Feasibility: There were several systems options for which the feasibility was evaluated. Cost-focused, user-friendly focused, maintainability focused, and process time focused were all alternatives that would solve the problem and evaluated below.

8. Design Model

Figure 5 shows the overall design model of Fruit2U. The process begins when banana is loaded into the Fruit2U system until they exit as boxes of packed, dehydrated bananas as seen in Figure 5 as 'Bananas Exit'. The gray, dotted box, outlined at the top of the illustration highlights the Level 1 items within the system boundary. Key users interacting with the system were described earlier in the 'Use Case' section. In this section, the expansion of the functioning of the system will be discussed.

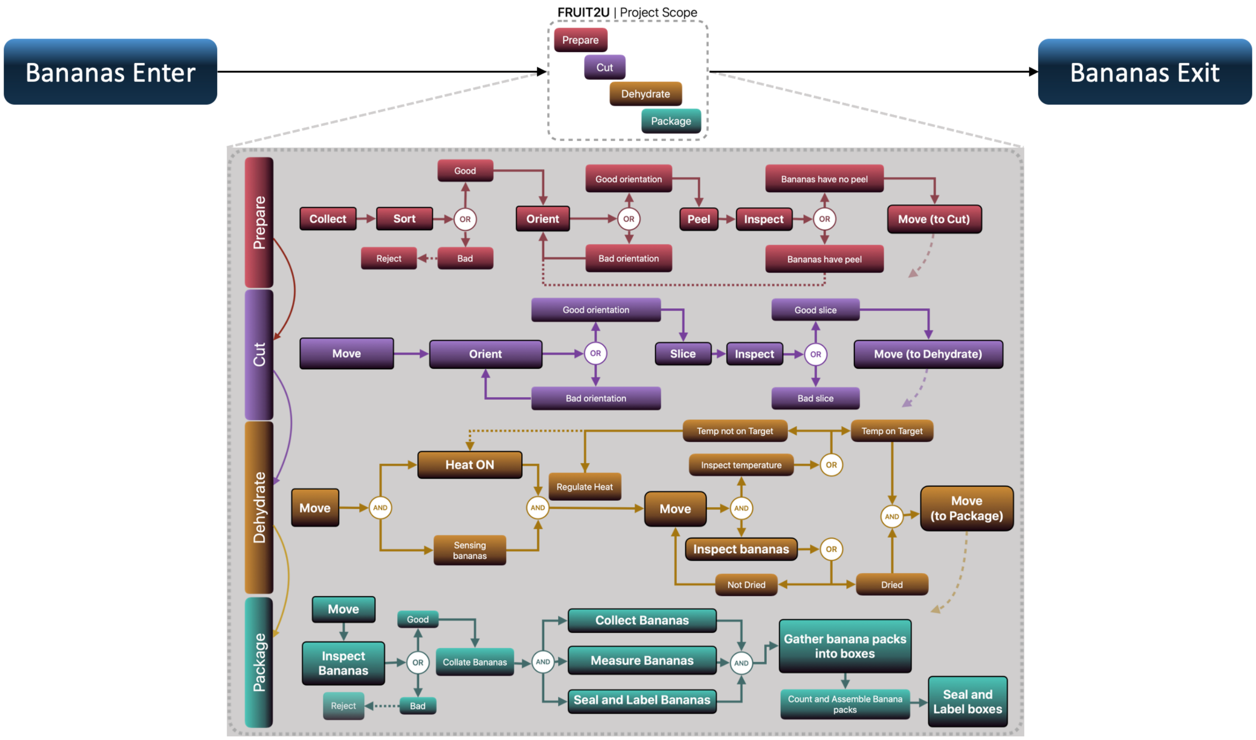

Figure 5: Functional Flow Block Diagram

The Functional Flow Block Diagram (FFBD) Shown in Figure 5 provides the details of Level 2 items in the system. The flow of the diagram is from the left to the right and then top to bottom, within the Level 2 items. The FFBD details additional components that link Level 2 items and simulate the flow of bananas through the Fruit2U system. Figure 6 below further highlights the FFBD through a logical top-down sequence going through each sub-system in order.

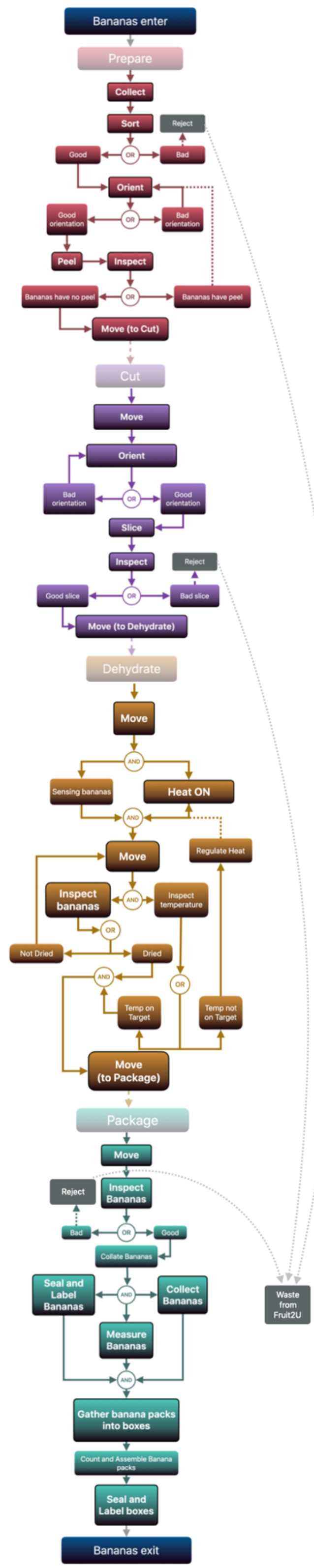

Figure 6: Detailed Process Flow

Figure 6 also details out the process flow within Fruit2U. This figure also helps highlight the process of handling reject / waste bananas. The goal of the system would be to capture the rejects from each sub-system into a central waste collection point and then send this minimal quantity for disposal. To further minimize the waste output, it can be noted that within the dehydrate system the bananas would be re-processed. Another alternative with this would be to collect the waste bananas and re-process them in a stand-alone batch. This would be evaluated in future iterations of the system based on customer feedback and overall efficiency (operating cost) of the system.

9. System Architectures

9.1 Functional Analysis

The following sections will highlight the functional and physical architecture used in the system. Functional analysis acts as a bridge between requirements and system design to choose between alternative options. The sections above have provided the details of the systems and sub-systems. For each of these sub-systems, the detailed physical architecture section (after the functional architecture section) will highlight the path chosen to explore alternate options and the analysis done to culminate at a final architecture. A glimpse of the exploration is highlighted here in Figure 7 however the details of the survey will be explored in the Technology Market survey section.

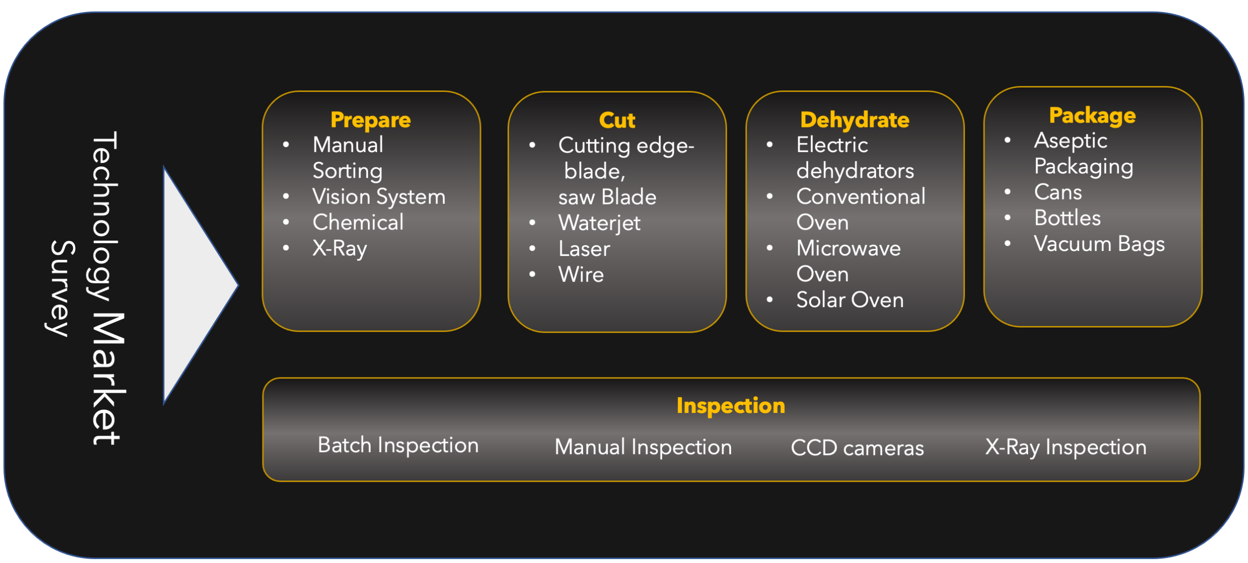

Figure 7: Technology Market Survey

The functional architecture on the other hand is agnostic of the sub-systems and primarily focuses on the function of the system. This will be described in the upcoming section.

9.1.1 Functional Architecture Description

Functional architecture is developed at the start of the systems engineering project effort and would describe the functions or actions that enable the system's objective or mission. The key functions of Fruit 2U can be described as per these functions (F_):

F1: Accept Bananas

F2: Remove peel of bananas

F3: Move bananas

F4: Convert whole bananas into chopped bananas

F5: Move bananas

F6: Convert raw bananas to dehydrated bananas

F7: Move bananas

F8: Group bananas

F9: Seal and label bananas

F10: Group packaged bananas

F11: Seal and pack into boxes

F12: Provide boxes to user

Figure 6 mentioned in the Design Model section further elaborates these functions into a detailed process flow.

9.1.2 Technology Market Survey

PREPARE				
Alternatives / Characteristic	Manual Sorting	Vision System Sorting	Chemical Sorting	X-Ray Sorting
Development Cost	9	5	3	7
Operational Cost	1	9	6	9
Reliability	8	7	5	4
Maintainability	9	7	7	7
Durability	9	8	6	6
Power consumption	9	7	5	7
Accuracy	8	9	9	3
Speed	1	9	7	7
TRL	8	4	4	8

Table 5: Technology Impact Matrix– Prepare Subsystem

The Prepare sub-system has several functions. For this lab the Scanning system was evaluated focusing on the alternatives of manual sorting of bananas, Vision System Sorting (for example CCD), Chemical Sorting (based on aldehyde emission and other ripeness chemicals), and X-Ray shown in Table 5 above. Manual Ripeness Sorting would not have a TRL as this relies on operators sorting bananas which would require Training rather than technical development. Vision and Chemical Ripeness sorting will require further development in their technology level, while X-Ray is a mature technology to implement. Additional characteristics were evaluated across the alternatives.

Research for Cut sub-system revealed the viable technology options: Cutting Edge, Water Jet, Laser and Wire. Some characteristics of these technologies are listed in a technology impact matrix as shown in Table 6 below.

CUT				
Alternatives / Characteristic	Cutting edge - Blade, saw	Waterjet	Laser	Wire
Cost	9	4	3	7
Reliability	8	5	3	7
Maintainability	8	5	4	7
Durability	8	4	3	7
Power consumption	8	4	3	5
Slice Speed	8	8	9	5
TRL	9	7	2	6

Table 6: Technology Impact Matrix – Cut Subsystem

For the Cutting sub-system TIM, technology market research was conducted on the food processing sector. Results showed blade-cutting technologies being used across a broad spectrum of food types, more so than any of the other technologies analyzed. As such, its TRL score was the highest. Conversely, laser technology had the lowest TRL, despite its high slicing speed, there were little references of laser technology being used in the food-cutting industry. Existing laser-cutting equipment for food could not be found. The laser-cutting equipment easily found was for steel and brick applications. The assumption here is that the technology readiness for laser technology is at a low maturity level in the food industry. Waterjet cutting technology like conventional blade or knife cutting, is efficient for food processing. However, with its heavy reliance on both water and power sources to run, it is not often seen as a viable option on a large-scale. And lastly, for cutting via the use of a thin wire. Although this practice is used in the food industry, it is only used in small scale food applications.

Research for Dehydrate sub-system revealed the viable technology options: Electric Dehydrator, Conventional Oven, Microwave Oven and Solar Oven. Some characteristics of these technologies are listed in a technology impact matrix as shown in Table 7 below.

DEHYDRATE				
Alternatives / Characteristic	Electric dehydrators	Conventional Oven	Microwave Oven	Solar Oven
Power consumption	5	8	6	9
Power rating	4	7	9	9
Maintainability	7	6	6	9
Durability	4	9	6	6
Cost	5	2	5	4
Temperature range	5	9	4	7
Constancy of temperature	9	9	4	3
TRL	7	9	8	6

Table 7: Technology Impact Matrix – Dehydrate Subsystem

The Technology Survey for the Dehydrate sub-component revealed several viable options that are of an acceptable TRL. Most of these technologies are available as out of the box products that can be reconfigured or reworked to accomplish the functional need.

Research for Package sub-system revealed the viable technology options: Aseptic Packaging, Cans, Bottles and Vacuum Bag. Some characteristics of these technologies are listed in a technology impact matrix as shown in Table 8 below.

PACKAGE				
Alternatives / Characteristic	Aseptic Packaging	Cans	Bottles	Vacuum Bags
Power consumption	4	8	7	6
Cost	4	6	4	8
Food Safety	9	7	8	6
Capacity	6	7	7	9
Seal Quality / Ingress	5	9	9	7
Process time	3	7	8	7
TRL	6	7	7	8

Table 8: Technology Impact Matrix – Package Subsystem

The comparison of these four options was done using key characteristics like power consumption, cost, food safety, capacity, quality of the seal, process time and TRL. These characteristics focused on both the equipment and the product. The goal of the TIM was to score each of these options to understand potential architectures.

Cans and bottles are viable options to store these packaged bananas and score high in terms of seal quality, power consumption (due to smaller number of sub-steps involved) and process time. They also have a high enough TRL due to the technology being well established for these packaging techniques.

Aseptic packaging is typically used for thermally stabilized liquids and scores a high value for food safety. This is because this technique is traditionally used to preserve liquids in Vacuum bags are another solution that has a high TRL rating due to their frequent use in the food and medical industry. The seal quality and process time are also high due to the ease of operation for this technique. High throughput is possible with this technique and thus it scores high in Capacity. Thinking in a similar manner, each item in the TIM for packaging was scored to create the table shown in Table 8.

Research for Inspection sub-system revealed the viable technology options: X-Ray Inspection, CCD Cameras, Manual Inspection and Batch Inspection. Some characteristics of these technologies are listed in a technology impact matrix as shown in Table 9 below.

INSPECTION				
Alternatives / Characteristic	X-Ray inspection	CCD Cameras	Manual Inspection	Batch inspection
Cost	2	3	6	8
Accuracy	6	5	7	4
Processing Time	2	7	4	8
Capacity	7	3	1	9
Ease of implementation	3	8	5	7
Power consumption	1	6	9	8
TRL	6	7	8	7

Table 9: Technology Impact Matrix – Inspection Subsystem

The 'Inspection' sub-system had down selected four options namely 1) X-ray, 2) CCD 3) cameras, 4) manual inspection, and batch inspection. The comparison of these four options was done using key characteristics like cost, accuracy, processing time, capacity, ease of implementation, power consumption and the TRL.

X-ray techniques are typically used in the manufacturing industry but has not been fully evaluated for an application such as this one. It also has a large overhead with the equipment, software, and implementation. Thus, this scored lower in the TIM for cost and power consumption. The technique was also scored a 6 for the TRL due to the extended research needed to study its application on the dehydrated fruit (like in our application). It scores high for capacity since once established, the technique could yield a high through-put.

CCD cameras rely on machine vision techniques to be able to inspect. Processing time, ease of implementation and TRL is rated high since CCD cameras with integrated software is currently used widely in the food industry. Capacity and cost scored lower since a higher number of cameras would be required to keep up with the volume of bananas processed.

Manual and batch inspection techniques are more human related since the former deals with a line of users visually inspecting bananas and then latter would involve randomly selecting bananas during a run for inspection. Both techniques scored better for cost (i.e., lower cost) and for power consumption and TRL. Manual inspection takes longer than batch inspection and thus scored a lower value for processing time. Thinking in a similar way, the rest of the numbers were filled in to fill in Figure 12.TRL levels were evaluated using the NASA "Technology Readiness Level Definitions." TRLs were described in each section above. See references for further details.

Manual and batch inspection techniques are more human related since the former deals with a line of users visually inspecting bananas and then latter would involve randomly selecting bananas during a run for inspection. Both techniques scored better for cost (lower cost) and for power consumption and TRL. Manual inspection takes longer than batch inspection and thus scored a lower value for processing time. Thinking in a similar way, the rest of the numbers were filled in to fill in Table 9. TRL levels were evaluated using the NASA "Technology Readiness Level Definitions." TRLs were described in each section above. See references for further details.

Once viable technology options for each subsystem had been identified from the technology market surveys/research, a morphological matrix of these options was developed to identify possible new combinations.

Morphological matrices were paired against four key criteria (cost, process-time, user-friendliness, and maintainability) that conformed to customer requirements as shown below. The customer requirements call for a system that is affordable, has a quick response to user operations, is easy to operate, and lastly, is easy to maintain. Four system architectures were derived and verified for compatibility.

Cost-Focused						Architecture 1
	1	2	3	4		
Scanner	Manual Sorting	Vision System Sorting	Chemical Sorting	X-Ray Sorting		Vision System Sorting
Slicer	Cutting edge - Blade, saw	Waterjet	Laser	Wire		Cutting edge-Blade, saw
Dehydrator	Electric dehydrators	Conventional Oven	Microwave Oven	Solar Oven		Solar Oven
Packager	Aseptic Packaging	Cans	Bottles	Vacuum Bags		Vaccum Bags
Inspection	X-Ray inspection	CCD Cameras	Manual Inspection	Batch inspection		Batch Inspection

Process Time						Architecture 2
	1	2	3	4		
Scanner	Manual Sorting	Vision System Sorting	Chemical Sorting	X-Ray Sorting		X-Ray Sorting
Slicer	Cutting edge - Blade, saw	Waterjet	Laser	Wire		Laser
Dehydrator	Electric dehydrators	Conventional Oven	Microwave Oven	Solar Oven		Microwave Oven
Packager	Aseptic Packaging	Cans	Bottles	Vacuum Bags		Vaccum Bags
Inspection	X-Ray inspection	CCD Cameras	Manual Inspection	Batch inspection		Batch Inspection

User-Friendliness						Architecture 3
	1	2	3	4		
Scanner	Manual Sorting	Vision System Sorting	Chemical Sorting	X-Ray Sorting		Vision System Sorting
Slicer	Cutting edge - Blade, saw	Waterjet	Laser	Wire		Cutting edge-Blade, saw
Dehydrator	Electric dehydrators	Conventional Oven	Microwave Oven	Solar Oven		Electric Dehydrators
Packager	Aseptic Packaging	Cans	Bottles	Vacuum Bags		Aseptic Packaging
Inspection	X-Ray inspection	CCD Cameras	Manual Inspection	Batch inspection		CCD Cameras

Maintainability						Architecture 4
	1	2	3	4		
Scanner	Manual Sorting	Vision System Sorting	Chemical Sorting	X-Ray Sorting		Chemical Sorting
Slicer	Cutting edge - Blade, saw	Waterjet	Laser	Wire		Cutting edge-Blade, saw
Dehydrator	Electric dehydrators	Conventional Oven	Microwave Oven	Solar Oven		Conventional Oven
Packager	Aseptic Packaging	Cans	Bottles	Vacuum Bags		Cans
Inspection	X-Ray inspection	CCD Cameras	Manual Inspection	Batch inspection		Manual Inspection

Table 10: Morphological Matrix Evaluation

All highlighted architecture selections contain technologies which are compatible with one another.

9.1.3 Physical Architecture Description

An evaluation of existing technologies of each subsystem was conducted from the technology market survey to determine viable technology options. The technology options selected were denoted a TRL (technology readiness level) to indicate their level of maturity in the food processing industry. A Pugh matrix of the four system architectures derived from the morphological matrices was then conducted. The Technology Option 3 was found to be the highest scoring combination

Technology Readiness Level
1. Basic principles observed and reported.
2. Technology concept and/or application formulated.
3. An analytical and experimental critical function and/or characteristic proof of concept.
4. Component validation in laboratory environment.
5. Component validation in relevant environment.
6. Prototype demonstration in a relevant environment.
7. Prototype demonstration in an operational environment.
8. System qualified through test and demonstration.
9. System proven through successful mission operations.

Table 11: Technology Readiness Level

Architecture 1 Cost-Focused	Architecture 2 Process Time	Architecture 3 User-Friendliness	Architecture 4 Maintainability
Vision System Sorting	**X-Ray Sorting**	**Vision System Sorting**	**Chemical Sorting**
Cutting edge-Blade, saw	**Laser**	**Cutting edge-Blade, saw**	**Cutting edge-Blade, saw**
Solar Oven	**Microwave Oven**	**Electric Dehydrators**	**Conventional Oven**
Vaccum Bags	**Vaccum Bags**	**Aseptic Packaging**	**Cans**
Batch Inspection	**Batch Inspection**	**CCD Cameras**	**Manual Inspection**

Table 12: Architecture down-selection

The Pugh Matrix was quickly completed with a low level of effort as exact values are not required. (Appendix A) General ratings across each attribute were created and each architecture was compared. For the Pugh Matrix, the User-Friendly Architecture was the best option. However, it was noted that the Pugh Matrix did not have high resolution on differences and that the analysis used equal weighting for criteria. Equally weighting was not acceptable as the Customer provided clear preferences. As such a Prioritization Matrix Pairwise Analysis and TOPSIS Analysis were completed.

The Prioritization Matrix was generated with a subset of criteria, 1) Process Time, 2) Safety, 3) User-Friendliness, and 4) Maintainability. (Appendix A) From this analysis, Process time was the most important criterium. Further discussion with the Customer revealed that Cost was more important to Process time. From this information, a TOPSIS Analysis was completed to compare Physical Architecture. Due to the preference for low-cost the Cost Architecture was the best option for the AoA. Although Processing Time was also highly rated, the Cost had the best TOPSIS score and still meets the Customer requirement to complete the dehydration processes in a single shift.

Quantitative metrics	Weight	Cost Focused	Process Time	User-Friendliness	Maintainability
Product Cost ($)	30%	$7,000	$20,000	$15,000	$12,000
Processing Time (hrs)	20%	7	3	6	9
Food Safety Rating (1-10)	12.5%	8	10	9	8
Power Consumption (kW-hrs)	10%	5.2	11.8	6.2	9.2
Ease of Implementation Rating (1-10)	10%	2	5	9	6
Capacity (sq ft)	7.5%	45	50	64	40
Repair and Maintenance Rating (1-10)	5%	7	3	7	10
Reliability Rating (1-10)	5%	7	7	8	5
Closeness to Ideal		**0.627**	.392	0.510	0.482
Rank		**1**	4	2	3

Table 13: Summary of results for TOPSIS Analysis

See Appendix A for additional details on the Pugh, Prioritization Matrix, and TOPSIS Analysis.

9.1.4 Architecture Documentation (N/A)

Section will be developed in later phase of program.

9.1.5 Architecture Quality Attributes (N/A)

Section will be developed in later phase of program.

10. Project Summary

Section will be developed in later phase of program.

10.1 Work Breakdown Structure (ASE 6001)

The Work Breakdown Structure (WBS) was created with a top-down approach by decomposition of the project scope and deliverables into manageable parts. The work packages were defined to the second level for which cost, and duration could be estimated and managed. A third level did not add value as it created more work in estimations and too much resolution in scope. The four primary level elements were identified as Systems Engineering, Project Management, Systems Test and Evaluation, and Systems Support and Maintenance.

Several WBS guidelines were reviewed (PMBOK, BABOK, NASA) but the MIL-STD-881E was leveraged to create the WBS Elements. The MIL-STD Appendix K Core Elements had several elements relevant to our project. These included Systems Engineering and Project Management elements, Systems Test and Evaluation, and five of six Systems Support and Maintenance elements.

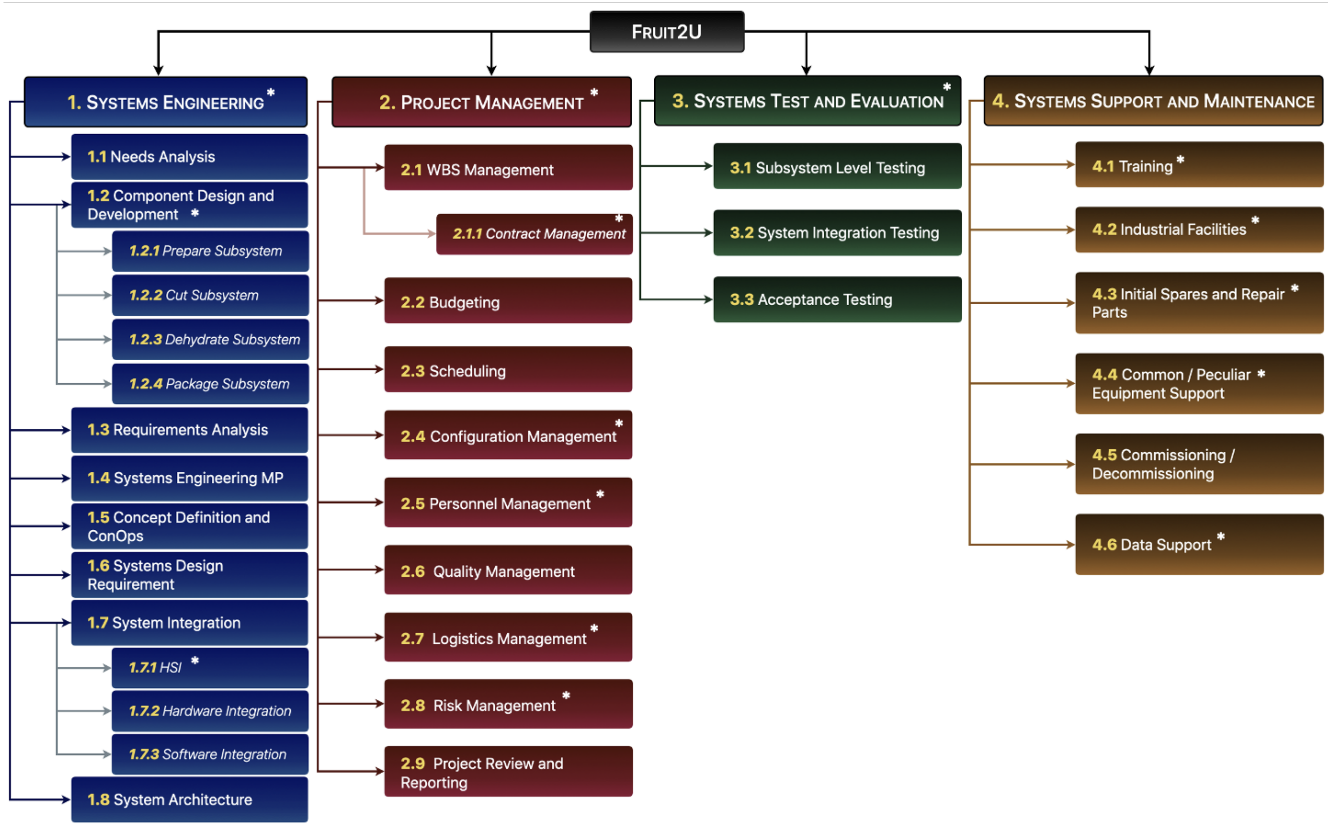

Figure 8: Fruit2U Work Breakdown Structure- **_*Elements leveraged from MIL-STD-881E_**

A comprehensive description, mapping of elements to the MIL-STD and task owner is shown below. The Fruit2U System will be developed in-house but minor Project Management activities and testing will be outsourced. These out-sourced items will still have Fruit2U personnel overseeing contractors to maintain cost, schedule, and project deliverables.

Cost Element	Description	Owner
1.1 Needs Analysis	The effort to create and maintain Needs Analysis with customer and stakeholders. (K3.2.4)	In-house development team
1.2 Component Design and Development	The effort to design components and continue through development. (K.2.4)	
1.2.1 Prepare Subsystem	The effort to design components and continue through development, partitioned by subsystem. (K.2.4)	
1.2.2 Cut Subsystem	The effort to design components and continue through development, partitioned by subsystem. (K.2.4)	
1.2.3 Dehydrate Subsystem	The effort to design components and continue through development, partitioned by subsystem. (K.2.4)	
1.2.4 Package Subsystem	The effort to design components and continue through development, partitioned by subsystem. (K.2.4)	
1.3 Requirements Analysis	The Systems Engineering effort to perform Requirement Analysis. (K3.2.4)	
1.4 Systems Engineering MP	The technical and management efforts of directing and controlling an integrated engineering effort of the system. (K3.2)	
1.5 Concept Definition and ConOps	The Systems Engineering effort to create and maintain the Concept Definition and ConOps. (K3.2.4)	
1.6 Systems Design Requirement	The Systems Engineering efforts to Design and create requirements. (K3.2.4)	
1.7 System Architecture	The Systems Engineering efforts to create and maintain System Architectures. (K3.2.4)	
1.7.1 HSI	The efforts to perform Human systems Integration. (K3.2.4)	
1.7.2 Hardware Integration	The efforts to perform Hardware Integration. (K3.2.4)	
1.7.3 Software Integration	The efforts to perform Software Integration. (K3.2.4)	
1.8 System Integration	The Systems Engineering efforts to perform Systems Integration. (K3.2.4)	

Cost Element	Description	Owner
2.1 WBS Management	The effort to understand and manage performance to successfully accomplish the program objectives. (K3.3.4)	In-house development team
2.1.1 Contract Management	The efforts to manage and maintain contractor support of the System. (K3.10)	
2.2 Budgeting	The effort to understand and manage cost to successfully accomplish the program objectives. (K3.3.4)	
2.3 Scheduling	The effort to understand and manage schedule to successfully accomplish the program objectives. (K3.3.4)	
2.4 Configuration Management	The efforts to manage the planning and execution of configuration management. (K3.3.5)	
2.5 Personnel Management	The efforts to manage and maintain personnel to support the project. (K3.3.5)	Sub-contractor and In-house
2.6 Quality Management Plan	The efforts to manage the planning and execution of quality management. (K3.3.5)	
2.7 Logistics Management	The efforts to manage the planning and execution of Logistics Management disciplines. (K3.3.2)	
2.8 Risk Management Plan	The efforts to manage the planning and execution of risk management activities. (K3.3.2)	In-house development team
2.9 Project Review and Reporting	The effort to support customer gate reviews and status reporting. (K3.3.5)	In-house development team
3.1 Subsystem Level Testing	The Subsystem Level Test and Evaluation conducted throughout the acquisition process to assist in engineering design and development and to verify that technical performance specifications have been met. (K.3.4.1)	Sub-contractor and In-house

Cost Element	Description	Owner
3.2 System Integration Testing	The System Level Test and Evaluation conducted throughout the acquisition process to assist in engineering design and development and to verify that technical performance specifications have been met. (K.3.4.1)	In-house development team
3.3 Acceptance Testing	The Test and Evaluation conducted to verify that assemblies meet the System/product requirements. (K.3.4.2)	
4.1Training	Deliverable training services, devices, accessories, aids, equipment, and parts used to facilitate instruction through which personnel will learn to operate and maintain the Fruit2U. (K3.5)	In-house development team
4.2 Industrial Facilities	The real estate, construction, conversion, utilities, and equipment to provide all facilities required to house, service, launch, test, build, support, and train end-users for the project. (K3.9/K3.5.3/3.4.6)	
4.3 Initial Spares and Repair Parts	The deliverable spare components, assemblies, and subassemblies used for initial replacement purposes. (K3.12)	
4.4 Common / Peculiar Equipment Support	Acquisition of project specific equipment as well as COTS equipment to support testing and to assure the availability of this equipment. (K3.7, K3.8)	
4.5 Commissioning / Decommissioning	Cost to commission and decommission sites. (K3.2.5)	
4.6 Data Support	The delivery of required data for the project. This included data analysis activities, packaging data into standard reports, and archival of data. (K3.6)	

Table 14: WBS Details

10.2 Project Plan (N/A)

Section will be developed in later phase of program.

10.3 Risk Management (N/A)

Section will be developed in later phase of program.

11. Lifecycle Management Plan (N/A)

11.1 Deployment Plan (N/A)

Section will be developed in later phase of program.

11.2 Support Plan (N/A)

Section will be developed in later phase of program.

11.3 Cost Estimates (ASE 6001)

This section will be finalized in ASE 6004.

The Cost Estimates for development will be calculation with a bottom-up approach based on the WBS elements shown in section 10.1

An early evaluation of the cost estimate is shown below. The 80% confidence Cumulative Distribution Function (CDF) was $650K. This estimate will be refined in ASE 6004, but this is completion of proof of concept using the available MATLAB to generate an estimate based on a Monte Carlo analysis and a CDF.

General experience and guidelines were used to estimate costs. Systems Engineering was estimated to be 14% of costs. Component development had the largest impact on costs. Approximately 8% of the cost was allocated to Management Reserve. Management reserve would cover risk mitigations, component development failures, contractor issues, schedule compression, and other programmatic issues.

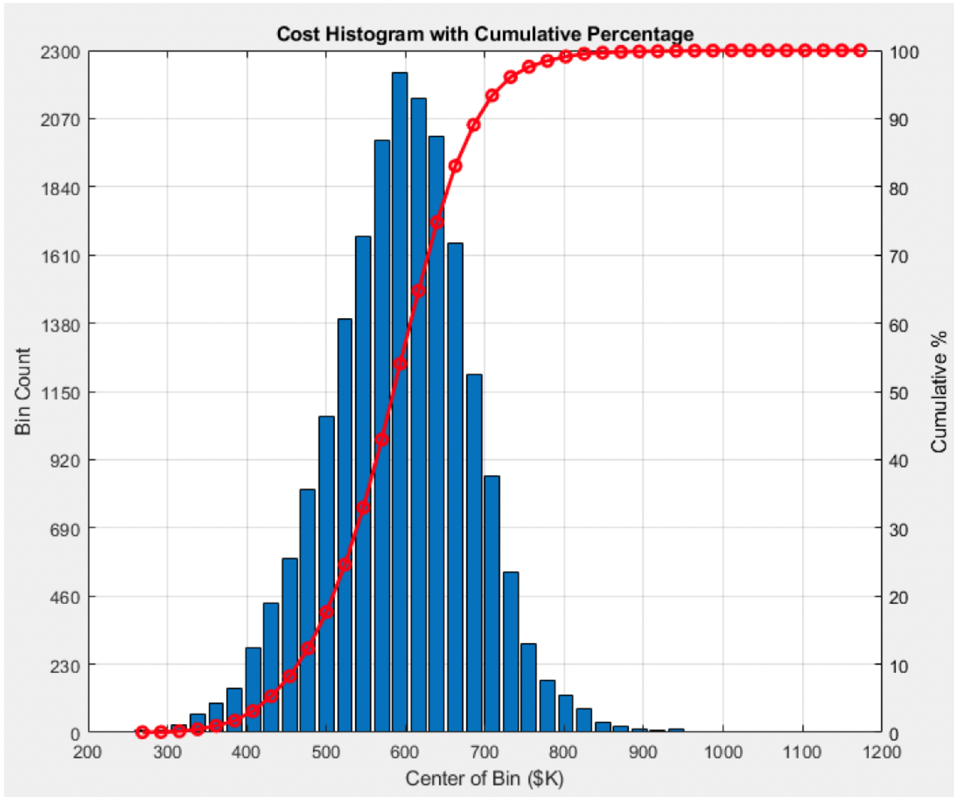

Figure 9: Cost Analysis Results

Cost Estimations used several distributions. (Table 13 below) The Gaussian curve was used when there was equal probability of over and under-running. The Lognormal and PERT-Beta allowed us to shift the PDFs to either be conservative with increased probability towards overrunning or to improve confidence in the estimation. Uniform and Fixed cost were used when costs were unclear and when there was certainty in the cost, respectively.

Distribution	Typical Application
Gaussian (normal)	Used when there is an equal chance of high/low occurring
Lognormal	Used when there is no better info is available.
PERT-Beta	Used when there is an Expert opinion available. It emphasizes the "most likely" value over the minimum and maximum estimates
Uniform	- Used when the likelihood of outcomes is unknown or unclear. - Useful in situations in which you have a minimum and maximum estimate available, but no other information
Fixed	Used when the value is unlikely to vary.

Table 14. Cost Estimation Distribution Summary

The table below shows the distribution and justification for the top-level WBS Elements. The bottoms-up approach for each Element used a combination of each type of distribution in the table above.

Cost Element	**Distribution**	**Justification**
Systems Engineering	Lognormal	The Systems Engineering activities have uncertainty and the probability distribution will accordingly be adjusted.
Project Management	PERT-Beta	The Project Management activities can be accurately planned for and will leverage expert opinion to shape the probability distribution function to be slightly pessimistic.
Systems Test and Evaluation	Gaussian	The cost of testing can be generally planned for with accepted variance. There is an equal likelihood of over- or under-running.
Systems Support	Uniform	Full systems support is unclear but would fall within a maximum and minimum estimation range

Table 15. Probability Distribution Function Selection for WBS Elements

12. Concept of Operations (ASE 6001)

*See Fruit2U ConOps document- **ASE6001_SEMP_ConOps_Fruit2U.pdf**.*

13. References

[1] Gustavsson, Jenny. “Global Food Losses and Food Waste - Home | Food and ...” FAO.Org, Food and Agriculture Organization of the United Nations, 2011, http://www.fao.org/3/i2697e/I2697E.pdf.

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14. Appendix A. Analysis of Alternatives (AoA)

Supporting tables for AoA.

Criteria	DATUM	Architecture 1	Architecture 2	Architecture 3	Architecture 4
Cost	3	+	-	-	+
Energy Efficiency	3	+	-	+	S
Reliability	7	S		+	-
Maintainability	5	+	-	+	+
Durability	7	S	-	S	S
Performance	6	-	+	+	-
TRL	9	S	-	-	+
Process Stability	4	-	+	-	S
Food Safety	8	-	+	+	-
Capacity	8	-	S	+	-
Seal Quality / Ingress	9	S	S	-	-
Ease of Implementation	6	+	-	S	+

Sum of Positives		4	4	6	4
Sum of Negatives		4	6	4	5
Sum of Same's		4	2	2	3
Weighted Sum of Positives		17	25	37	23
Weighted Sum of Negatives		26	33	25	38
Overall Score:		-9	-8	12	-15

PUGH Matrix Legend

S	Standard
+	Better than

-	Less than

Table 16: Pugh Matrix results

Criteria relative importance	Safety	User Friendly	Process Time	Maintain-ability	Total across rows	% Of Grand Total
Safety		1.00	1.00	5.00	7.00	0.32
User Friendly	1.00		0.20	1.00	2.20	0.10
Process Time	1.00	5.00		5.00	11.00	0.51
Maintainability	0.20	1.00	0.20		1.40	0.06
Column Total	2.20	7.00	1.40	11.00	21.60	1.00

Table 17: Prioritization Matrix Results

Quantitative metrics	Cost Focused	Process Time	User-Friendliness	Maintainability
Cost ($)	7,000	20,000	15,000	12,000
Ease of Implementation Rating (1-10)	2	5	9	6
Capacity (sq ft)	45	50	64	40
Power Consumption (kW-hrs.)	5.2	11.8	6.2	5.5
Repair and Maintenance Rating (1-10)	7	3	7	10
Reliability Rating (1-10)	5	8	7	7
Processing Time (hrs.)	7	3	6	9
Food Safety Rating (1-10)	8	10	9	8

Improvement	Weight	**Weighted Metrics**	Cost Focused	Process Time	User-Friendliness	Maintain-ability
min	0.300	Cost ($)	0.0734	0.2098	0.1573	0.1259
max	0.100	Ease of Implementation Rating (1-10)	0.0166	0.0414	0.0745	0.0497
max	0.075	Capacity (sq ft)	0.0334	0.0371	0.0475	0.0297
min	0.100	Power Consumption (kW-hrs.)	0.0339	0.0770	0.0404	0.0359
max	0.050	Repair and Maintenance Rating (1-10)	0.0243	0.0104	0.0243	0.0348
max	0.050	Reliability Rating (1-10)	0.0183	0.0293	0.0256	0.0256

min	0.200	Processing Time (hrs.)	0.1058	0.0454	0.0907	0.1361
max	0.125	Food Safety Rating (1-10)	0.0569	0.0711	0.0640	0.0569

	Cost Focused	Process Time	User-Friendliness	Maintainability
Closeness to Ideal	**0.627**	0.392	0.510	0.482
	1	4	2	3

Table 18: TOPSIS Analysis