BURGE HUGHES WALSH

The Systems Thinking Tool Box

Dr Stuart Burge

".. bump, bump, bump, on the back of his head. It is, as far as he knows the only way of coming downstairs, but sometimes he feels that there really is another way, if only he could stop bumping for a moment and think of it."

Winnie the Pooh - A. A. Milne

Input-Output Diagram (IOD) alias SIPOC

What is it and what does it do?

An Input-Output Diagram is a simple high-level representation of a system that shows:

- The major inputs to a system and their suppliers.
- The major outputs from a system and their customers.
- The major components of the system necessary for it to achieve its purpose through transforming inputs to outputs.

It allows a team or an individual to produce a high-level model of an existing or planned system that defines the boundary of the system of interest and its interactions with the critical elements in its environment.

Figure 1 shows an Input-Output Diagram for a Works Cafeteria. The top "half" of the diagram comprises five columns that respectively contain the:

- **Supplier:** the external entities that provides a particular system input.
- **Inputs:** the inputs to the System of Interest.
- **System:** the name and Operational Requirements for the System of Interest.
- **Output:** the outputs from the System of Interest.
- **Customer:** the external entities that receive the system outputs.

The lower half of the Input-Output Diagram contains a high-level system Sequence Diagram [1]. This diagram shows how the basic functionality has to co-operate in order to transform the system inputs into the system outputs. The system Sequence Diagram has a time order with time increasing from left to right.

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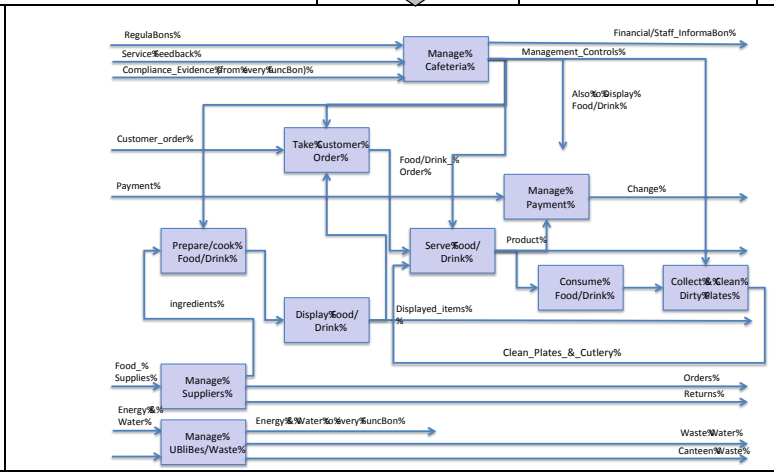
Input – Output Analysis for Works Cafeteria				
Supplier	**Inputs**	**System**	**Outputs**	**Customer**
Cafeteria_ Customer	Customer_Feedback	System Purpose:	Product	Cafeteria_Customer
	Customer_Order		Receipt	
	Payment		Change	
	Dirty_Crockery/ Cutlery	To prepare and serve in a friendly fashion healthy quality food and drinks at affordable prices during the working day	Menu	
Suppliers	Food_Supplies		Displayed_items	
Utility_Company	Water		Cafeteria_Waste	Waste_Collector
	Energy (gas/electric)		Waste_water	Utility_Company
Regulator	Regulations		Financial/Staff_ information	Company_Systems
			Orders	Suppliers
			Returns	
			Compliance_Evidence	Regulators
High Level System Sequence Diagram				

Figure 1: Input-Output Diagram for a Works Cafeteria

Similar outcomes to constructing an Input-Output Diagram can be achieved using either a Context Diagram [2] or a Use Case Diagram [3] (see Appendix A – but read below first).

Why do it?

There are many reasons for constructing an Input-Output Diagram. It can:

- Where and help define and agree the scope or boundary of the system of interest.
- Provide a simple high-level picture of the system of interest. All systems operate in an environment; failure to pay attention to that environment will lead to failure.
- Help identify the elements in the environment of the system of interest that it interacts with.
- Identify and define the external interfaces – the input and outputs - the System of Interest logically has to have with the outside world.

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- Provide a high-level view of the basic functionality necessary to transform inputs to outputs.
- When used within a team context, allows the whole team to share information and agree at a common understanding.

When to use it?

An Input-Output Diagram is particularly useful in:

- understanding and engineering requirements for a new system.
- analysing and existing system.

They are, in general, relatively simple to construct and can help scope the project by defining the boundary of the system. In essence, the high-level system Sequence Diagram defines the scope the system to be designed or analysed. The external elements are taken to be out of scope. It therefore provides a simple understandable pictorial representation that can be used to obtain and document agreement about the scope of a project or problem.

Who does it?

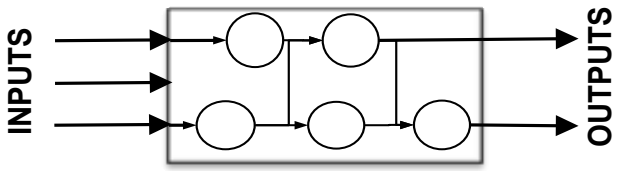
An individual or a team can construct an Input-Output Diagram. Whether it is team or individually based depends on the problem being tackled and the phase of system development.

How to do it?

Constructing an Input-Output Diagram comprises two related but distinct views of the system of interest:

- A “black box” view where we are not concerned with what’s inside the system, “how it will work”, but focuses on just the inputs and outputs and their sources (suppliers) and destinations (customers).

- A “white box” view which focuses on what is inside the system and how it works in terms of the functionality necessary for the system to achieve its purpose.



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The starting point is a clear definition of the System's purpose and context. Here, if available the system's Operational Requirement[1] is appropriate. If this is not available, the first task of the diagraming team or individual is to formulate one. The 18-Word Statement tool [5] is particularly useful here in drafting a suitable statement.

It is also very important when starting to construct an Input-Output Diagram that the team understands the context of the problem particularly that related to the lifecycle phase. For any System of Interest it is often possible to construct a variety of Input-Output Diagrams for different points in time. Figure 1, for example, shows a works cafeteria up-and-running on a day-by-day basis. In other words, it shows the operational phase of the system's lifecycle. It is possible to construct other lifecycle views such as implementing a works cafeteria. The fact we can view any system from many different perspectives is important to recognize when constructing an Input-Output Diagram. It is essential that the perspective is defined clearly and everybody in the team is clear what view is being taken. Some projects may demand that we capture several perspectives. In such instances, it is recommended to start with the day-to-day operation of the System of Interest and then consider the other views later.

Having agreed the lifecycle phase, we start the construction of the Input-Output Diagram by capturing the "black box" view of the system where we focus on the inputs and output of the system and where the respectively come from and go to – the Suppliers and Customers. What happens inside the system is not considered yet (but will be later). It is important when capturing the inputs and outputs not to ignore any. There is flexibility in whether to begin with inputs or outputs; I tend to start with the outputs and the 'customers' who receive the respective outputs. The outputs typically fall into a number of categories:

- Physical outputs
- Documents
- Information
- Waste.

It can be worthwhile checking against this list, particularly waste. Since this is not a desirable output it often overlooked. Sometimes:

- it is helpful to think of "who are the Customers?" first and then use these to help identify the outputs.
- starting with outputs first and then determining the customers is easier.

[1] The Operational Requirements of a system state is major purpose (what it fundamentally does) together with the key overarching constraints that define the context. For more information, see tools description for the Holistic Requirements Model [4].

When thinking of outputs, particularly when we are not clear where the system boundary is, we need to be conscious of mistaking *Outcomes* for Outputs:

- OUTPUTS relate to what is delivered/done by the system. They are the direct and measurable products, services and/or generated information of a system. Outputs are usually quantifiable and tangible and focus on what happens at the end of a system activity.
- OUTCOMES relate to "what difference is there?" They are the longer term changes and benefits, learning or other effects that happens as a consequence of the system's outputs. They are hard to measure, rely on a knowledge of the starting point and are often expressed in terms of an increase in understanding, and improvements in desired behaviours or attitudes of participants or customer satisfaction level. A single outcome is often the result of multiple outputs.

When you first generate a list of potential system outputs, it may well also contain outcomes. Returning to the works cafeteria an outcome that could be listed as a potential output is:

Effective and efficient staff

Actually the output is "fed staff". However, organizations often provide a works cafeteria because of the need to maintain blood sugar levels which are essential for effective and efficient staff. It is important to realise that the process is iterative. Capture what we believe the system outputs are but review these to ensure that they true outputs.

You may also want to consider grouping outputs together to simplify the view. For example with the works cafeteria shown in Figure 1 the first output is labeled "Product" which is a grouped output comprising any meal and drink that the restaurant sells off the menu. But do keep a dictionary to record any definitions of flows. For example **Product** can be defined as:

Product = (**Meal**) + (**Drink**)

This uses a set of standard conventions is used to explain the make-up of inputs or outputs. These are:

Operator	Shorthand
IS EQUIVALENT TO	=
AND	+
EITHER-OR	[option1/option2]
INTERATIONS OF	{items}
OPTIONAL	(item)

Hence, the definition of **Product** above means, that **Product** is equivalent to optionally **Meal** and optionally **Drink**. As a general rule, it is always best to simplify

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where possible, but this does need a dose of pragmatism in that situations can be over-simplified.

Once we have list of outputs, the team should determine and define the INPUTS necessary for the system to generate the outputs and the Supplier of those inputs. Again, we should not ignore inputs because we “feel” that they are not important, all inputs should be considered. Typically, the inputs fall into a number of categories:

- People
- Materials
- Equipment
- Methods
- Environmental
- Information

This list can serve a useful check of completeness.

We may wish to group similar inputs together and name them using a collective name in order to keep the diagram simple. Note that a Supplier can also be a Customer. For example, in the works cafeteria the “Cafeteria_Customer” is both a Supplier and Customer. The use of the underscore between “Cafeteria” and “Customer” is deliberate to indicate that we are talking about one thing.

Once we have identified the inputs and outputs, our attention turns to a white box and how the inputs are transformed into outputs. The team should develop a simple **Sequence Diagram** [1] to show the major components (functions, activities, sub-system) of the system in their time order as shown in Figure 2.

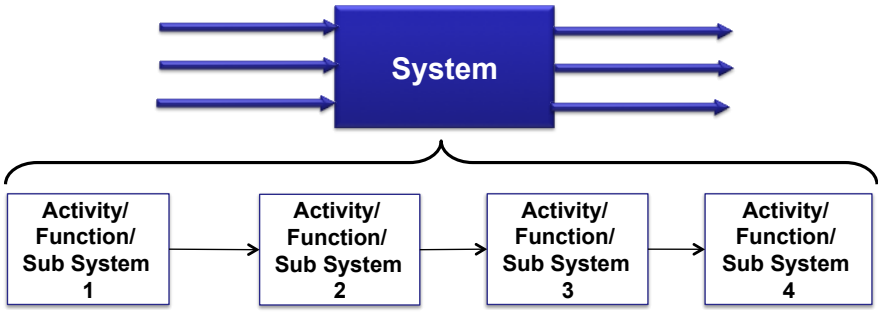

Figure 2: The white box view showing the activities /functions necessary to turn inputs in to outputs.

I find the easiest way to accomplish this is to brainstorm activities/ functions as verb-noun combinations on to sticky notes and then arrange these in time order. For the works cafeteria the Sequence Diagram shown in Figure 3 was developed.

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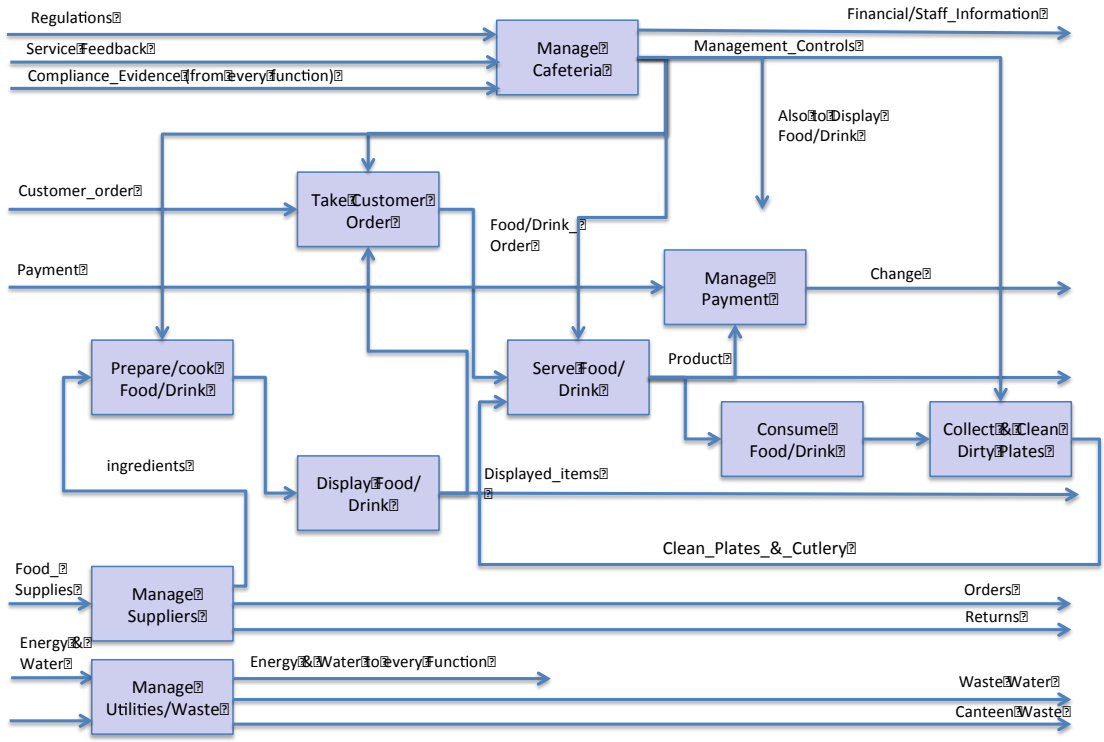

Figure 3: A System Sequence Diagram for the Works Cafeteria

Tips for Constructing Input-Output Diagrams

- Do consider using white-boards for the early drafting work. The initial diagram will require several iterations and a white provides a convenient medium. Furthermore, it is useful if team members can "sketch" out their ideas to show other team members. If white boards are not available, flip charts are an alternative, but are less easy to modify. Software tools are available to capture the outcome, but, in general they are less useful for constructing diagrams using a team.
- Consider the operational view of the system first. It is possible to create many different models of any one system (usually based on phases of the lifecycle of the system). This may well be necessary at some point, but when initiating a modelling exercise it is best practice to start with, the operational view, i.e. the system has been designed and installed and consideration is aimed at its day-today operation.
- The initial drafting of a Input-Output Diagram should consider every possible input and output. This often results in a very "busy" diagram and there is a tendency to either ignore inputs or outputs because they are considered not important. It is preferable to capture all these and rationalise and simplify the diagram later. Indeed, having captured all the inputs and outputs the diagram can be simplified by collecting similar flow together and creating a collective-name that can be detailed in the system dictionary.

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What Goes Wrong: The limitations of Input-Output Diagrams

An Input-Output Diagram is a very simple but powerful tool for exploring the environment and boundary of a proposed system or analysing an existing one. It does build a model of the system of interest, but like ALL modelling methods it has limitations. The following outline these limitations and where possible propose approaches to minimise their effect.

- Input-Output Diagram are abstract models that focus on the system's input-output transformation. The resulting model is not a physically related model and teams, particularly inexperienced teams, try to construct a diagram that reflects the likely physical manifestation of the system. In the Works Cafeteria example the cafeteria user – the customer – will physically be inside the cafeteria but from a systems viewpoint be outside the system boundary!
- Input-Output Diagrams do not readily lend themselves to the simultaneous capture of multiple modes of operation. Many systems have several different modes of operation (often due to dealing with different scenarios or lifecycle phases). In consequence, the result is a model that is difficult to read because it attempts to mix modes of operation or a number of diagrams that individually are ephemeral.

Success Criteria

The following list represents a set of criteria that have been found to be useful when constructing an Input-Output Diagram.

- Team size between five and eight.
- Team constitution covers system life cycle and potential technology.
- Use an experience independent facilitator.
- Plan for a one to two hour session.
- Draft out an Input-Output Diagram on a large white board or equivalent using sticky notes for the various elements. Be wary of constructing the diagrams directly in software! People should be encouraged to draw out their understanding – if they are intimidated by not being able to drive the software they will agree too readily with a team member view rather than explore their view.
- Show the draft Input-Output Diagram to other interested parties for verification and validation.

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References

[1] Burge S. “Sequence Diagram” www.burgehugheswalsh.co.uk

[2] Burge S. “Context Diagram” www.burgehugheswalsh.co.uk

[3] Burge S. “Use Case Diagram” www.burgehugheswalsh.co.uk

[4] Burge S. “Holistic Requirements Model” www.burgehugheswalsh.co.uk

[5] Burge S. “18 Word Statement” www.burgehugheswalsh.co.uk

Appendix A: Context Diagrams, Use Case Diagrams and Input-Output Diagrams

When determining the scope of a System of Interest and the interactions it will have with its environment there are several tools that can be used:

- Context Diagram
- Use Case Diagram
- Input-Output Diagram.

Each of these diagrams provides a simple “birds-eye” view of the System of Interest; yet individually provide slightly different perspectives. Each has strengths but also weaknesses and the purpose of this appendix is to provide a quick overview of these together with an indication where each tend to be used.

For comparison purposes the example of the Works Cafeteria described above is used. This is predominantly a service-based system. Other dominant system types are hardware-based and software-based.

Context Diagram

Figure A1 is a Context Diagram for the Works Cafeteria. It shows the System of Interest, the Works Cafeteria as a single bubble. This central bubble also contains the system’s Operational Requirements. The squares around the System of Interest define the external entities that the Works Cafeteria interacts with on a day-to-day basis. Finally, the named arrows show what comprises the interactions, as information, material or energy flows, between the external entities and the System of interest.

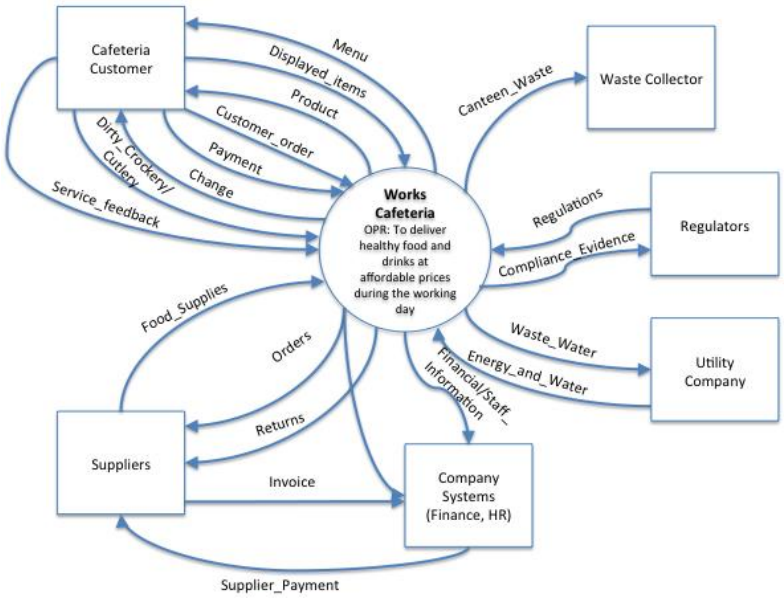

Figure A1: A Context Diagram for a Works Cafeteria.

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The strengths of a Context Diagram include:

- Easy to comprehend
- Clear indication of system boundary
- Definition of external entities with which the System of Interest interacts
- Identification and documentation of external system interfaces.

The weaknesses of a Context Diagram include

- No indication of the internal functionality
- No timing or order system interaction with its external entities
- Limitations in capturing moded systems.

Use Case Diagram

Figure A2 shows an equivalent Use Case Diagram for the Works Cafeteria.

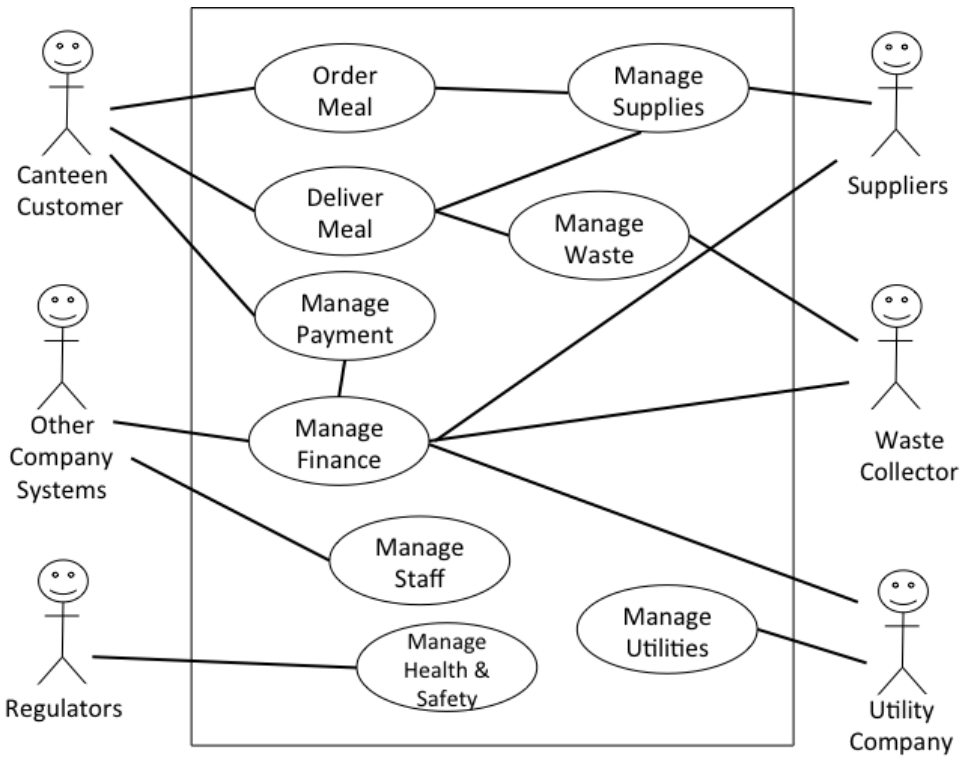

Figure A2: A Use Case Diagram for the Works Cafeteria

In a Use Case Diagram, the “box” represents the boundary of the System of Interest. The “stick men” outside the box are called “actors” and represent the external entities that the System of Interest interacts with in some way – these actors will make some “use” of the System of Interest. The named “bubbles” inside the box are the high-level functions that capture the various uses the actors have for the system. Accordingly, the names inside the bubbles must start with a verb.

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To indicate that an actor will make use of a particular system function a line is drawn between the actor and the function. Some people put arrows on the lines, however, care must be taken in the interpretation of these since they do NOT represent flows or interfaces as such. It is also usual, if appropriate, to include lines between functions. This can be particularly useful when following up the Use Case Diagram with Sequence Diagrams to uncover the lower-level system functionality.

Figure A2 has been drawn as an equivalent to the Context Diagram given in Figure A1. There is, however, an important difference between Context Diagrams and Use Case Diagrams that is NOT shown in these two figures. While Context Diagrams, because of the flows, struggle to show multiple modes simultaneously, Use Case Diagrams can. This can lead to a more compact representation – it can also be a source of confusion by over populating the diagram. Figure A3 shows the extension to Figure A2 to capture modes of operation other than the day-to-day running of the works cafeteria by presenting a “through life” view.

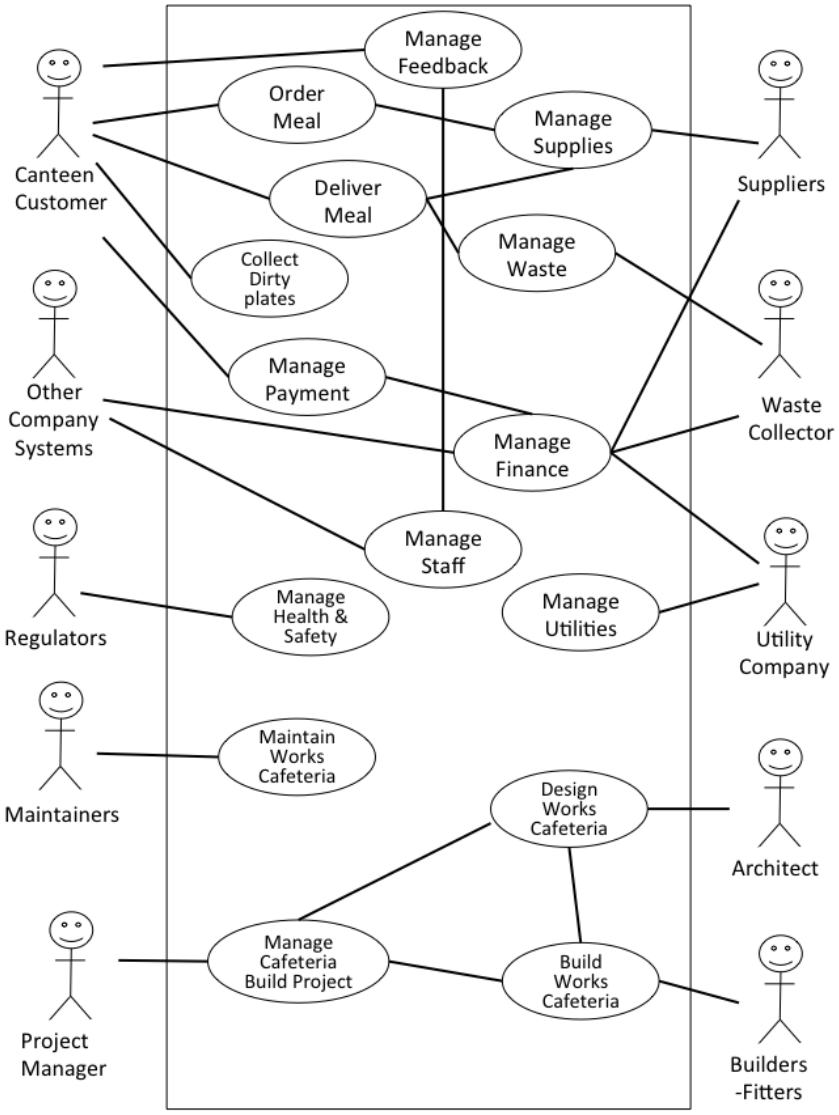

Figure A3: Through Life Use Case Diagram for Works Cafeteria

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The strengths of a Use Case Diagram include:

- Easy to comprehend.
- Clear indication of system boundary.
- Definition of external entities with which the System of Interest interacts.
- Identification and documentation of high-level internal system functionality.
- Captures moded systems.

The weaknesses of a Use Case Diagram include

- No clear definition of the system interfaces – but does suggest their existence.
- Shows only limited internal connectivity between system functions.
- No timing or order system interaction with its external entities.
- Limitations in capturing moded systems.

Input-Output Diagram

Figure A4 shows an equivalent Input-Output Diagram for the Works Cafeteria. The top "half" of the diagram comprises five columns that respectively contain the:

- **Supplier:** the external entities that provides a particular system input
- **Inputs:** the inputs to the System of Interest
- **System:** the name and Operational Requirements for the System of Interest
- **Outputs:** the outputs from the System of Interest
- **Customer:** the external entities that receive the system outputs.

The lower half of the Input-Output Diagram contains a high-level system map. This diagram shows how the basic functionality has to cooperate in order the transform the system inputs into the system outputs. The system map has a time order with time increasing from left to right.

The strengths of an Input-output Diagram include:

- Clear indication of system boundary
- Definition of external entities with which the System of Interest interacts
- Identification and documentation of external system interfaces
- Identification and documentation of high-level internal system functionality
- Connectivity between system functions
- Information about the sequencing of the internal functionality.

The weaknesses of an Input-Output Diagram include

- More difficult to easily comprehend
- Limitations in capturing moded systems

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General Remarks

Of all the three tools, the Input-Output Diagram is the most comprehensive. It is for this very reason the more difficult to comprehend. As the Work Cafeteria example has demonstrated all three can provide similar information and perform similar tasks. In general, however, we find that:

- Context Diagrams: used in hardware and software intensive systems
- Use Case Diagrams: used in software intensive system
- Input-Output Diagrams: used in process intensive systems.

If time and resource is available, the very best option is to construct all three since they each provide a slightly different perspective on a system. Indeed, in constructing the Works canteen example each tool provided something the other did not! The final diagrams presented herein are the result of several iterations.

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Input – Output Analysis for Works Cafeteria

Supplier	Inputs	System	Outputs	Customer
Cafeteria_ Customer	Customer_Feedback	System Purpose:	Product	Cafeteria_Customer
	Customer_Order		Receipt	
	Payment		Change	
	Dirty_Crockery/ Cutlery	To prepare and serve in a friendly fashion healthy quality food and drinks at affordable prices during the working day	Menu	
Suppliers	Food_Supplies		Displayed_items	
Utility_Company	Water		Cafeteria_Waste	Waste_Collector
	Energy (gas/electric)		Waste_water	Utility_Company
Regulator	Regulations		Financial/Staff_ information	Company_Systems
			Orders	Suppliers
			Returns	
			Compliance_Evidence	Regulators

High Level System Sequence Diagram

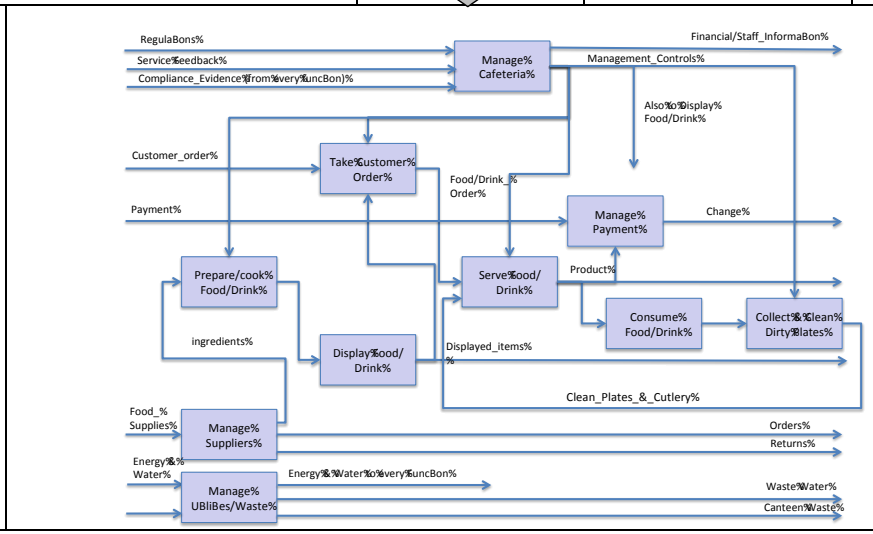

Figure A4: Input - Output Analysis for The Works Cafeteria

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