Process Flow Chart

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Use of this Guide

The Process Flow Chart (PFC) guideline is part of the Construction Product Quality Planning (CPQP) process and should be used in conjunction with the CPQP Guide and its toolset, published by the Construction Innovation Hub.

Intended as a guideline to aid the process of creating process flow charts, this document provides the basic principles and a suggested methodology. The templates provided can be changed and modified to suit individual companies.

This guideline is intended for use by companies manufacturing offsite construction products largely using the CPQP process with their customers and suppliers. It aims to provide enough knowledge to enable the CPQP team to complete a process flow chart, particularly where this subject is new to them, as well as to provide ongoing aid. Over time, companies will develop their own expertise, methods and standards through training and practice.

For a list of the acronyms and abbreviations used in this document, refer to Appendix B – List of Abbreviations.

For the various terms used in this document, refer to Appendix C – Glossary of Terms.

For further information about the CPQP Guide and its toolset please contact:
cpqp@constructioninnovationhub.org.uk

Introduction

Introduction

The Process Flow Chart (PFC) describes the entire process undertaken to manufacture or assemble the product from 'goods in' to 'goods out'. It is broken down into the relevant steps to manufacture the product, also showing when it is inspected, moved and stored. It uses visual representation as well as descriptive text including relevant technical detail.

The product could be a complete assembly system that comprises many sub-assembly systems or components. The product, sub-assemblies, and components each have manufacturing operations. Multiple PFCs may be required in a hierarchy to describe the entire manufacturing and assembly processes for the product. A company manufacturing a complex 3D volumetric assembly where other sub-assemblies or components are manufactured internally, would have multiple PFCs as shown in Figure 1.

Components or sub-assemblies that are outsourced and manufactured by sub-contractors do not need to be detailed and can be shown as an input to the appropriate step, as indicated by the yellow box in Figure 1. The suppliers of these products would have their own detailed PFCs.

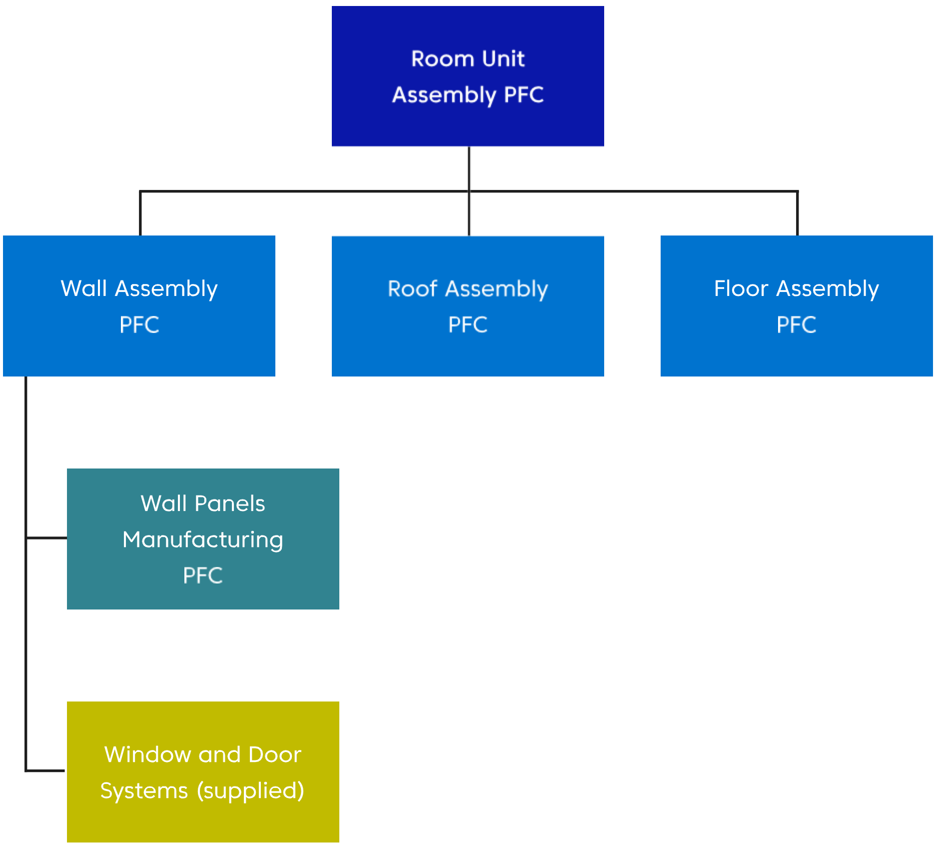


Figure 1. PFC Hierarchy

How does a PFC fit in with Construction Product Quality Planning?

The PFC is developed in the early stages of the CPQP process. It is an output of the manufacturing process design and a deliverable of Phase 3 - Process Design and Development in CPQP - (see Figure 2).

An iterative approach is required for the PFC as the design of the product and process evolves.

A preliminary flow chart is initiated in Phase 1 and updated throughout the CPQP resulting in a finalised, signed off and approved chart in Phase 3.

The PFC is a major input for the Process Failure Mode and Effects Analysis (PFMEA), and therefore is completed before the PFMEA is started. However, as a result of completing the PFMEA and analysing process failure risk, the process may need to change or be modified and reflected in the PFC.

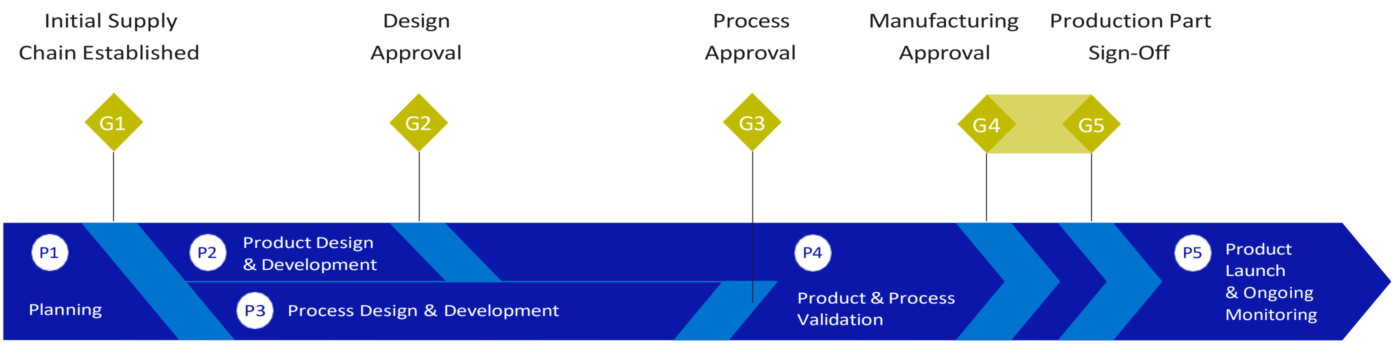


Figure 2. CPQP Timeline

In the early stages of the PFC development, the CPQP team may use higher level process maps or SIPOC (Supplier Input Process Output Customer) charts to start designing the flow. This is helpful if the flow is not initially clear or if the product is complex. As the project progresses, the detail will develop and the PFCs will be updated.

Benefits

Starting the PFCs as early as possible in CPQP, in a New Product Introduction (NPI) programme, helps the team to understand the process flow and allows them to:

- Give early Design for Manufacture and Assembly (DfMA) inputs to the product design;
- Develop the sourcing strategy and supply chain;
- Plan the manufacturing equipment needs and Capital Expenditure;
- Design the factory layout and equipment;
- Understand the requirements of the manufacturing facility;
- Understand internal logistics needs;
- Highlight any gaps in current capability (for example, we do not have a machine to do that); and
- Understand where processes need further development (for example, we do not have a process to do that).

It is good practice and cost effective to identify risks associated with the product and process design early on in the design and development stage. Engineers use early PFCs to help identify the process steps and the key inputs and outputs. This gives the best opportunity to ensure the process is designed to meet the customer needs and to mitigate against risk, avoiding costly errors occurring late in the development programme. For example this could be the early identification of a lack of factory space for the required manufacturing footprint.

Figure 3 shows shows how identifying risks earlier increases the ability to impact process design and control costs.

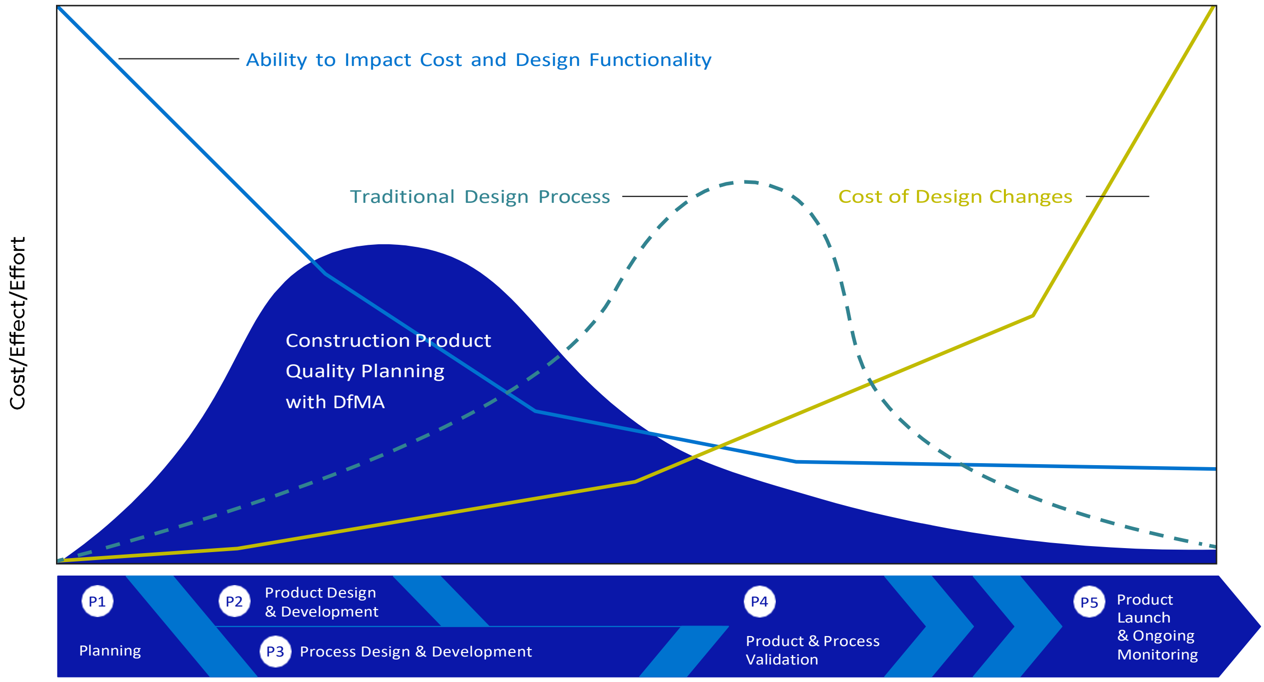


Figure 3. Cost of Changes vs Project Time

Methodology

Methodology

PFC creation is an activity that takes place concurrent to the design of the manufacturing and supply processes. It is an output of CPQP Phase 3 - Process Design and Development - and a required deliverable. The chart is a detailed document that inputs into the PFMEA and other NPI and CPQP activities.

The Process Design and Development phase of CPQP, and hence the creation of the PFC, has a number of key inputs. The creation of the PFC is iterative as the design evolves and the inputs are defined. The manufacturing process design evolves concurrently.

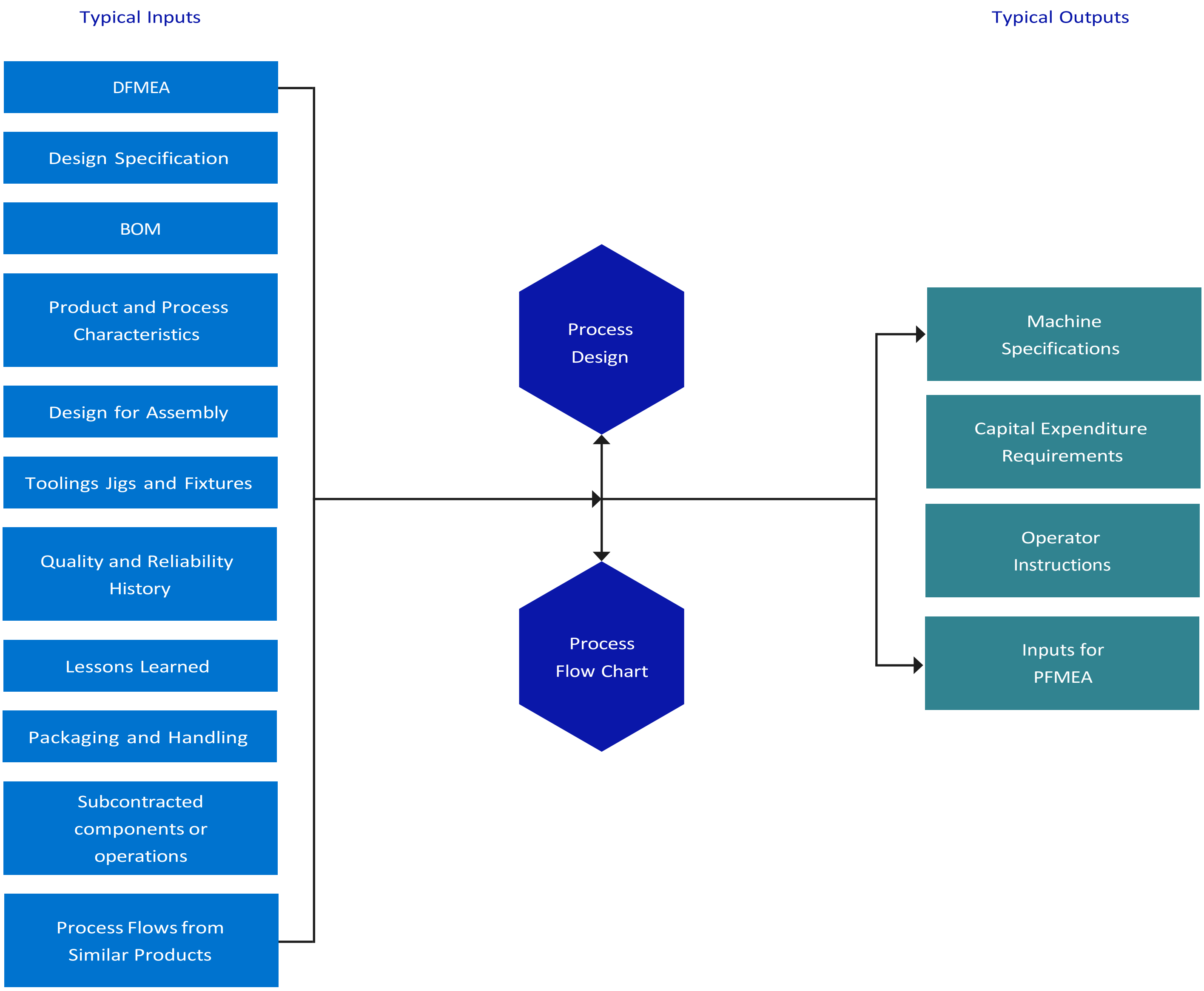


Figure 4. Process Flow Chart Inputs and Outputs

A cross-functional team led by manufacturing engineers and including (but not limited to) design, purchasing, operations, and logistics personnel should develop the PFCs.

During the early stages of a project, actual data is limited and the process is yet to be designed. Initial process flow documents should be created using best known data or assumptions (that should be documented). These should be aligned to the customer requirements and to any data used in the business case for the project, for example, product demand rate.

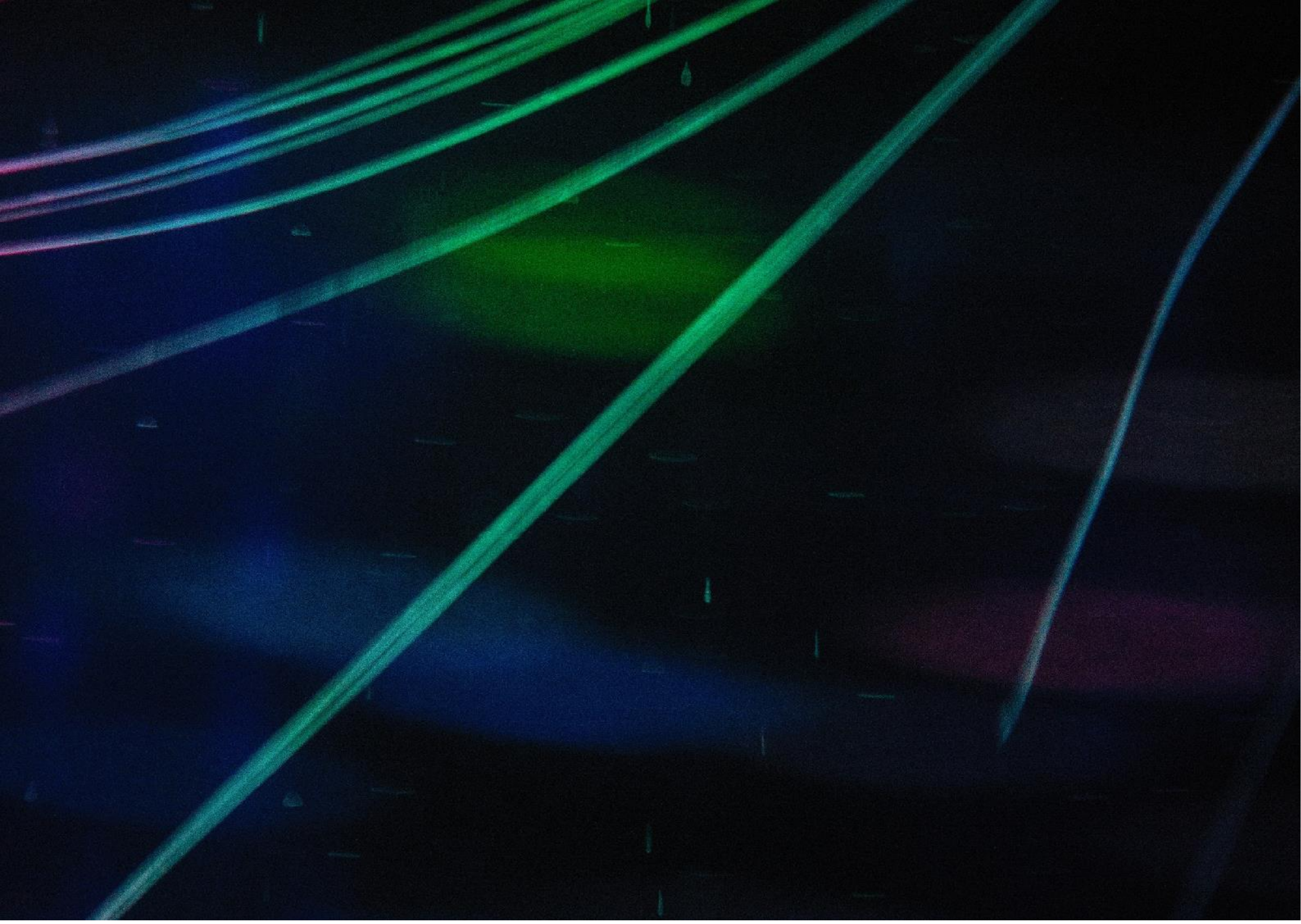
There are three steps to creating a production representative PFC. These provide useful output at the relevant stages in the NPI and CPQP process aiding early decision making and reduction of risk. The steps are:

- Step 1: Create a high-level process map and SIPOC (Chart and Table);
- Step 2: Create the Preliminary Process Flow Charts; and
- Step 3: Create the Process Flow Charts

Note: An additional step (4), involves the updating and amendment of the created components.

PFC Development Step		CPQP Phase				
		1	2	3	4	5
1	Create a high-level process map – SIPOC	Y				
2	Create the preliminary process flow charts	Y	Y			
3	Create the Process Flow Charts		Y	Y		
4	Update and Amend (3)				Y	Y

Table 1. PFC Development vs CPQP Phases



Guideline

Guideline

As outlined above, the following steps are key in creating PFCs:

- Step 1: Supplier Input Process Output Customer - SIPOC;
- Step 2: Preliminary process flow charts; and
- Step 3: Process flow charts

These steps run concurrently with the process design activities in an NPI process and are deliverables in Phase 1 and Phase 3 of CPQP. The chart will be developed from the Preliminarily PFC in Phase 1, through Phase 2 to final sign-off in Phase 3. Although the chart is not a deliverable of Phase 2, it should be updated and reviewed. The flow charts should also be updated in Phase 4 and 5, subject to change control procedures.

The steps for creating a PFCs are described herein using a simple example.

Step 1: Supplier Input Process Output Customer - SIPOC

The first step is to produce a high-level process map or flow chart. One method is to use the SIPOC map as described here and shown in Figure 5.

The SIPOC is a high-level, visual representation of the process, ideally on one page, to help the team understand the process and develop it. It can potentially contain a lot of information, therefore only information that is helpful to the team and drives decision making should be included.

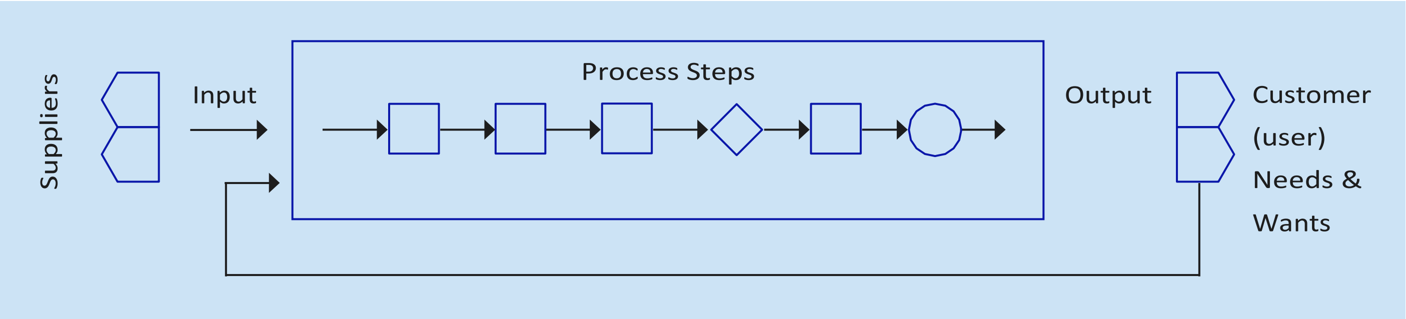


Figure 5. SIPOC with Process Map

The process steps in the middle, shown in Figure 5, are often listed as a table or drawn as a flow chart. The SIPOC should be created with a cross-functional team. The team should decide on the best format for creating it.

A – Boundaries

Firstly, the boundaries for the process need to be established. These are the starting and end points of the process (the manufacturing of the product). These would typically be 'goods in' and 'goods out', as shown in Figure 6. At the early stages of process flow development, it may be unclear which steps of the manufacturing process are to be undertaken in house or subcontracted, or perhaps cover multiple sites. The location of the work should not define the boundary; rather the boundaries should be defined as the process steps, which are under the manufacturing company's influence.

Figure 6. SIPOC Boundaries

B – High Level Process Steps

The second action is for the team to identify the high-level process steps for the end-to-end manufacturing process within the boundaries. A high-level process step is one that people would recognise as having its own inputs and outputs where a significant operation or set of operations converts the product from one state to another state, for example, concrete casting converts multiple raw materials into a shaped concrete component. These would typically be associated with a particular machine, an assembly process, an automated line, or a continuous process. It is beneficial not to have too many at this stage and to keep it at a high level. The process steps will be developed and turned into the PFCs later when the further detail is known.

If the boundaries for these steps are unknown, i.e. they may be subcontracted out pending a sourcing decision, the team should include them until the decision is made.

The example developed below is for the manufacturing and assembly of a Wall Panel system.

Wall Panel Assembly System
Processes
Panel Conversion
Insulated Wall Panel Sub-Assembly
Uninsulated Wall Panel Sub-Assembly
Wall Assembly
Finishing and Fitting Out

Table 2. Process for SIPOC

The above could be represented as a flow chart. This is shown in Figure 7.

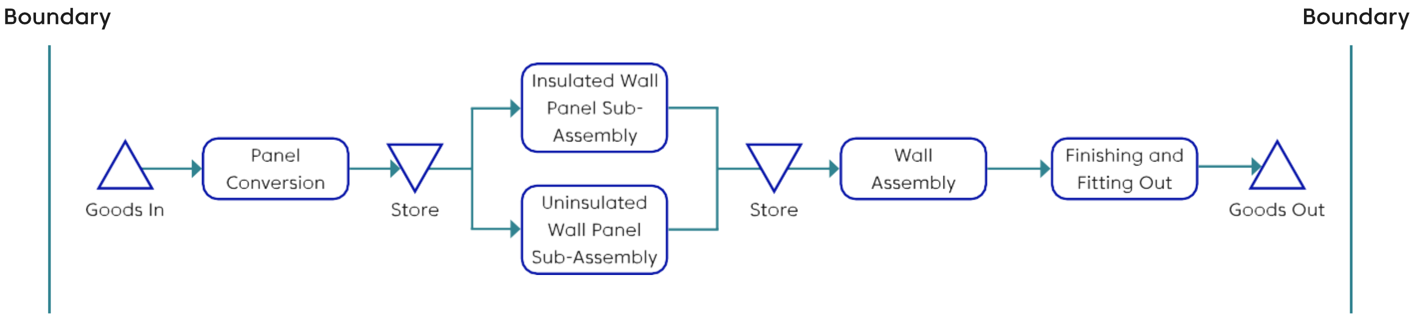


Figure 7. Process Flow for SIPOC

C – Inputs and Outputs

The 'inputs' to and the 'outputs' from the process now need to be listed and added to the table and chart.

Inputs are typically all the resources required to make the process work. This includes equipment (machines, tooling), utilities, people, information, and materials (assemblies, sub-assemblies, components, commodity items). This list can be long so it is important at this stage to identify the key inputs and or group other inputs together. For example, only the major bought in items (sub-assemblies, outsourced services) should be shown rather than every item on the Bill of Materials (BOM).

Similarly, the outputs should be listed at an appropriate level. Outputs include any data produced by the process, i.e. traceability data.

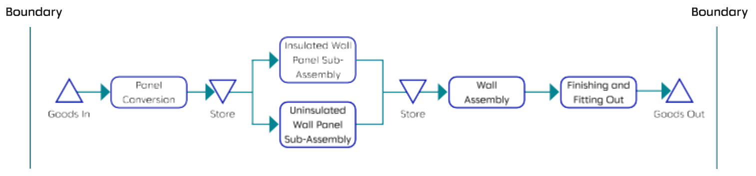
Wall Panel Assembly System		
Inputs	Processes	Outputs
Panel Conversion	Panel Conversion	Cut Panels
Converted Panels	Insulated Wall Panel Sub-Assembly	Sub-Assemblies
Insulation Material	Uninsulated Wall Panel Sub-Assembly	Final Assembly
Manning	Wall Assembly	Build Traceability data
Process Equipment and Line	Finishing and Fitting	
		

Table 3. Inputs and Outputs for SIPOC Table

D – Suppliers and Customers

After the inputs and outputs are listed, suppliers and customers are added.

The team needs to identify the supplier(s) of each input. For example, if a machine is required, who is supplying the machine? Is the machine already in place, do we have a supplier to buy one from? Corrective action(s) should be raised and managed for any unidentified suppliers.

For each output, the team needs to identify the customer(s). Note: this might not be the end user or the paying customer. It could be a third-party logistics provider who will deliver the product to the customer. The team then checks that the outputs are correct for each customer or checks with the customer if the process is giving the correct output. Actions to address gaps can be established.

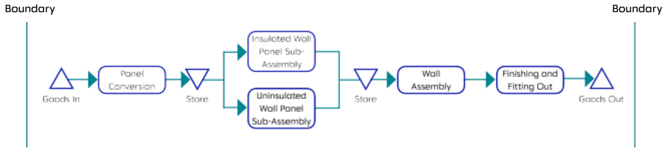
Wall Panel Assembly System				
Supplier	Inputs	Processes	Outputs	Customer
Material Supplies	Panel Conversion	Panel Conversion	Cut Panels	Assembly Process
Operations	Converted Panels	Insulated Wall Panel Sub-Assembly	Sub-Assemblies	On Site Construction Company
Equipment Suppliers	Insulation Material	Uninsulated Wall Panel Sub-Assembly	Final Assembly	Logistics Company
	Manning	Wall Assembly	Build Traceability Data	Construction Workers
	Process Equipment and Line	Finishing and Fitting		
				

Table 4. Suppliers and Customers for SIPOC Table

E – SIPOC Iteration

Developing the SIPOC will be iterative and will continue to evolve throughout the product and process development. The main activity in creating the SIPOC occurs in the early planning stages of NPI and CPQP with the detailed PFCs coming later.

The team should use the SIPOC to check that the outputs of the process are meeting those required by the customer. If the outputs are incorrect the team can determine how to rectify the problem. Similarly, the team can check if all the inputs are being supplied to the processes to deliver the required outputs. Any gaps that are identified can be actioned and the SIPOC updated.

By using the SIPOC method early on in the CPQP and NPI processes, when little detail is known, the team can create initial inputs for other activities and deliverables. This includes input to the project plan, product design requirements, the BOM, sourcing plan, the supply chain, the manufacturing layout and facility, equipment, requirements and resourcing needs. This allows these activities to be started and developed concurrently. Ultimately, the SIPOC feeds into the more detailed process design and hence the PFCs.

Step 2: Preliminary Process Flow Chart

Having completed the initial high level SIPOC, each process step should be turned into a preliminary PFC. This is a deliverable of CPQP Phase 1.

The preliminary PFC can be filled out in the same way as the Process Flow Chart using the same template as explained in Step 3 Process Flow Chart.

At the early stages of NPI and CPQP, the detailed steps will not be known as the process is not yet designed. Information, such as process times and required equipment, are not likely to exist. At this stage, the team should use best known data and assumptions from similar processes, research or machine suppliers.

The preliminary PFC should have the header filled out, it should list all the Operation Steps as they are known or envisaged, it should show the Operation Types, estimated Process Cycle times, and include equipment and tooling, jigs, or fixtures as known, or give an indication of what is required (detailed machine names of tooling references will not be known).

The preliminary PFC should be considered Revision 1 of the PFC. Phase 1 of CPQP is the Planning phase so the preliminary PFC should be used to start planning the process design. Completing the preliminary PFC gives the team the opportunity to identify gaps or risks in the process early in the development. It will highlight the areas that will need focus as CPQP and NPI move through Phase 2 and into Phase 3, process design and development.

At the end of CPQP Phase 1, the team should have a good idea and outline from the preliminary PFC of what the process will be and where the issues lie in order to start developing the detail in Phase 2 and 3. As stated, creating the PFC is an iterative process and the preliminary PFC will rapidly mature into the final PFC as the project develops.

Step 3: Process Flow Chart

A detailed PFC is required to show the operations and flow of the manufacturing, production, or assembly processes. This includes steps such as transport, inspection, delay, and storage.

Each PFC details one major process in the overall end-to-end process. If the team has used the SIPOC method then a PFC is required for each one of the process steps identified. Multiple PFCs could therefore be required for the product. If the process is continuous, then one PFC can be used.

For example, from the SIPOC created in step 1, there are five main manufacturing process steps. Each of these processes would be designed during the development of the product and the manufacturing equipment required would be designed in parallel. The PFC is developed as an output of the manufacturing process and equipment design.

There are many possible PFC formats. The format referenced in this guide covers many good practice points and works well with the PFMEA. The team may develop other methods or standards that meet the overall requirements.

Refer to the template for the following criteria, which can be modified to suit individual companies.

A – Header Data

The header data needs to be filled in for the project, product, and process that the PFC relates to.

The correct part name, number and revision level needs to be filled in under part type. The PFC should reflect the latest part revision.

The process name and description that the PFC relates to must be included. An overall description of the process, its purpose and its outputs should be made clear. The major inputs and materials to the process should be noted e.g., cut panels.

There should be a PFC reference number, date and revision level. Any changes in a revision level should be noted in a register associated with the PFC and changes should go through a change control procedure.

B – Process Data

For each process step, the following data should be included:

Operation Description

- **Operation Number** – Sequential number that can be used to identify or reference the step e.g. Op 10, Op 20 Op 30. It may be useful to set up a hierarchy of PFCs and operations if multiple charts exist and reflect this in the numbering;
- **Operation Step** – This is a short descriptive statement that describes the operation e.g. 'Screw 4 M10x40 bolts through Part A to attach to Part B' or 'Machine the outside diameter of the flange';
- **Operation Outcome** – This is what is expected after completing this step. This should be a qualified statement, reference to a specification or to dimension, e.g., 'Part B is attached with 4 bolts tightened to 20Nm' or 'Outside diameter turned to 102mm +/-.0.5mm'; and
- **Characteristic** – Note here if this process step affects a Significant Characteristic (SC) or Critical Characteristic (CC) of the product.

By completing these four steps for each process, the PFC can directly feed into the PFMEA. The PFMEA needs to look at the failure mode of the process. By stating the expected outcome in the PFC, the team has a defined statement to consider how the process might fail, e.g., only three bolts fitted, wrong bolt fitted, over-tightened, under-tightened and so on.

Not all steps on the PFC need to be carried over to the PFMEA however, only the steps that are changing the part, affecting its characteristics or are essential for the process. For example, inspection steps do not need to be included in the PFMEA. See PFMEA guideline for further information.

Operations Type

Apply the appropriate symbol for the operation step.

- Operation – These are the steps, which physically convert the supplied material or part to the next state e.g., machining, assembling, processing steps or steps important to make the process work. There is no need to include steps that do not convert the product e.g., inspection;
- Transport – These steps relate to physically moving the part with a forklift truck, crane, conveyor etc. This can be within the process or at the end, when the part is moved to another process or storage;
- Delay – These steps relate to points in the process where the part has to wait before continuing. Part may wait for another part of the process or may be required to wait to allow drying, cooling, setting times etc;
- Inspection – These steps indicate when the parts need to be checked for quality. These should relate to the control plan and could include visual checks or detailed measurement; and
- Storage – Typically, these steps are at the end of the process when the component is stored awaiting delivery or the next process.

When all the processes are complete with symbols, the flow is often shown by joining the symbols with a line. This can be used to assess if there is excessive movements, delays or storage in comparison to the number of operations.

Operation Information

This part of the PFC gives additional process information, which is useful when designing the process and also planning and running the process in full production.

- Process Cycle time – This is the planned time it takes for the process step to be completed;
- Manning – An indication whether the process is manual or automated. If it is manual, the number of operators required should be noted;
- Equipment / Consumables – Any equipment used should be recorded. This could be the machine, hand tools, transport equipment and should include any significant consumables;
- Tooling/Jigs/Fixture – Any specific tooling, jigs, or fixtures should be noted here. For example, assembly jigs, inspection fixture or press tools. If they have specific reference numbers, these should be included;
- Controls – Any methods used to control the process at this point, that are deemed important to running the process. These could include full-proofing devices or settings and can relate to the control plan; and
- Comment – Any additional information or comments for the process step.

Completion of this information will provide the basis of standard operating processes, equipment, process times, and manning for the business. It aids in the design and development of the process in CPQP Phase 3 and provides a single visual document for reference.

C – Sign Off, Review, and Development

The PFC is signed off by the Engineer responsible and a higher-level signature that represents the actual operations team, i.e. operations manager and/or quality manager. This is an important part of the manufacturing sign off and review process and is a check for assuring the process is understood and accepted. As part of the CPQP process, the customer may approve it as it is a CPQP deliverable and part of the Production Submission Warrant (PSW). See the Construction Planning Approval Process Handbook
As a product is developed, during an NPI program and using CPQP, the data and information will evolve. The PFC is a deliverable of Phase 3 of CPQP (Process Design and Development). At the end of Phase 3, the process is signed off and released and hence the PFC is frozen. Any changes after this point will be subjected to design change control. The information should therefore be complete and represent the process being signed off to go forward to Phase 4 (Product and Process Validation).

During Phase 4, the PFC should be updated with verified and validated information from production trials, such as updating process times and manning levels.

During Phase 5 of CPQP and then ongoing production, the PFC should be updated with any changes resulting from design changes, quality problems or continuous improvement activities.

References and Appendices

References

[1] Automotive Industry Action Group. (2008). Advanced product quality planning (APQP) and control plan reference manual (2nd ed.). Southfield, MI: AIAG.

[2] International Electrotechnical Commission. (2013). Enterprise - control system integration - Part 1: Models and terminology. In International Electrotechnical Commission IEC 62264-1.

[3] Tanner, S. and Bailey, M. (2014). The Business Improvement Handbook (4th ed.). London, UK: BSI Group.

[4] Society of Automotive Engineers. (2016). Aerospace Series – Requirements for advanced product quality planning and production part approval process. AS9145. SAE International

Appendices

Appendix A – Tool Templates

Templates to be use within the context of this guideline are available, please contact: cpqp@constructioninnovationhub.org.uk

Appendix B – List of Abbreviations

The following is a list of initialisations and acronyms used in this guideline.

A	APQP	Advanced Product Quality Planning
B	BOM	Bill of Materials
C	CC	Critical Characteristic
	CPQP	Construction Product Quality Planning
D	DfMA	Design for Manufacture and Assembly
F	FMEA	Failure Mode Effects Analysis
N	NPI	New Product Introduction
P	PFMEA	Process Failure Mode Effects Analysis
	PFC	Process Flow Chart
	PSW	Production Submission Warrant
S	SC	Significant Characteristic
	SIPOC	Supplier Input Process Output Customer

Appendix C – Glossary of Terms

The following is a list of commonly utilised quality, manufacturing and construction specific terms and their definitions within this context used within this guideline.

A

Advanced Product Quality Planning (APQP)

A quality framework used for developing new products. It was developed by the automotive industry but can be applied to any industry and is similar in many respects to the concept of design for Six Sigma; see AIAG Reference [1].

B

Bill of Materials (BOM)

A hierarchical listing of the physical assemblies, subassemblies, and components needed to fabricate a product as well as the quantity of each material required [2].

C

Critical Characteristic [CC]

An attribute or feature whose non-conformance would result in loss of primary function of the product resulting in catastrophic or hazardous failures without any warning. These are failures that would potentially lead to loss of life and/or irreparable damage.

Construction Product Quality Planning (CPQP)

An adaptation of Advanced Product Quality Planning (APQP) that is aimed at those enterprises that will feed construction with new componentry for offsite builds.

D

Design for Manufacture and Assembly (DfMA)

Product design with design priority given to ease of both assembly and manufacture.

F

Failure Mode Effects Analysis (FMEA)

'A tool for facilitating the process of predicting failures, planning preventative measures, estimating the cost of the failure, and planning redundant systems or system responses to failures [3].' 'The FMEA assists in the identification of critical items as well as key design and process characteristics, helps prioritize action plans for mitigating risk and serves as a repository for lessons learned [4].'

N

New Product Introduction [NPI]

This the process of designing, developing and introducing a new product into production and supply including the design of the manufacturing and supply processes. It is usually defined in a project framework consisting of processes organised into several phases that have controlled gates that the project must pass through based on achieving certain deliverables and targets. CPQP sits within an NPI project.

P

Process Failure Mode Effects Analysis (PFMEA)

An application of Failure Mode Effects Analysis (FMEA) for process design and implementation.

Process Flow Chart (PFC)

A chart showing the sequential steps for the flow of a manufacturing process. Described by a combination of a chart and descriptive text including relevant specifications.

S

Significant Characteristic [SC]

An attribute or feature whose non-conformance would result in loss of primary function of the product resulting in major failures without any warning. These are failures that cause significant disruption and costs to the client.

Supplier Input Process Output Customer (SIPOC)

A method of showing a process in a single table or diagram with the Process in the middle and then the inputs and outputs and the suppliers and customers of those in the outer columns. It shows the relationship between the five items and is used to make sure the process gives the customers the correct output by applying the right inputs.

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mtc Manufacturing Technology Centre

cdbb Centre for Digital Built Britain

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