InCoCo-S

Innovation, Coordination and Collaboration in Service Driven Manufacturing Supply Chains

Deliverable Nr. DL 4.3

Development of Correlations between Performance Measures

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Executive Summary

In Deliverable (DL) 4.2 the Service Performance Measurement System (SPMS) has been developed in order to quantify both the efficiency and effectiveness of industrial service operation activities and to support the measurement of customers` benefit through industrial service activities. The SPMS is equipped with a comprehensive set of approximately 200 performance indicators (PIs) structured in a hierarchical way by different target areas and distinguishing between service activities and service objects. Furthermore, a comprehensive set of performance indicators facilitating the measurement of industrial service operations has been linked to standardise reference service processes developed in DL2.6, the InCoCo-S Reference Model (IRM). This development of key PIs to assist manufacturers and their service providers in their bid to streamline processes, enhance performance and to manage costs is one overall goal of the InCoCo-S project. But performance indicators are only a measurable expression of the underlying system performance, a system which is ordinarily complex in nature.

The identification of interdependencies between performance indicators is critical to the ability of two or more organisations to monitor, assess and implement improvements. The impact of interventions in one area of the business need to be understood in order to support negotiation between manufacturer and service provider and, ultimately, to improve perfomance of the whole system. Best practices (BP) for coordination between entities, as discussed and evaluated in Task 3.4, will have an impact on the behaviour of both the manufacturer and the service suppliers. Without this understanding of interdependence, implementing improvements in one area of a business could result in detremental effects elsewhere. Task 4.3 has highlighted the strength of interdependencies between business areas spanning both manufacturer and service provider and will, together with further work in later tasks, serve as a blueprint for understanding the coordination needs across organisational boundaries.

Based on a comprehensive literature review and making best use of the tools and expertise available to the InCoCo-S consortium, a process to develop an understanding of the interdependencies between performance indicators was created and executed. The results provide both the service provider and the manufacturing customer with an insight into those performance indicators to be targeted for improvement and those better suited to monitoring. The output from this task will also be used to inform the design and operation of the System Dynamics simulation developed during Work Package 5.

1 Introduction

1.1 Objectives of the deliverable

The objective of Task 4.3 was to develop an understanding of the interdependency between the performance indicators (PI), identified in earlier tasks, through the creation of a cause-and-effect matrix for each of the Service Clusters, maintenance, packaging, retrofit and quality control, as introduced during the project (deliverable 2.6). Activities in the task make use of the InCoCo-S Reference Model (IRM) and the Service Performance Management System (SPMS) developed during Task 4.2.

Figure 1-1 illustrates the procedure in WP4 and shows how Task 4.3 is connected to the IRM Service Clusters, the SPMS and the industrial partners in InCoCo-S.

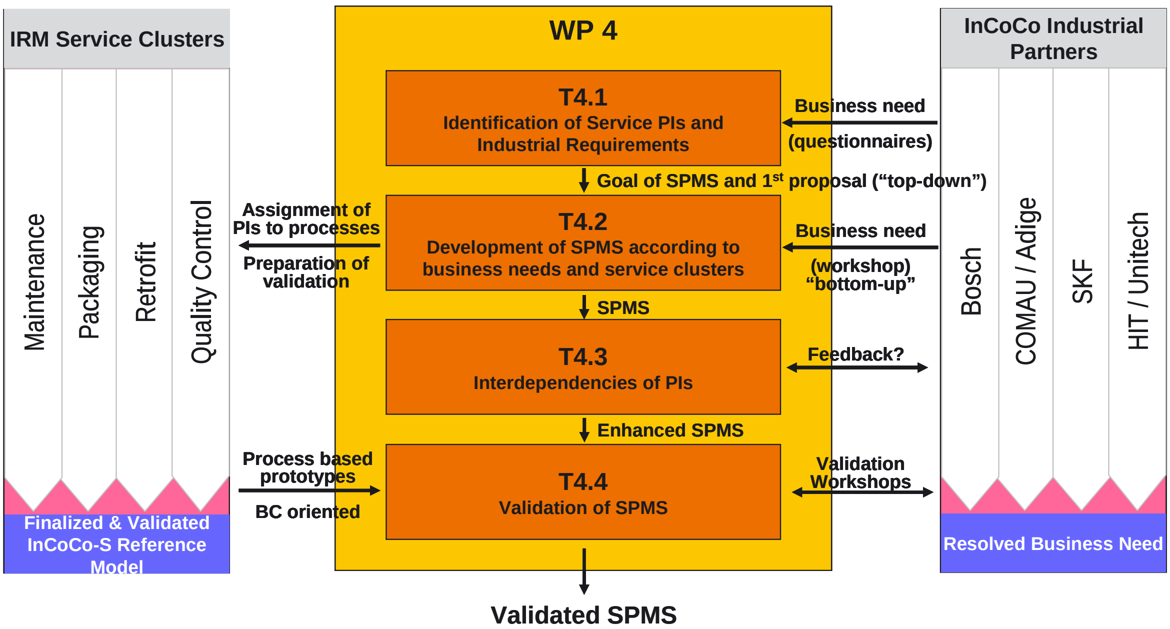

Figure 1-1: Interaction in Workpackage 4

The purpose of task 4.3 is to visualise and quantify the interdependencies among Performance Indicators on different levels by using the underlying service processes and corresponding PIs on Level 1 and 2. In addition the relationships between high-level PIs are indicated and the nature of their interrelationship has been further elaborated.

1.2 Research methodology

The research methodology incorporates the principles of action research, which consist of involvement of the industrial partners SKF, Sigpack Services, COMAU, HIT and UNITECH through workshops. The research process comprises first an analysis of state-of-the-art methods for investigating correlation between PIs in theory and practice by means of a literature review. The workshops at the partners of the InCoCo-S project were used to describe the influences among cluster specific PIs on Level 1 and 2. The System Dynamics (SD) software tool, Vensim®, has been used in the development of correlation between previously isolated PIs.

2 Methodology to develop Correlations between Performance Measures

Andy Neely analysed 1,352 papers published in 546 different journals that contained the phrase “performance measurement” in its title, keywords or abstracts for his study “The evolution of performance measurement research”, published in 2005. The results of the research suggest that an academic professionalism in the field of performance measurement has not yet occurred. Before the late 1990s the most frequently cited works were more practical pieces. After that an increasing shift in the performance measurement literature to more theoretical and methodological pieces occurred, which is an indicator for academic professionalism (Neely 2005). Neely in essence argued that the field of performance measurement is less than 15 years old and given this the limited professionalism to date is not surprising.

The immatureness of performance measurement is still obvious. Although it is common sense that most organisations operate in an ever rapidly changing environment, many still fail to adapt and respond appropriately to the dynamic complexity of the new environment. The use, therefore, of adequate performance measurement and management frameworks would be helpful for many organisations to act more successfully in a climate of change (Santos 2002). According to Neely’s research agenda, performance measurement systems need to be dynamic rather than static. Furthermore, he recommends developing performance measurement systems which are can be enhanced so they can cope with organisational changes (Neely 2005). But what is necessary to receive a dynamic and flexible performance measurement system?

Based on the researched literature only a few authors have given consideration to the relations between performance measures. In the following chapters the focus is on available methods and tools which might be useful for analyzing interdependences among performance measures. In this regard, a very important step is the need to establish a new way of thinking, enabling a better understanding of system behaviour. Our view has to move from analysing isolated elements to a holistic approach considering the interactions between performance measures.

2.1 Interdependences within performance measurement systems

The first and most important step for establishing a performance measurement system is the phase of design. Within this step, all relevant measures are stated and consequently the performance measurement system inherent interdependences are fixed too. Therefore it is very important to think about interdependences between possible performance measures right from the beginning. A later revision might be very difficult and intensive in time and cost.

In reference to Grüning, performance measurement comprehend itself within a systematic view as a concept for measuring, planning and steering the multi-dimensional, through interdependences, strategic and operative aspects integrated performance of organisational units (Grüning 2002). Grüning´s definition already contained interdependences as part of performance measurement. But, as mentioned in the introduction, only little consideration is given to this topic at present. In this chapter a detailed overview to the origin of interdependences is given. With a short introduction into the world of systems, the theoretical background of interdependences will be described. Furthermore, problem areas like dynamic complexity and how to deal with it are presented

2.2 What are systems?

The term »system« is used in everyday speech for many purposes (e.g. traffic system, economic system, political system or ecological system). Due to its formal character further completions are possible. Probst and Ulrich define a system as a whole consisting of elements. By speaking about a whole, the system is, on the outside clearly distinguishable by other things and even the inside is heterogeneous. Vester (1999) adds another essential attribute of systems. Besides the fact that systems consist of distinguishable parts, it is important to mention that these parts are linked to each other in a certain structure (Vester 1999). The nature of these relations are, however, not further explained. In reality it could be flows of material, information or energy as well as cause-and-effect relations. The extension of Vester also fits the first definition of systems by von Bertalanffy (1968). He said that systems are “sets of elements standing in interaction” as illustrate in Figure 2-1.

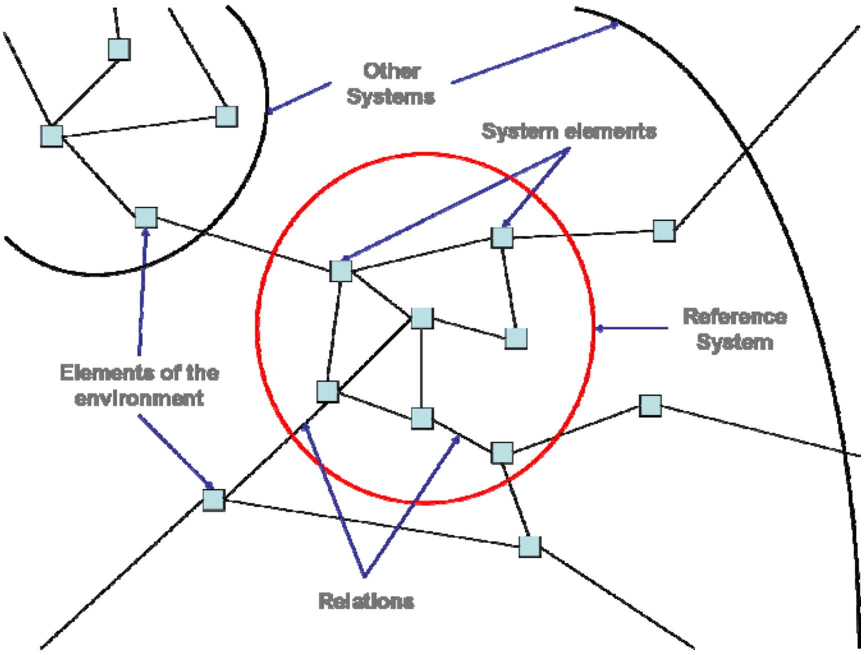

Figure 2-1: Sets of elements standing in interaction

All known systems are open systems, i.e. the system interacts with elements of the environment. Without any relations to the environment every system would tend to disability, which is reasoned by an increasing disorder. An explanation for an increasing disorder is given by the second law of thermodynamics. It says that the entropy of a non-open system will increase and consequently it aspires after disorder. Is interaction with the environment absolutely essential, therefore, because otherwise it will end as a non-system and fall into pieces? (Vester 1999). Referring to Figure 2-1 it is obvious that our reference system is interacting with elements of the environment, which are again part of other systems. All elements of the reality are integrated in systems. Each system is related to another system in some kind of hierarchy. But be aware that even an isolated element out of a system could be a system of itself which again consists of elements. The border of a system must not be physically tangible or visible. Most often it depends on the point of view of how a system border is settled (Haberfellner Daenzer 2002).

Another aspect when dealing with the character of systems is the ability to change its status over time. The system inherent interactions as kind of activity imply the existence of time. Without the recognition of time we would deal with static systems, which do not exist in the real world. Consequently every system in reality is active and changes itself over time. This characteristic is described with the term »dynamic«. An enhancement of dynamic is »complexity«. Complexity is defined as the ability of systems to change its current status over time in many (highly) different states. In reference to Foerster, Probst and Ulrich distinguish two types of systems (see Figure 2-2).

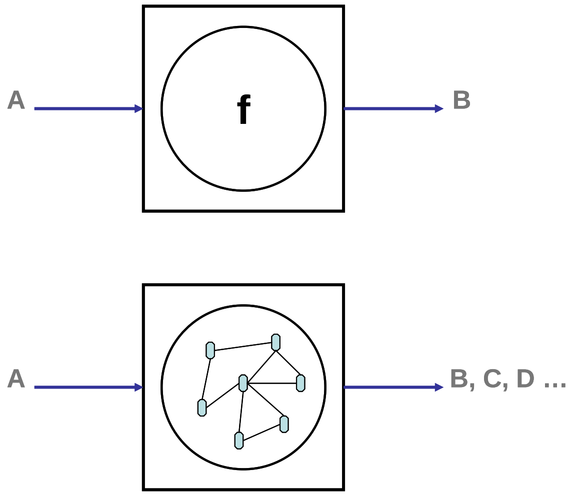

Figure 2-2: Trivial and non-trivial systems (Probst/ Ullrich)

A trivial system behaves like a simple Input-Output-Transformation. This kind of system can change from the current status only into a few different states. Therefore it is deterministic and predictable in respect to the system behaviour. The underlying standardized function of the system (f) transfer a certain input (A) always into a certain output (B). Determination and predictability are attributes which are aimed for in the development of technical facilities. For example a nuclear power plant shall generate energy concerning the customer demand and nothing else.

A non-trivial system behaves like a complex system. The given input (A) will be transferred into a varying output (B, C, D …). The development of complex systems over time leads to many different system behaviours. As a matter of fact, non-trivial machines are not predictable. One reason for this phenomena is the system inherent self dynamic. A good example of a complex system is a social system, such as an organisation, whose behaviour is not predictable. The main reason for this is the volatile work of human beings within the system. Humans do not work like machines, which are programmed to achieve a certain aim. Humans are unstable and make errors. Therefore it is highly uncertain to achieve the aspired goals of the organisation.

2.3 Interdependencies between system elements

Systems and elements are linked to each other by various relations. These relations can be in the form of energy, material or information flows. Interdependences are reasonable by the strong fragmentation of almost every area of our life. For example, organisations divide the whole organisation into several independent departments. By fragmenting the organisation a better transparency and manageability is realised but there is a need for efficient material-, information - and communication flow. The departments have to work with each other and therefore interaction in the meaning of interdependence is absolutely necessary.

Better knowledge and understanding of interdependences is preferable in respect of a more effective system analysis. The most common way of analysing a system is by focusing on the structure and the isolated system elements. The information gained from this analysis contains nothing about how the system elements interact with each other, an important point from a dynamic view. Without consideration of interdependences, developments or changes of a system are neither presentable nor predictable.

The etymological meaning of »interdependence« (lat.) is mutual dependence.[1] This postulates that the decision of person A has an influence on the decision of person B. Vice versa, the decision of person B has an influence on another decision of person A. Interdependence contains, in contrast to dependence, a retrospectiveness among all involved objects. One can find interdependences almost in every ordinary situation. It is not really surprising, therefore, to observe an inflationary use of this term and, accordingly, several definitions for each applied field exist. Practical or special definitions in the field of Performance Measurement do not exist. In this Deliverable the etymological meaning of interdependence will be the working definition.

2.4 Systems Thinking

System Thinking, as an alternative way of thinking, could lead to a better understanding of systems underlying every performance measurement system. It facilitates the analysis of systems especially in the field of interdependences between performance measures.

Following the research analysis, certain system behaviour results from the interaction of system elements. In order to be able to understand trivial or nontrivial systems, it is necessary to know these relations. The upcoming question is which methods and tools are known to overcome the obstacles of the increasingly complex world?

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[1] [=110 - Kraif 2007 Duden - Das Fremdwör...=]

Well known is the approach of dividing the system into ever smaller parts, analyzing these and the related structure. The underlying idea is to understand the function mode of the individual parts and thereafter combine these single understandings to receive a picture of the whole. This so called »analytic thinking« is quite common and corresponds to the principle “From the detail to the whole”. In complex situations this kind of thinking has its limits. Analytic thinking splits the system into parts and thus the relations between the parts become lost. A system can’t be determined alone by an understanding of its isolated components. The system performance depends rather on how system elements interact with each other. This includes the interaction with system elements of other systems.

Linear cause and effect thinking

In reality, most of us are not conscious of the omnipresence of interdependence. For example, experts compile a business strategy, the results of which do not correspond to the plan. One reason for this is the common way of linear cause-and-effect thinking. Referring to Figure 2-3, a cause-effect chain consists of several causes and effects which are ordered in a row. The important characteristic of a cause-and-effect chain is that every effect will be a cause for another effect, ending in a single effect. Cause-and-effect chains follow the linear way of thinking, which leads to the fact that every incident of the real world is depicted by a causal tree. Causal trees represent all involved elements of an incident in a linear way, but what about the interdependences between these elements?

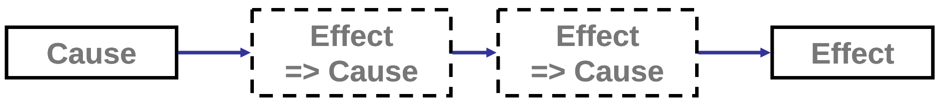

Figure 2-3: Cause-effect chain

It is quite logical that every cause-and-effect chain starts with a cause. But within Systems Thinking every cause affects itself by one or more feedback loops (compare Figure 2-4). Therefore the border between cause and effect is not that obvious anymore. Furthermore every cause could result in more than one effect as well as every effect could be influenced by several causes. It becomes increasingly difficult, therefore, to analyse systems the traditional way and to make any decision with regard to systems behaviour. This problem becomes even larger by the underlying influence of time, which is an undisputable part of reality.

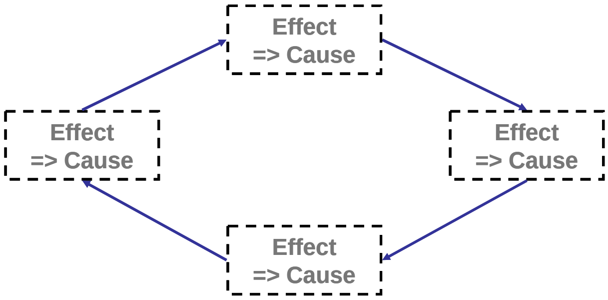

Figure 2-4: Feedback loops within cause-effect chains

Beyond Systems Thinking

As already described, certain states of non-trivial systems are not predictable. Even with a continuously constant input the resulting output will be different. This does not mean that the output will never be the same. But the factual and temporal reasons for the appearance are not known. Furthermore the same output can also occur as a result of different inputs. A reason for this is the inherent interdependency between the elements of non-trivial systems. A good example for the intricate problem of predicting a certain system status is a soccer match. Every soccer match consists of 22 players, one referee, one ball and a set of given rules. Within the game the constellation of all participants will change permanently. None of the constellation will be predictable. But if any player does not stick to the rules (e.g. offside, foul) he will get judged, which leads to a certain result (e.g. penalty, free kick). There is not only one appointed constellation. Referring to this point, Vester highlights the existence of basic principles, which makes the different “goal constellations” comparable and increases transparency. According to Vester it is not necessary and even not possible to get all information out of a certain system status. Vester mentioned three problem areas which we have to deal with by analysing a system (Vester 1999):

1. The resulting amount of data out of a traditional system analysis is very difficult to manage
2. The system inherent interdependences between internal and external elements have to be considered
3. Dynamic systems are not static

Moreover the last two points would increase the first problem. To handle these problem areas Vester recommends to pay rather more attention to the relations than to the details of system elements. The occurring picture of the system is not that sharp but represents the essential and right information. To illustrate the suggestion of Vester, which is the core idea of

Systems Thinking, the picture of Abraham Lincoln shall be helpful, Figure 2-5. The picture of Abraham Lincoln does not represent any detail. It is a synonym for pattern recognition as the key idea of Systems Thinking. The point is that without having any precise details it is possible to recognize the person on the picture. You need to adopt a systems viewpoint while you are standing back far enough – in both space and time - or by having a fuzzy view on the picture. Despite missing details you will be able to see the underlying web of interdependences which will support you to recognize Mr. Lincoln on the picture (Richmond 1991).

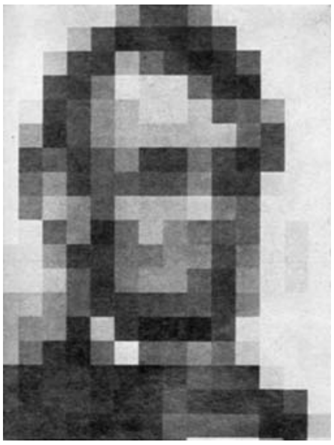

Figure 2-5: Abraham Lincoln by L.D. Harmon; Vester (2001), p. 54

The so called “fuzziness” is helpful to push the details into the back and highlights the underlying relations between the given details. Due to the fact that the given details do not contain enough information, you will automatically link the details. By linking the given details a pattern of relations will emerge. The missing details of the reality will be added by our brain. At the end you will be able to recognize more than the given details of Abraham Lincoln (Vester 2001) Referring to this phenomena Richmond says that "you're employing a systems perspective when you can see the forest (of relationships), for the trees. You are not employing a systems perspective when you get “trapped in an event” (Richmond 1991).

The allegory of Richmond about a person who “gazed out at the lights from high above a city, or gazed down upon a river valley from a mountain top”, is excellent to point out the main characteristics of Systems Thinking:

1. Details fade.
2. Patterns of relationships emerge.
3. Time seems to slow.

The new perceptions in regard to a new way of thinking are rightly summarized by Senge, who says that “the essence of the discipline of Systems Thinking lies in a shift of mind. It is a framework for seeing relationships rather than linear cause-effect chains, for seeing patterns of change rather than static 'snapshots’”, (Senge 2007).

A Continuum of System Thinking Activities

According to Richmond, Systems Thinking is, in practice, a continuum of activities ranging from the conceptual to the technical (Richmond 1991). Richmond’s continuum is quite similar to the concept of Ossimitz, who developed his concept independently from Richmond. Moving rightward along the continuum as depicted in Figure 2-6 the reader will see the different activities of Systems Thinking by Richmond.

Figure 2-6: A Continuum of Systems Thinking Activities (Richmond)

Influence Diagrams (ID)

Starting with the systems perspective, the occurring perceptions due to the systems perspective will be frozen by influence diagrams. These are simple maps of what is hooked up to what (Richmond 1991). Influence diagrams present nothing else than the system inherent interdependences, which are responsible for the system behaviour, in a clear, qualitative way. Mostly influence diagrams are kind of causal-loop-diagrams as they are long used in academic work. Causal-loop-diagrams consist of knots, which represent system elements, and arrows, which represent the causal relation and the underlying effect from one element to another. Arrows are completed by a positive “+” or negative “-“ sign to declare the type of effect. A positive sign indicates that changes in the cause result in changes in the effect *in the same direction*. That is, increases in the cause lead to increases in the effect, for example. On the other hand, a negative sign indicates that a change in the cause results in a change in the effect *in the opposite direction*. In the example, therefore, an increase in the cause would result in a decrease in the effect. These two signs are enough to illustrate incidents of the real world in a causal-loop-diagram. Similarly, a closed feedback loop can be distinguished as being either positive (reinforcing) or negative (balancing). A positive loop tends to reinforce or amplify whatever is happening in the system. As illustrated in Figure

2-7 more chickens lay more eggs, which hatch and add to the chicken population, leading to still more eggs, and so on. The loop is self-reinforcing, hence the loop polarity identifier, R. If this loop would be the only one operating, the egg and chicken population would increase exponentially. In reality no quantity can grow forever, so a negative feedback as limiting factor is obligate.

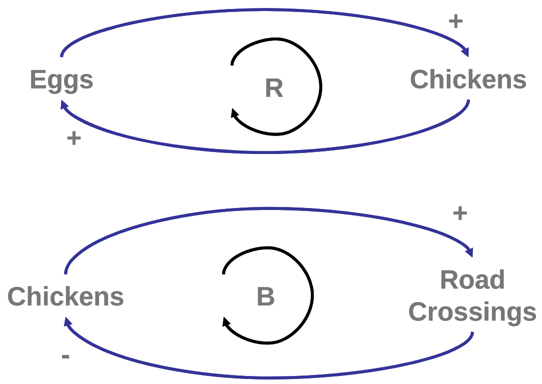

Figure 2-7: Positive (R) and negative (B) feedback loops (Sterman)

Negative feedback loops are self-correcting. They counteract change. The chicken population in Figure 2-7 grows, hence the negative loop will act to balance the chicken population. The more chickens, the more road crossings they will attempt. If there is any traffic, more road crossings will lead to fewer chickens. As follows the chicken population will be limited by the risk of crossing the road. The B in the centre denotes a balancing feedback (Sterman 2000).

Structural Diagrams

The next step is the construction of structural diagrams, which attempt to show what really makes a system tick. Influence diagrams and structural diagrams, also called stock-and-flow-diagrams, look quite similar in design. But in contrast to influence diagrams, structural diagrams are used for quantitative modelling. All elements in a structural diagram are quantitative elements. Furthermore, arrows used have a more specific meaning than in the case of influence diagrams. An arrow from A to B no longer indicates only a qualitative effect. A is an input which is measurable and changes B substantially. The two key elements of structural diagrams are stocks and flows. Stocks are those elements which are able to store information or any kind of input over time. A stock is comparable to a reservoir. Reservoirs consist of a storage place, some kind of supply and one or more outflows. The storage level of the reservoir will be regulated by using these two flows. The outflow is used to reduce the amount of stored water in the reservoir while the supply increases the reservoir stock. The increase or decrease of a stock is symbolized by a flow, also known as a rate (Ossimitz 2000). In contrast to stocks, rates or flows represent a change over a period of time (e.g. birth and death rate of a population in course of a year). Stocks represent the amount of a population at any point in time.

Equations/ Simulation

Far right in the Systems Thinking continuum by Richmond, the reader can find equation and simulation as the last step. One might take the step by simply translating the structural diagram into a set of equations, which are fundamental to simulate the given system. Equations characterise the nature of the relationships laid out in the structural diagram. This activity also includes assigning numerical values to define the direction and strength of these relationships. Completing this step enables the simulation of system behaviour through the use of a computer. Being able to do this often is very important because it permits you to "close the loop" on your thinking. You can answer the question: Can the set of reciprocal relationships that I've pieced together in fact generate the behaviour patterns that are being produced by the actual system?" (Richmond 1991).

2.5 Methods for Interdependency Analysis

2.5.1 Cognitive and strategy maps

“Trying to identify factors affecting performance and to explicitly represent their relationships, " Kaplan suggested the use of cognitive maps and Kaplan and Norton (2001) the use of strategy maps. These cause and effect diagrams are very valuable to capture and make explicit the managers’ “theory of the business” and consequently they may prove very useful in identifying appropriate performance measures. Nevertheless, strategic maps and/or cognitive maps do not allow participants to understand fully the implications of interconnections between the factors affecting performance due to the existence of non-linear interactions, delays, feedback loops and other elements that give rise to dynamic complexity and which are not incorporated in these types of mapping. To deal with the dynamic complexity inherent in social systems and to infer dynamic behaviour, quantitative simulation is required (Senge, 1990; Sterman, 1989). Therefore, and particularly in those situations where it is important to understand the interactions among measurements over time, the value added by strategy maps and/or cognitive maps can be significantly increased if they are complemented by simulation modelling. The combined use of qualitative and quantitative modelling enriches the analysis and can provide very useful insights for the design of measurement systems.” (Neely 2005).

“Strategy maps assume a logical and causal set of relationships between dimensions of organisational performance, yet in reality these relationships are recursive and dynamic” (Brignall, 2002; Nørreklit, 2000).

“Several tools or facilitative processes can be used to foster creative thinking in order to identify performance measures and to increase understanding about their relationships. However these maps provide only qualitative representation of the feedback structure of systems and, consequently, are not themselves very useful in inferring dynamic behaviour. To derive dynamic insights from complex feedback systems, quantitative simulation is required. Causal loop diagrams (CLDs) are an important tool for identifying and representing feedback loops and, given that it is the interaction between these loops that determines the dynamics of the system, they may prove very effective in helping to identify appropriate performance measures and to understand their dynamic relationships. CLDs are maps showing the causal relationships among a set of variables operating in a system and they are developed following well- established guidelines” (see, for example, Coyle, 1996; Sterman, 2000)

2.5.2 System Dynamics (SD)

"SD was conceived and developed in the late 1950s and early 1960s at the Massachusetts Institute of Technology (MIT) by Jay Forrester. Indeed the advent of SD is generally considered to be the publication of Forrester's pioneering book, Industrial Dynamics in 1961. Since then, significant advances have been made, and a cursory examination of the literature indicates that the number of organisations using SD models for the development of both strategic and operational policies is growing rapidly. An overview of SD can be found, for example, in Forrester (1961), Richardson and Pugh (1981) and Sterman (2000). SD models are frequently developed and used to represent, analyse, and explain the dynamics of complex systems. The dynamics or behaviour of a system is defined by its structure and the interactions of its parts. The main goal of SD is to understand through the use of qualitative and quantitative models how this behaviour is produced, and to use this understanding to predict the consequences over time of policy changes to the system" (Santos 2002).

Following Santos, the following advantages emerge from the use of causal loop diagrams (CLDs) (Santos 2002):

- It gives a clear picture of the different elements of the problem and the interconnectedness between them. Cause and effect, feedback loops, delays and other elements that give rise to dynamic behaviour can be easily represented using CLDs. It is possible to take a holistic view of the system being assessed through the development of qualitative diagrams and of SD simulation models. Teams tasked with developing measurement systems can better understand how the different measures interact with each other over time and in this way gain a greater (and shared) understanding of the processes that determine the organisation's performance.
- The use of CLDs allows the identification of intervention points or policy levers that can be used to control the performance
- The process of building the CLD representation of the system, guided and assisted by an effective facilitator, helps to clarify people's thinking on the subject and on their objectives. Discussion among the members of the working group leads to a clearer understanding of the problem situation and fosters consensus and commitment about what should be measured, why and how.

It is important to mention that CLDs (qualitative SD) may help to visualise interdependencies and feedback processes that generate dynamic behaviour in the system being assessed, they do not allow rigorous conclusions to be drawn regarding this behaviour.

In conclusion, to fully understand the dynamics of complex systems quantitative models are essential. Only through the development and use of SD simulation models can managers fully understand the implications of non- linearity, feedback and delay among the performance measures and be able to identify the highest leverage points in the system.

The system's perspective tells us that we must look beyond symptoms to understand important problems and to find fundamental solutions (Forrester, 1961; Senge, 1990). Only thorough analysis of the underlying structure of problems allow us to find their real causes and the areas of highest leverage, that is, those areas where actions can lead to lasting and significant performance improvements. To get insights into the real causes of problems and to find the highest leverage areas. Senge (1990) suggests that people must learn to see "structure" rather than "events" and think in terms of "processes" rather than "static snapshots". SD has repeatedly been demonstrated to be an effective analytical tool in fostering this way of thinking. The focus on the causal structure of problems and the search for leverage points are some of the strengths which make SD an appropriate approach to foster understanding of the process underlying performance generation and to identify the factors that may prompt effective changes in the system. Kaplan and Norton (2001) have themselves recognised the value of system dynamics modelling to increase understanding of a business' value creation process.

The use of qualitative SD based on causal loops and quantitative SD based on computer simulation can be very valuable in assisting decision makers to gain a greater understanding about how the organisation is performing, why, and what to do to improve results. …cautions needs to be taken in inferring behaviour from CLDs alone. In most cases, quantitative simulation models are essential to understand fully the dynamics of complex systems. In addition, the use of SD simulation models not only provides understanding of what has happened but also can generate valuable insights about what might be about to happen next.

The support to group learning that SD modelling can provide (Vennix, 1996) can also be invaluable in the performance measurement and management context. The model building process clarifies thinking and encourages the different systems stakeholders to learn about the system being assessed as a whole. In addition, SD simulation modelling may play a vital role in testing and comparing alternative actions to improve system's performance.

2.5.3 Interdependency Matrix

The Interdependency Matrix (IM) is based on the so-called paper computer according to Vester (Ninck et al. 2004; Gomez & Probst 1999) and depicts the interdependencies among the PIs. The two-dimensional matrix contains all performance indicators arranged vertically and horizontally with the matrix entries indicating the strength of influence of the PI on the vertical axis, on those PIs arranged along the horizontal. In the IM, a value of “1” or “2” mean that the PI in the corresponding row has a medium or strong influence on the PI of the corresponding column, while a value of “0” indicates that there is no significant influence in general.

The IM is defined as follows:

- $IM^{n \times n}$ is a n x n-Matrix with n = number of PIs
- for each element $m_{ij} \in IM$: m_{ij} is the weighted influence of PI_i on PI_j with i, j = 1…n and $m \in \{0, 1, 2\}$

The objective of the IM is to assess the role of each PI in order to better understand its role and use in the framework of the SPMS. In order to facilitate this, the following figures are calculated (see Ninck et al. 2004):

- Active sum of PI_i: $AS_i = \sum m_{ij}$ for j = 1...n

  AS_i indicates the degree of influence of a certain PI_i on other PIs. The higher AS, the higher the influence on other PIs.

- Passive sum of PI_j: $PS_j = \sum m_{ij}$ for i = 1...n

  PS_j indicates the degree of how a certain PI_j is influenced by other PIs. The higher PS, the higher the PI is influenced by other PIs.

- Product of PI_i: $P_i = AS_i \times PS_i$

  P_i indicates the intensity of crosslinking of a certain PI_i. The higher P, the more a certain PI is crosslinked with other PIs.

- Quotient of PI_i: $Q_i = AS_i / PS_i$

  Q_i indicates the intensity of activity of a certain PI_i. A low Q (Q < 1) means that a certain PI is more influenced by other PIs than influencing other PIs.

See Table 2-1 for a simple example.

Influence of ↓ on →	PI 1	PI 2	PI 3	PI 4	AS	P
PI 1		1	1	0	2	6
PI 2	1		1	1	3	15
PI 3	0	2		2	4	8
PI 4	2	2	0		4	12
PS	3	5	2	3		
Q	0.7	0.6	2.0	1.3		

Table 2-1: Interdependency Matrix (IM) (example)

Using the figures AS, PS, P, and Q, the results can be assessed and interpreted as follows (Ninck et al. 2004; Gomez & Probst 1999):

- Active PIs with Q > 1 are influencing other PIs to a high degree and are hardly influenced by other PIs.
- Passive PIs with Q < 1 are influenced by other PIs to a high degree and hardly influencing other PIs.
- Crosslinked PIs with P = high (e.g., P > 0.5 x Max (P_i) with i = 1…n) are highly connected to other PIs and are involved into many cause-effect relationships (interdependencies). Their influence is high and they are influenced.
- Isolated PIs with P = low (e.g., P < 0.5 x Max (P_i) with i = 1…n) are hardly influencing other PIs and are not highly influenced.

The PIs can be positioned in an Interdependency Portfolio (IP) based on the P and Q values, see example in Figure 2-8.

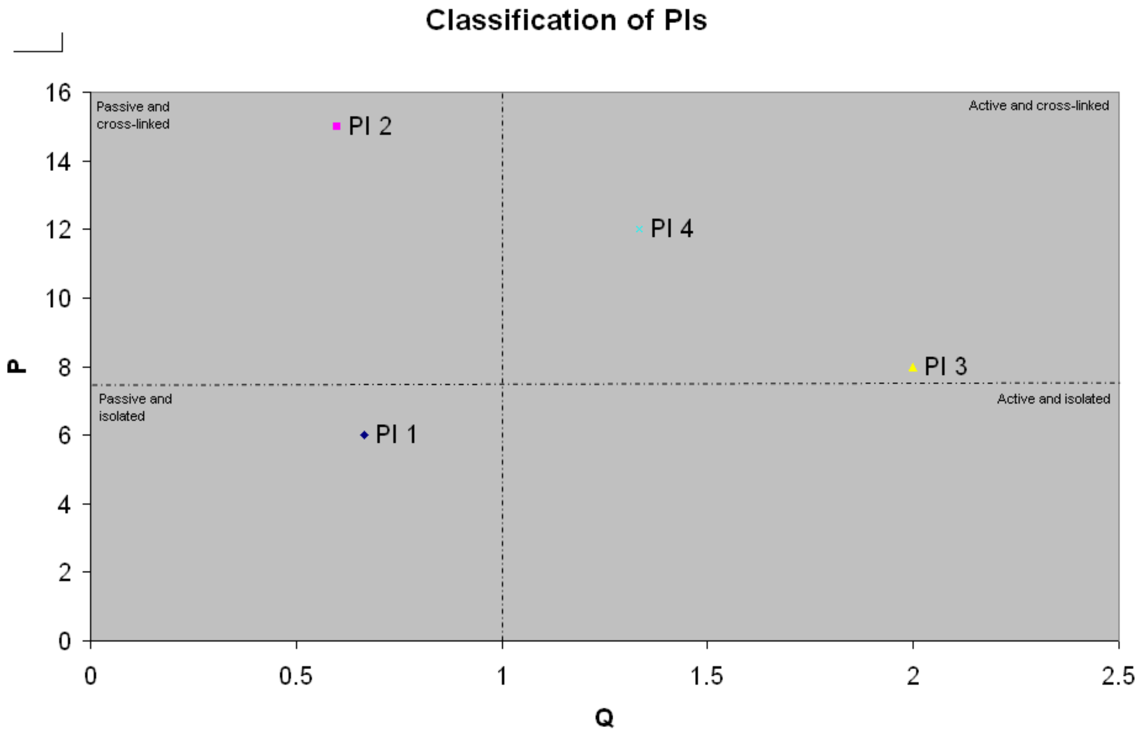

Figure 2-8: Interdependency Portfolio (IP) (example)

The positioning of the PIs in the IP can be used to determine the appropriate use of the PIs (Ninck et al. 2004; Gomez & Probst 1999) in the framework of the SPMS and to develop improvement strategies (Schnetzler & Sennheiser 2003). Each performance indicator is classified by its quadrant in the Interdependency Portfolio, Table 2-2 descibes the nature of the PI as assessed during the “paper computer” exercise.

	Q < 1 (passive)	**Q > 1 (active)**
P = high (cross-linked)	**Passive and cross-linked: Indicators, Monitoring** Such PIs should primarily used as indicators for monitoring the status of a system on a mid or long term basis. In order to improve them, drivers have to be identified and interventions should be primarily made there.	**Active and cross-linked: Accelerators, selective interventions** Selective interventions here are crucial and may be used as accelerators of trends. There may be feedback loops that intensify the impact. Therefore, such interventions should be used with precaution in order to prevent undesired side effects by analyzing the interdependencies thoroughly. In particular, such PIs may be influenced via their drivers.
P = low (isolated)	**Passive and isolated: Stabilizers, Monitoring** Since such PIs show influences with delays, they are stabilizers and should be used for long term monitoring. Interventions in order to improve the whole system do not make much sense here. In some cases, isolated measures can be used in order to improve a certain PI in this area.	**Active and isolated: Intervention, Controlling** Interventions here can have a huge impact on other PIs. Therefore, they are levers that can be used to influence a system in a targeted way. For a targeted intervention, the interdependencies should be analyzed thoroughly in order to assess its impact.

Table 2-2: Use of PIs and generic improvement strategies (adapted from Schnetzler & Sennheiser 2003 and Ninck et al. 2004)

These considerations support the better understanding of the appropriate use of a certain PI and its role in a cross linked system as well as the development of improvement strategies (where and how to intervene in order to improve certain PI).

2.6 Task Method; System Dynamics, Vensim Causal Tracing™ and Interdependency Matrix (Paper Machine)

Throughout InCoCo-S work package 5, the Vensim System Dynamics (SD) simulation tool will be utilised in quantification of the complex relationships within and between the manufacturer and service suppliers' operations. In addition to this quantification, Vensim provides the project with a vast array of powerful analysis tool one of which, Causal Tracing™ enables causal relationships between elements of a system to be explored rapidly in diagrammatic form, see Figure 2-9.

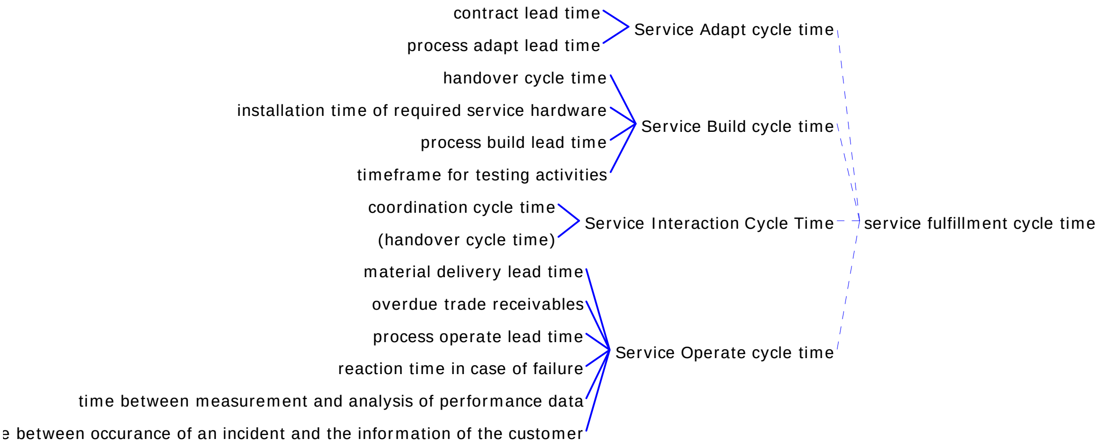

Figure 2-9: Causal Tracing Example; Causes Tree

Taking the InCoCo-S Reference Model (IRM) and the hierarchy of performance indicators (PI) found in the SPMS, Vensim is used to develop a seamless causal analysis model for flexible and rapid display of relationships throughout the service-supply system. This causal tracing ability and the continued use of Vensim and System Dynamics in Work Package 5 led to the choice of Vensim software in this task.

IRM level 3 processes and all performance indicators from level 1 down to level 3 were captured in the Vensim software (see Figure 2-10 for the causal tree showing all 38 Level 2 PIs at the end of the tree). Causal analyses of the level 2 PIs were used to create causes trees for each. These were then provided to consortium members (cluster managers and industry partners) for an analysis of interdependencies. In order to best describe the interrelationships between these PIs, it was decided to make use of the so-called "Paper Computer" or Interdependency Matrix, described in 2.5.3.

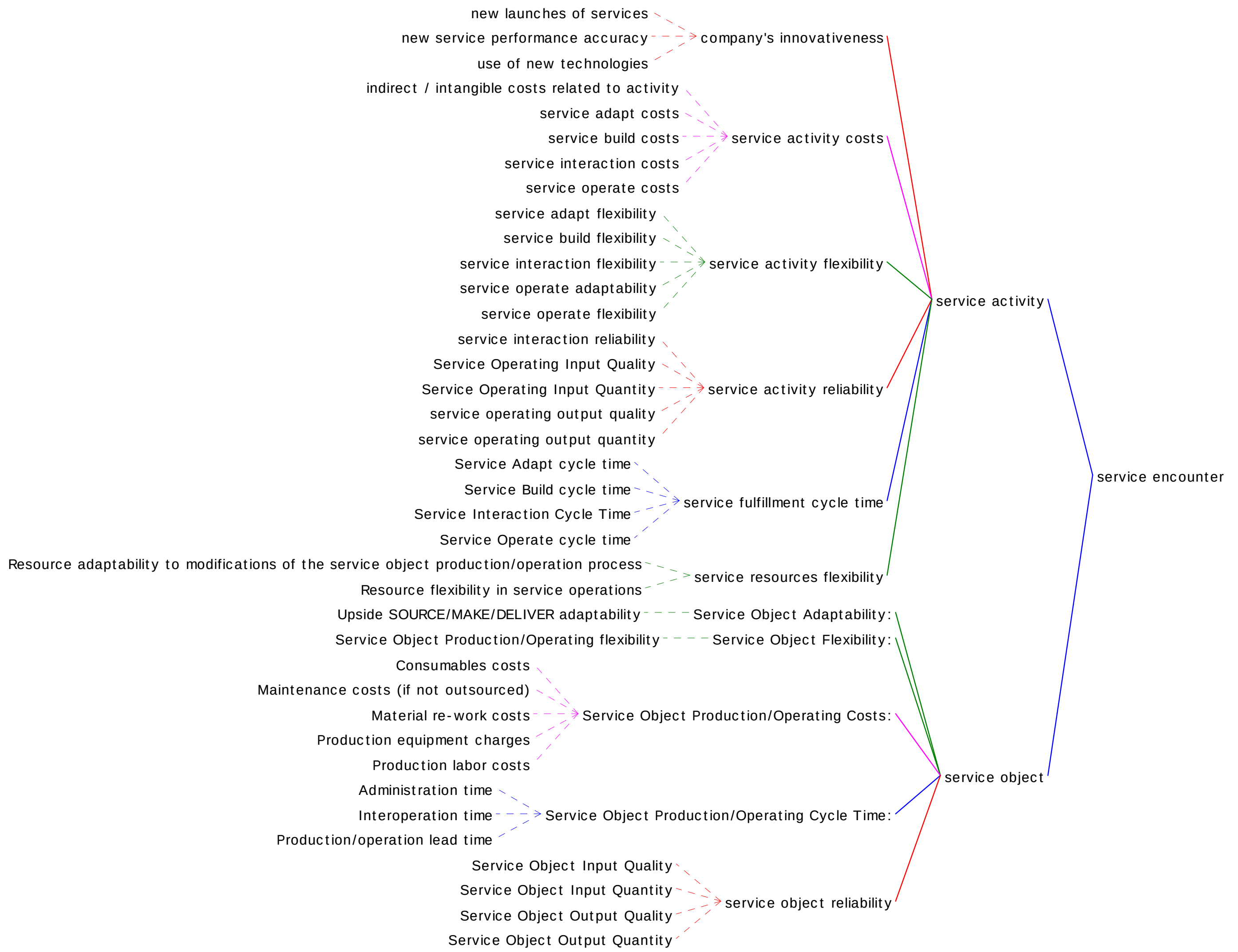

Figure 2-10: SPMS Hierarchy in Vensim; Causal Tree (with Level 2 PIs far left)

3 Interdependence between Performance Measures in service-supply chain

This section describes the processes used in the development of the Interdependency Matrix (IM) and subsequent analysis. The Vensim Causal Tracing™ capability was exploited to provide causal trees for analysis by cluster managers and industry partners.

3.1 Vensim and Causal Trees

The hierarchy of Performance Indicators (PIs) developed in the SPMS (InCoCo-S Task 4.2) were transferred to the Vensim software in order to be able to exploit the causal tracing capabilities of the package. These were further combined with the InCoCo-S Reference Model (IRM) in order to present a complete causal picture of the relationship between processes, their performance indicators at level 3, and the hierarchy of PIs up to level 1. An example of a section of the Vensim process model is shown at Figure 3-1. The diagram shows part of the IRM, including processes and PIs for the "Build" phase.

During development, the following colour-coding was used to distinguish between the categories of Performance Indicator from the SPMS:

- Effectiveness / Reliability
- Flexibility
- Responsiveness / Time
- Assets / Costs

To assist in the assessment of interdependence between Level 2 Performance Indicators, individual causal trees for the 38 Level 2 PIs were created (see example at Figure 3-2). These trees are automatically created by the software when analysing the structure of the model and were specifically designed to show all influences on the level 2 PI down to the level 3 IRM processes.

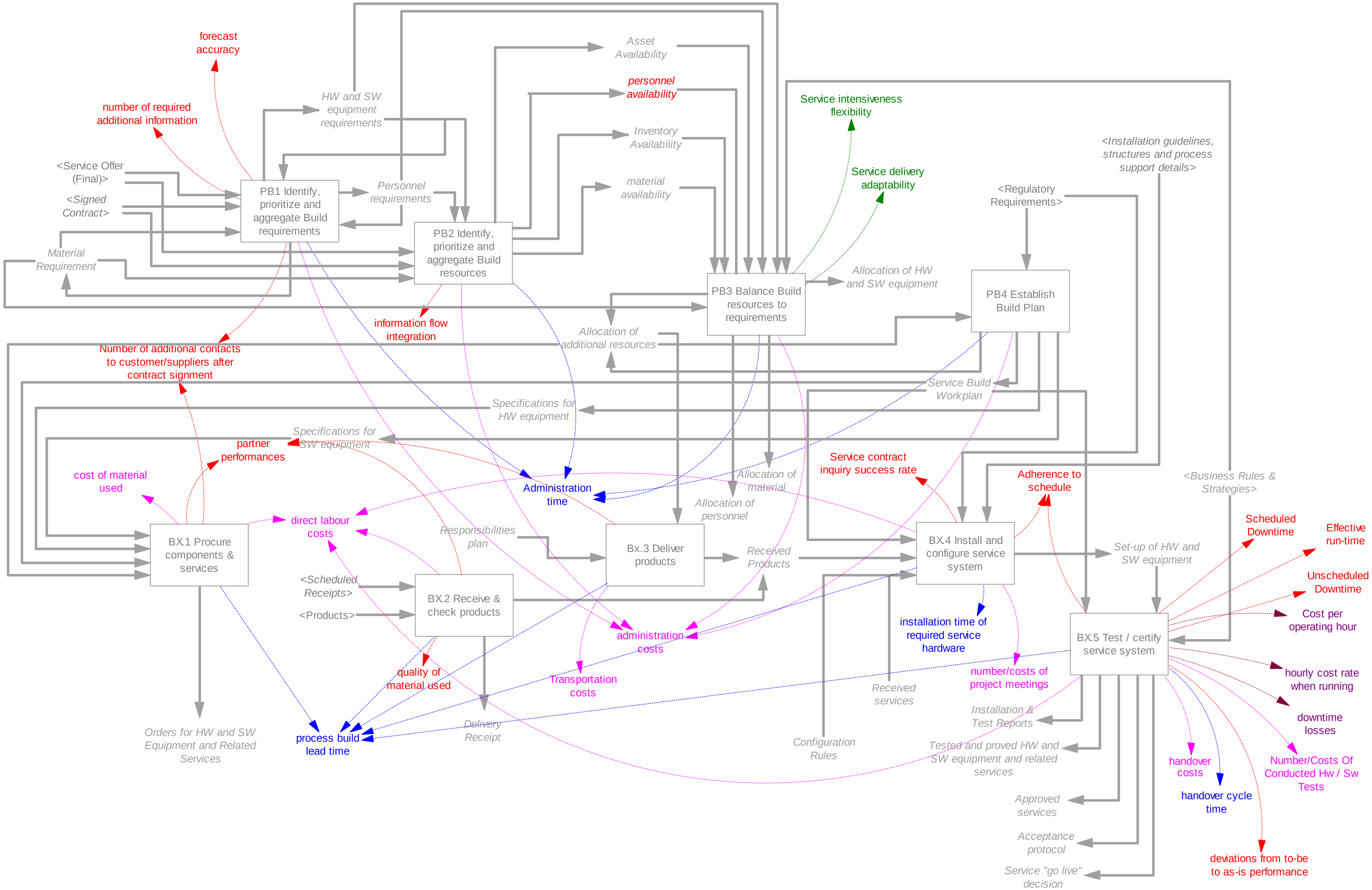

Figure 3-1: Example Process Flow Representation in Vensim, with associated level 3 Performance Indicators

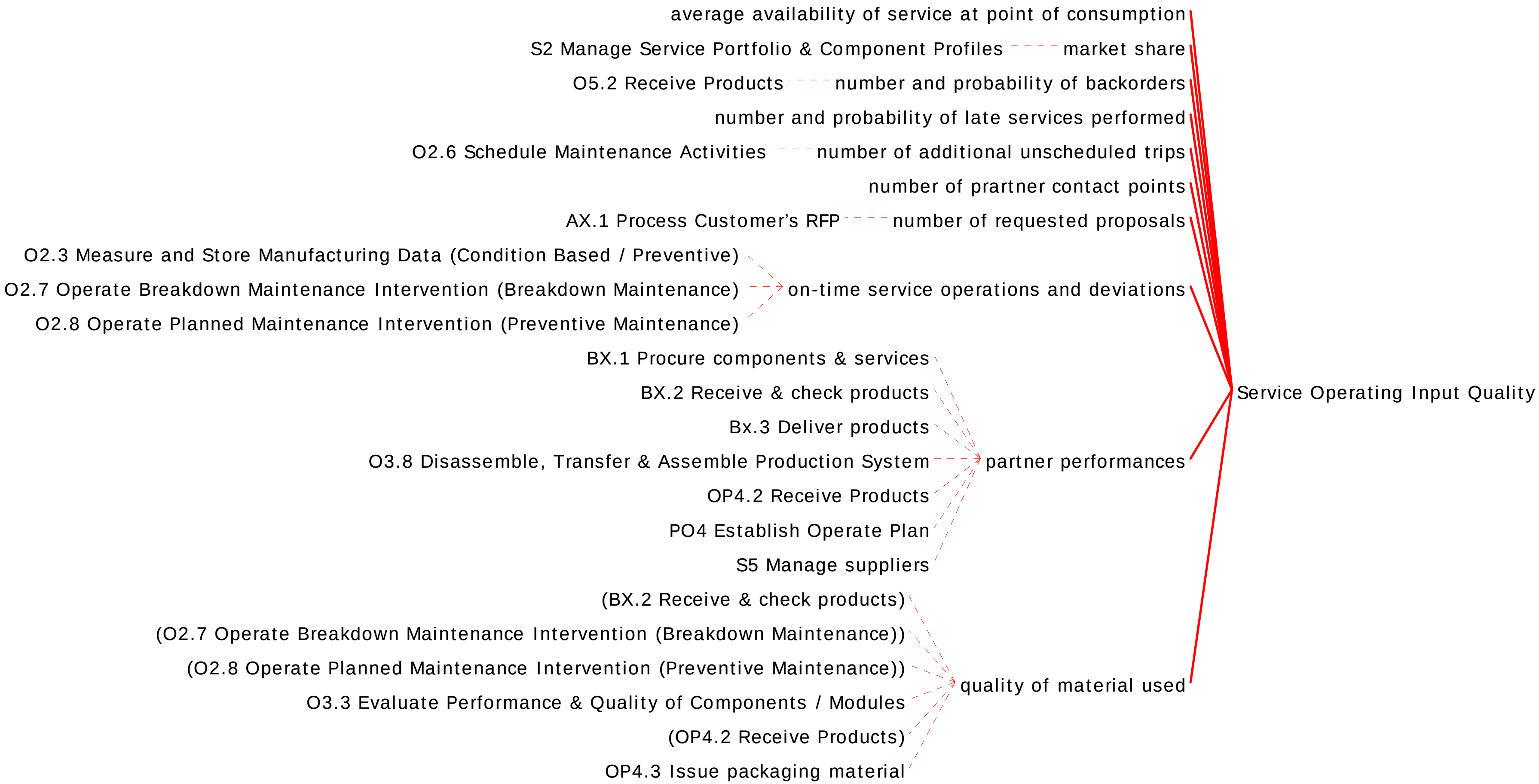

Figure 3-2: Example Level 2 Causes Tree

3.2 Interdependency Matrix (IM)

The 38 Vensim causes trees were captured and saved as PDF – format files and made available to the cluster managers with the following guideline for development of the IM. Together with the responsible industry partner, an Interdependency Matrix could be developed between level 2 PIs, with due regard to the connection of these PIs to the level 3 processes within the IRM.

Guideline for Creation of Interdependency Matrix

The text below was provided to cluster managers and relevant industry partners to assist their discussions on interdependence between level 2 PIs:

You have been provided with 38 PDF documents[2], one for each of the **level 2 Performance Indicators (PI)**. Each document displays a causes tree[3] for the named PI, displaying the PI, its level 3 component PIs (if applicable) and any processes from the InCoCo-S Reference Model (IRM) linked to the level 3 PIs (see example at Figure 3-3).

You have also been provided with an Excel spreadsheet containing an empty Interdependency Matrix (IM), for recording the influences between pairs of **level 2 PIs**.

An Example

- *Influence Strength Options*
    - 0 – no or negligible influence
    - 1 – medium influence
    - 2 – strong influence
- *Level 2 Performance Indicators (PI)*
    - 1: new launches of services
    - 2: service operate adaptability
    - 3: service output input quality
    - 4: service object output quality
    - 5: service adapt flexibility

The aim of this exercise is to discuss and note influences between level 2 PIs; for example, between “PI 2”, “*service operate adaptability*” and “PI 1”, “*new launches of services*”.

---

[2] File name “PIx <Level 2 PI name>”, where x = PI number
[3] A Vensim tool used to display cause-and-effect relationships.

Example Interdependency Matrix

PI	*1*	*2*	*3*	*4*	*5*
1	-	0	2	0	1
2	**2**[1]	-			
3	2		-		
4	0			-	
5	2				-

[1]*prerequisite to offer new services is a clear picture on the amount of adaptability – a high adaptability allows more new services*

In the above example, the influence of "PI 2" on "PI 1" has been assessed as "strong" and a value of "2" has been entered. A note has also been entered; "*prerequisite to offer new services is a clear picture on the amount of adaptability – a high adaptability allows more new services*" to record the reason for the decision.

In assessing the nature of the relationship between PI 1 and PI 2, the "respondents(s)" would have made use of the level 3 PIs and relevant level 3 process names, appearing in the causes tree, to assist.

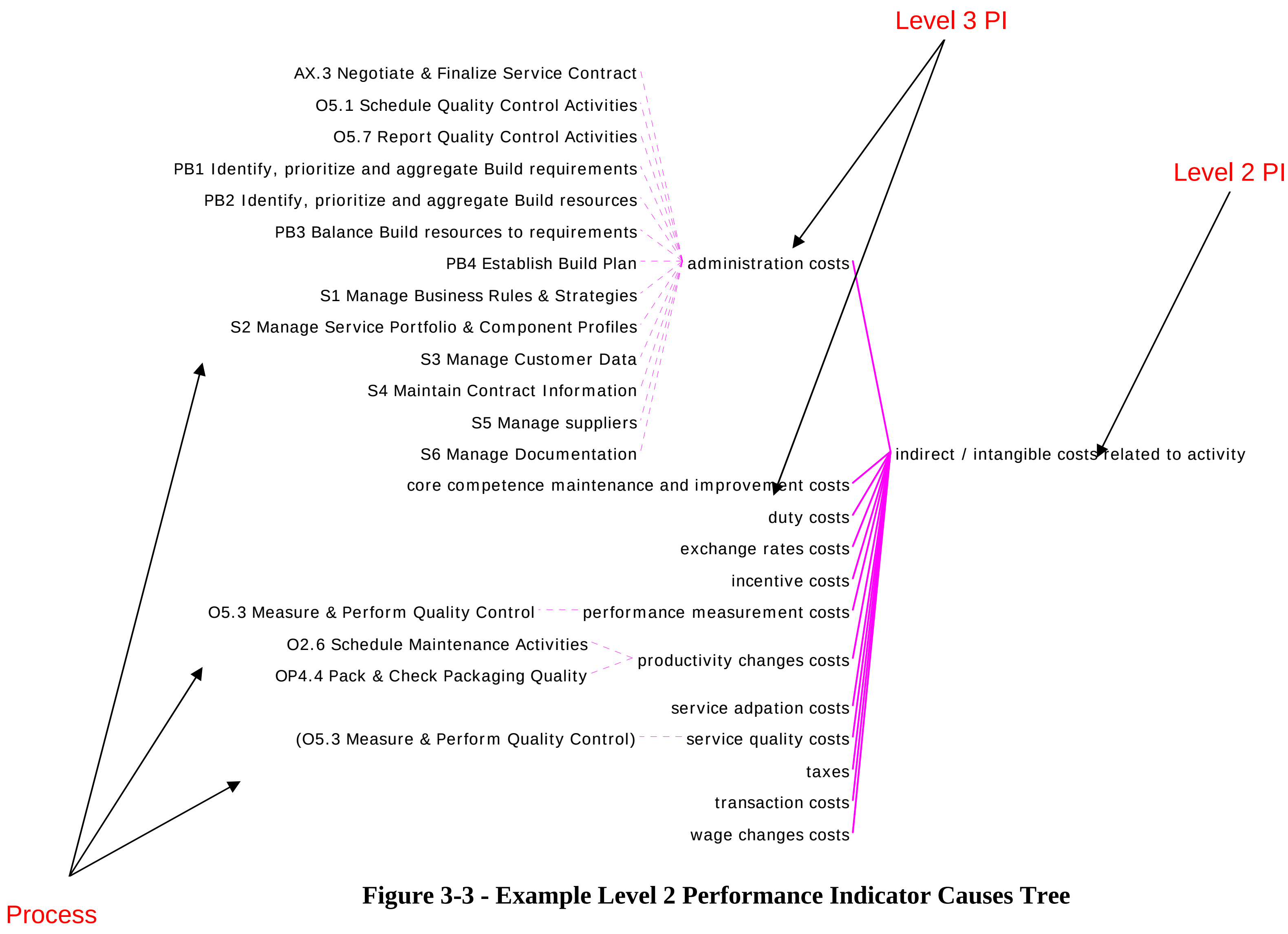

Figure 3-3 - Example Level 2 Performance Indicator Causes Tree

Methodology

This section describes the processes to be followed when considering the **cross-influences of level 2 performance indicators**. The hierarchy of PIs from level 1 down to level 3, and their interaction with level 3 processes, have been entered into a Vensim model and the Vensim tool, "*causes tree*", used to display the level 3 PIs and processes related to each of the 38 level 2 PIs of interest in this task. These have been saved as individual "PDF" documents.

- Print each of the PDF documents, one for each of the 38 level 2 PIs of interest (plus an overall causal tree listing the hierarchy down to level 2, called "Service Encounter.pdf").
- Arrange print-outs on a large table, in the following order;

PI	Name	
1	New launches of services	Effectiveness / Reliability
2	New service performance accuracy	
3	Use of new technologies	
4	Service interaction reliability	
5	Service operating input quality	
6	Service operating input quantity	
7	Service operating output quality	
8	Service operating output quantity	
9	Service object input quality	
10	Service object input quantity	
11	Service object output quality	
12	Service object output quantity	
13	Service adapt flexibility	Flexibility
14	Service build flexibility	
15	Service interaction flexibility	
16	Service operate adaptability	
17	Service operate flexibility	
18	Resource adaptability to modifications of the service object	

PI	Name	
	production/operation process	
19	Resource flexibility in service operations	
20	Upside SOURCE/MAKE/DELIVER adaptability	
21	Service object production/operating flexibility	
22	Service adapt cycle time	Responsiveness / Time
23	Service build cycle time	
24	Service interaction cycle time	
25	Service operate cycle time	
26	Administration time	
27	Interoperation time	
28	Production/operation lead time	
29	Indirect/intangible costs related to activity	Assets / Costs
30	Service adapt costs	
31	Service build costs	
32	Service interaction costs	
33	Service operate costs	
34	Consumables costs	
35	Maintenance costs (if not outsourced)	
36	Material re-work costs	
37	Production equipment charges	
38	Production labour costs	

Starting with “PI 1”, discuss and identify any influence relationships between “PI 1” and each other PI, in turn. If “PI 1” has a strong influence on “PI 2”, for example, enter a value of “2” in the relevant cell of the Interdependency Matrix (IM); cell ‘D5’ in the current version. Also consider the influence in reverse; does “PI 2” influence “PI 1” (please note that the influence, in most cases, is not the same in both directions)? The values for the Interdependency Matrix should be selected from the following, in order to signify the strength of the relationship;

0 – no or negligible influence
1 – medium influence
2 – strong influence

- The level 3 PIs and the processes listed in the causes tree support you in understanding probable relationships (you can find easy examples then) – focus on the processes which are of your cluster.
- Please check consistency of assignments while working on the table – are there indicators which would be necessary for your cluster but are not assigned? Please take notes of probable changes.
- Once a particular PI has been addressed (influences with all other PIs addressed), remove its print-out from the table.
- Rename the completed spreadsheet (adding the cluster name to the end) and return the spreadsheet and supporting notes.

4 Consolidated Results: Interdependency Matrix

This section details the results of the interdependency exercise undertaken by each of the clusters in the InCoCo-S project. An analysis of the Interdependency Matrices is presented and the section concludes with an overall interpretation of the results.

The following definitions are used:

Interdependence Categories:

- **Active and isolated**: Intervention, Controlling
  Interventions here can have a huge impact on other PIs. Therefore, they are levers that can be used to influence a system in a targeted way. For a targeted intervention, the interdependencies should be analyzed thoroughly in order to assess its impact.
- **Active and cross-linked**: Accelerators, selective interventions
  Selective interventions here are crucial and may be used as accelerators of trends. There may be feedback loops that intensify the impact. Therefore, such interventions should be used with precaution in order to prevent undesired side effects by analyzing the interdependencies thoroughly. In particular, such PIs may be influenced via their drivers
- **Passive and isolated**: Stabilizers, Monitoring
  Since such PIs show influences with delays, they are stabilizers and should be used for long term monitoring. Interventions in order to improve the whole system do not make much sense here. In some cases, isolated measures can be used in order to improve a certain PI in this area.
- **Passive and cross-linked**: Indicators, Monitoring
  *Such PIs should primarily used as indicators for monitoring the status of a system on a mid or long term basis. In order to improve them, drivers have to be identified and interventions should be primarily made there***.**

Performance Indicator Categories:

- Effectiveness / Reliability
- Flexibility
- Responsiveness / Time
- Assets / Costs

4.1 Packaging Cluster

Of the 38 Level 2 Performance Indicators (PIs), 33 (87%) were considered in this cluster. Of these 33, 17 were active and 16 passive. Of the 17 active PIs, 9 (27%) were considered *active and isolated* with PIs 18, 19 and 21 being the most notable (all within the *Flexibility* category of PIs).

Figure 4-1 shows a summary of the allocation of PI interdependency types across the 4 PI categories considered while Figure 4-2 describes each PI in turn.

	Effectiveness / Reliability	Flexibility	Responsiveness / Time	Assets / Costs	
Active and Cross - Linked	6	1	1	0	***8***
Active and Isolated	1	4	4	0	***9***
Passive and Cross - Linked	2	0	0	0	***2***
Passive and Isolated	2	2	2	8	***14***

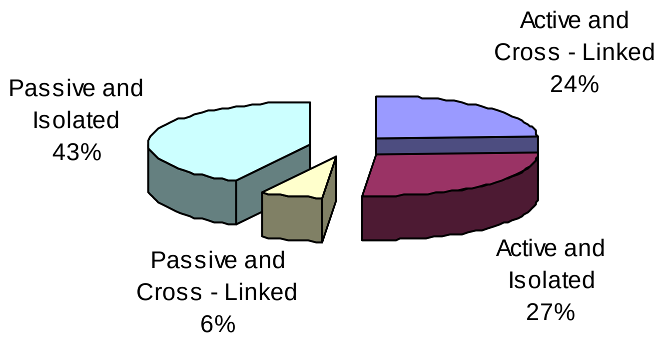

Figure 4-1: Packaging Cluster PI Interdependency Summary

PI #	**PI Name**	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
1	New launches of services		✓		
2	New service performance accuracy				✓
3	Use of new technologies				
4	Service interaction reliability		✓		
5	Service operating input quality		✓		
6	Service operating input quantity		✓		
7	Service operating output quality	✓			
8	Service operating output quantity				✓
9	Service object input quality			✓	
10	Service object input quantity		✓		
11	Service object output quality		✓		
12	Service object output quantity			✓	
13	Service adapt flexibility			✓	
14	Service build flexibility				
15	Service interaction flexibility		✓		
16	Service operate adaptability			✓	
17	Service operate flexibility	✓			
18	Resource adaptability to modifications of the service object production/operation process	✓			
19	Resource flexibility in service operations	✓			
20	Upside SOURCE/MAKE/DELIVER adaptability				
21	Service object production/operating	✓			

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
	flexibility				
22	Service adapt cycle time	✓			
23	Service build cycle time			✓	
24	Service interaction cycle time	✓			
25	Service operate cycle time		✓		
26	Administration time			✓	
27	Interoperation time	✓			
28	Production/operation lead time	✓			
29	Indirect/intangible costs related to activity			✓	
30	Service adapt costs			✓	
31	Service build costs			✓	
32	Service interaction costs			✓	
33	Service operate costs			✓	
34	Consumables costs			✓	
35	Maintenance costs (if not outsourced)				
36	Material re-work costs				
37	Production equipment charges			✓	
38	Production labour costs			✓	

Figure 4-2: Packaging Cluster PI Interdependencies Table

Packaging Cluster Reasons for Strong Influence

During this exercise the packaging cluster manager and industry partner entered descriptive reasons for all entries in the IM judged to be a strong influence (value = 2). Figure 4-4 illustrates the packaging cluster IM with colour codes for all "strong" influences, the colour code chart, with reasons, can be seen at Figure 4-5.

For example, PI 19, *resource flexibility in service operations* has a strong influence on PI 1, *new launches of services*; the reason; *adaptability and flexibility are basis for developing new services or performing services on higher service level*. The same reason is given for the strong influence of *resource flexibility in service operations* on PI 2, *new service performance accuracy*.

In another example, *service interaction reliability* (PI 4) has a strong influence on *service adapt cycle time* (PI 22), *service build cycle time* (PI 23), *service interaction cycle time* (PI 24) and *service operate cycle time* (PI 25). The higher the interaction reliability in terms of availability and quality of shared information with customers and other service providers (3rd party suppliers), the fewer communication loops are necessary to ensure a timely delivery of material and man power. Another interesting observation is the strong interrelation between service adaptability/flexibility and the ability to launch new services (PI1) and to perform existing services to a higher level of performance (PI7). This is due to the fact that, e.g. better Resource flexibility in service operations (PI 19) comprising higher education level, number of languages spoken and investments in personnel trainings result in advanced service operations performance. This connection expresses the importance of staff trainings for the ability to offer new services (e.g. taking over of the complete packaging process) and the efficient processing of regular services. In addition, PI 19 has a medium impact on almost every Level 2 PI across the different target areas (cost and reliability) highlighting the power of PI 19 (active and isolated) to influence the system in a targeted way.

The most common reason given for a strong influence is that enhanced quality or accuracy of a process results in higher effort and/or cost. Such strong interdependencies account for 23% of the packaging cluster total.

A further 21% of the strong influences are due to interdependencies in performance between pairs of PIs. For example, *service operate cycle time* (PI 25) has strong influence on *service object input quality* (PI 9), *service object input quantity* (PI 10), *service object output quality* (PI 11) and *service object output quantity* (PI 11).

Another 18% are a result of the performance indicators being very similar. For example, *service interaction flexibility* (PI 15) and *service operate flexibility* (PI 17). This might suggest a future rationalisation of the PIs.

11% of the strong influences are due to the relationship between adaptability / flexibility and the ability to develop new services and to perform existing services to a higher level of performance. A typical example is in the strong influence of *service adapt flexibility* (PI 13) on *new launches of services* (PI 1).

10% of the strong influences are due to *high reliability on service partners results in high performance accuracy (and vice versa)*. For example, *service interaction reliability* (PI 4) has a strong influence on *service adapt cycle time* (PI 22), *service build cycle time* (PI 23), *service interaction cycle time* (PI 24) and *service operate cycle time* (PI 25).

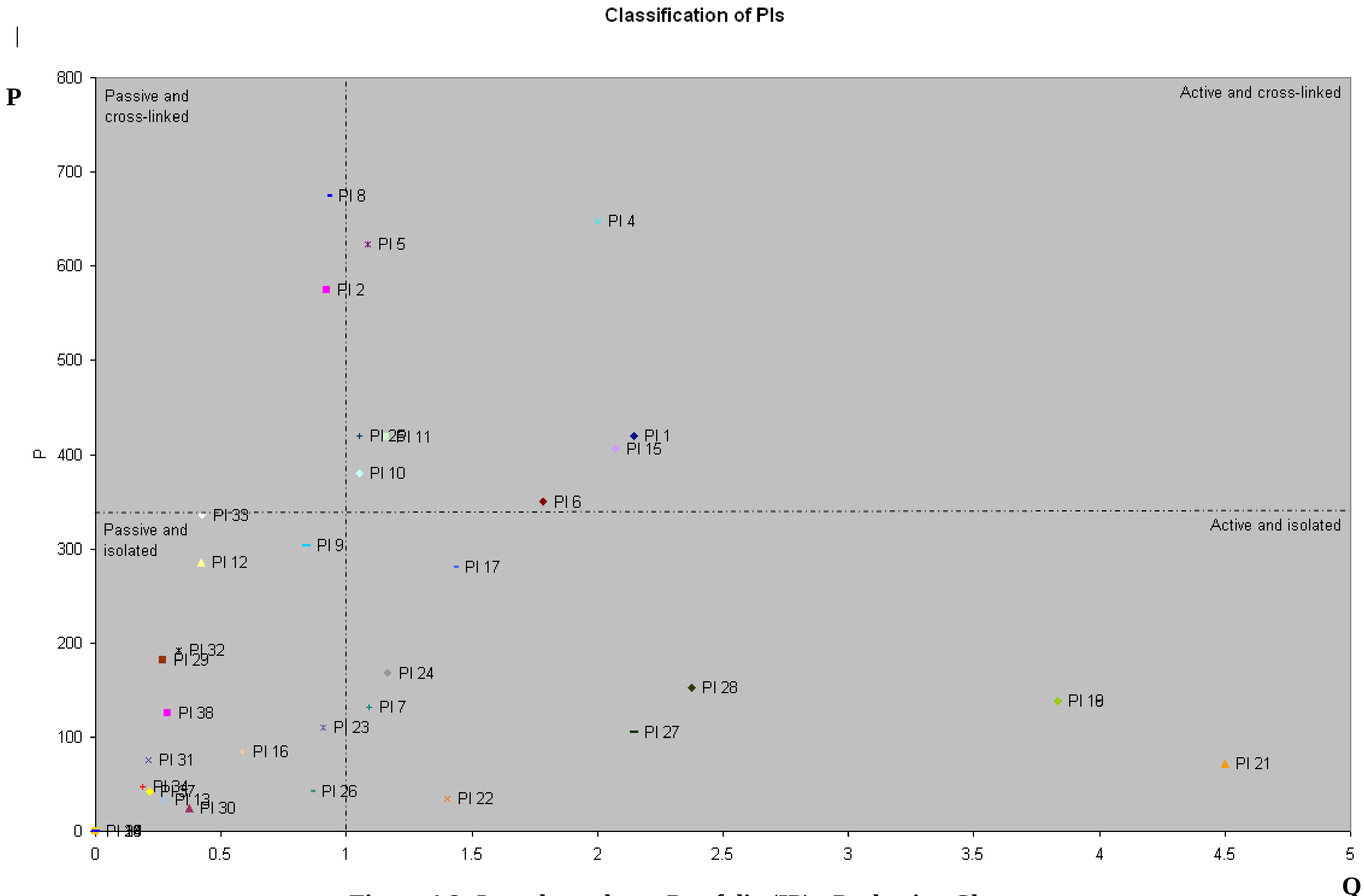

Figure 4-3: Interdependency Portfolio (IP) - Packaging Cluster

Influence of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	AS
PI 1		0	0	1	2	1	2	2	2	2	2	1	1	0	1	1	1	0	1	0	0	0	1	0	0	2	0	0	1	0	2	2	1	0	0	0	0	1	30
PI 2	0		0	1	0	0	1	1	1	1	2	2	0	0	1	0	0	1	1	0	1	0	0	0	1	0	1	1	1	0	0	2	2	1	0	0	0	1	23
PI 3	0	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
PI 4	0	1	0		2	2	2	2	1	1	2	2	0	0	0	2	2	0	0	0	0	2	2	2	2	1	0	0	1	2	2	2	1	0	0	0	0	0	36
PI 5	0	1	0	2		2	2	2	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	2	2	2	1	0	0	0	0	26
PI 6	0	2	0	2	2		0	2	1	2	0	2	0	0	0	1	1	0	0	0	0	0	1	1	2	0	2	2	0	0	1	0	1	0	0	0	0	0	25
PI 7	0	2	0	2	2	0		2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	12
PI 8	0	1	0	2	2	0	2		2	2	2	2	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	2	1	0	0	0	1	25
PI 9	0	1	0	1	1	0	0	2		2	0	2	0	0	0	0	0	0	0	0	1	0	1	0	2	0	0	0	1	0	1	0	1	0	0	0	0	0	16
PI 10	0	2	0	1	0	0	0	2	2		0	2	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	1	2	0	0	2	2	20
PI 11	1	2	0	0	1	0	0	2	1	0		2	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	1	0	1	1	2	1	0	0	1	2	22
PI 12	0	0	0	0	1	0	0	2	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0	0	2	1	11
PI 13	2	0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
PI 14	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 15	2	2	0	1	1	1	0	2	0	0	0	0	2	0		2	2	2	2	0	0	1	1	2	0	1	0	0	1	1	1	2	0	0	0	0	0	0	29
PI 16	0	0	0	0	0	0	0	0	1	0	1	1	2	0	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
PI 17	1	0	0	0	0	1	0	1	1	0	1	1	2	0	2	1		1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	1	1	0	0	1	1	20
PI 18	2	2	0	0	0	1	1	1	0	1	1	0	2	0	2	1	1		2	0	0	0	1	0	1	0	0	1	1	0	0	1	1	0	0	0	0	0	23
PI 19	2	2	0	0	0	1	1	1	0	0	1	0	2	0	2	0	1	2		0	0	1	1	0	1	0	0	1	1	0	1	0	1	0	0	0	0	1	23
PI 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 21	1	1	0	0	1	1	0	1	1	1	0	2	0	0	0	0	2	0	0	0		0	0	0	0	0	1	0	1	0	1	0	1	1	0	0	1	1	18
PI 22	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	7
PI 23	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		2	0	0	0	0	0	0	2	2	0	0	0	0	0	0	10
PI 24	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2		1	1	0	0	1	0	2	2	1	0	0	0	0	0	14
PI 25	0	1	0	0	2	1	0	0	2	2	2	2	0	0	0	1	1	0	0	0	0	0	0	0		0	0	0	2	0	0	1	2	1	0	0	0	1	21
PI 26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0		0	0	2	0	0	1	0	0	0	0	0	0	6
PI 27	0	1	0	0	0	0	0	0	1	2	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0		2	0	0	0	0	0	1	0	0	2	2	15
PI 28	0	1	0	0	1	0	0	0	1	2	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	2		0	0	0	0	2	2	0	0	2	2	19
PI 29	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	1	0	0	0	0	1	7
PI 30	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	1	0	0	0	0	0	0	3
PI 31	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0		1	0	0	0	0	0	0	4
PI 32	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1		1	0	0	0	0	0	8
PI 33	0	0	0	0	1	2	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1		1	0	0	1	1	12
PI 34	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	1	3
PI 35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
PI 36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
PI 37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0		2	3
PI 38	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	2		6
PS	14	25	0	18	24	14	11	27	19	19	19	26	11	0	14	12	14	6	6	0	4	5	11	12	20	7	7	8	26	8	19	24	28	16	0	0	14	21	

Figure 4-4: Packaging Cluster IM with Reasons

Colour Code	Reason	Count	(%)
	new processes need some time to get used to	6	4%
	adaptability and flexibility are basis for developing new services or performing services on higher service level	16	11%
	more complexity needs more administration	1	1%
	more processes to introduce leads to higher costs	2	1%
	high reliability on service partners results in high performance accuracy (and vice cersa)	14	10%
	correlation is strong because the indicators are pretty similar	25	18%
	quality (accuracy) of process performance results in higher effort/costs	32	23%
	high reliability on service partners indicates a high availability (and vice versa)	7	5%
	non-avalability leads to wrong/delayed services	5	4%
	plan/schedule incorporates availability	1	1%
	maintaining a high availability requires high costs	1	1%
	a good process performance has direct impact on the related (process) indicator	30	21%

Figure 4-5: Colour key to packaging cluster "high" IM entries

4.2 Maintenance Cluster (SKF)

Of the 38 Level 2 Performance Indicators (PIs), 21 (55%) were considered in this cluster. Of these 21, 11 were active, and 10 passive. All of the 11 active PIs (52%) were considered *active and isolated* with PIs 31 to 33 being the most notable (all within the *Assets / Costs* category of PIs).

Figure 4-6 shows a summary of the allocation of PI interdependency types across the 4 PI categories considered while Figure 4-7 describes each PI in turn.

	Effectiveness / Reliability	Flexibility	Responsiveness / Time	Assets / Costs	
Active and Cross - Linked	0	0	0	0	***0***
Active and Isolated	3	2	0	6	***11***
Passive and Cross - Linked	1	0	0	0	***1***
Passive and Isolated	3	2	4	0	***9***

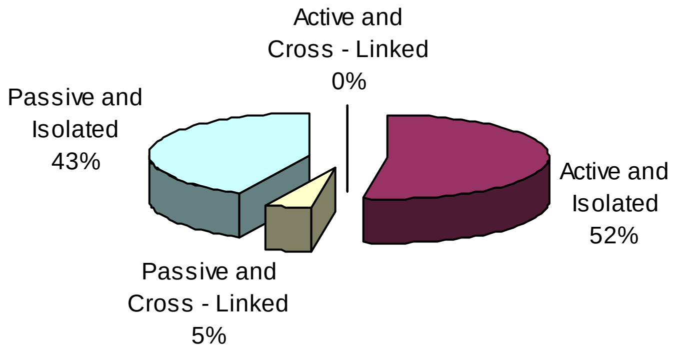

Figure 4-6: Maintenance Cluster(SKF) PI Interdependency Summary

PI #	PI Name	Active and Isolated: *Intervention, Controlling*	Active and cross-linked: *Accelerators, selective interventions*	Passive and isolated: *Stabilizers, Monitoring*	Passive and cross-linked: *Indicators, Monitoring*
1	New launches of services				
2	New service performance accuracy				
3	Use of new technologies				
4	Service interaction reliability				✓
5	Service operating input quality			✓	
6	Service operating input quantity				
7	Service operating output quality			✓	
8	Service operating output quantity	✓			
9	Service object input quality			✓	
10	Service object input quantity	✓			
11	Service object output quality	✓			
12	Service object output quantity				
13	Service adapt flexibility			✓	
14	Service build flexibility				
15	Service interaction flexibility				✓
16	Service operate adaptability	✓			
17	Service operate flexibility	✓			
18	Resource adaptability to modifications of the service object production/operation process				
19	Resource flexibility in service operations				
20	Upside SOURCE/MAKE/DELIVER adaptability				

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
21	Service object production/operating flexibility				
22	Service adapt cycle time			✓	
23	Service build cycle time			✓	
24	Service interaction cycle time			✓	
25	Service operate cycle time			✓	
26	Administration time				
27	Interoperation time				
28	Production/operation lead time				
29	Indirect/intangible costs related to activity	✓			
30	Service adapt costs	✓			
31	Service build costs	✓			
32	Service interaction costs	✓			
33	Service operate costs	✓			
34	Consumables costs				
35	Maintenance costs (if not outsourced)				
36	Material re-work costs				
37	Production equipment charges				
38	Production labour costs	✓			

Figure 4-7: Maintenance Cluster (SKF) PI Interdependencies Table

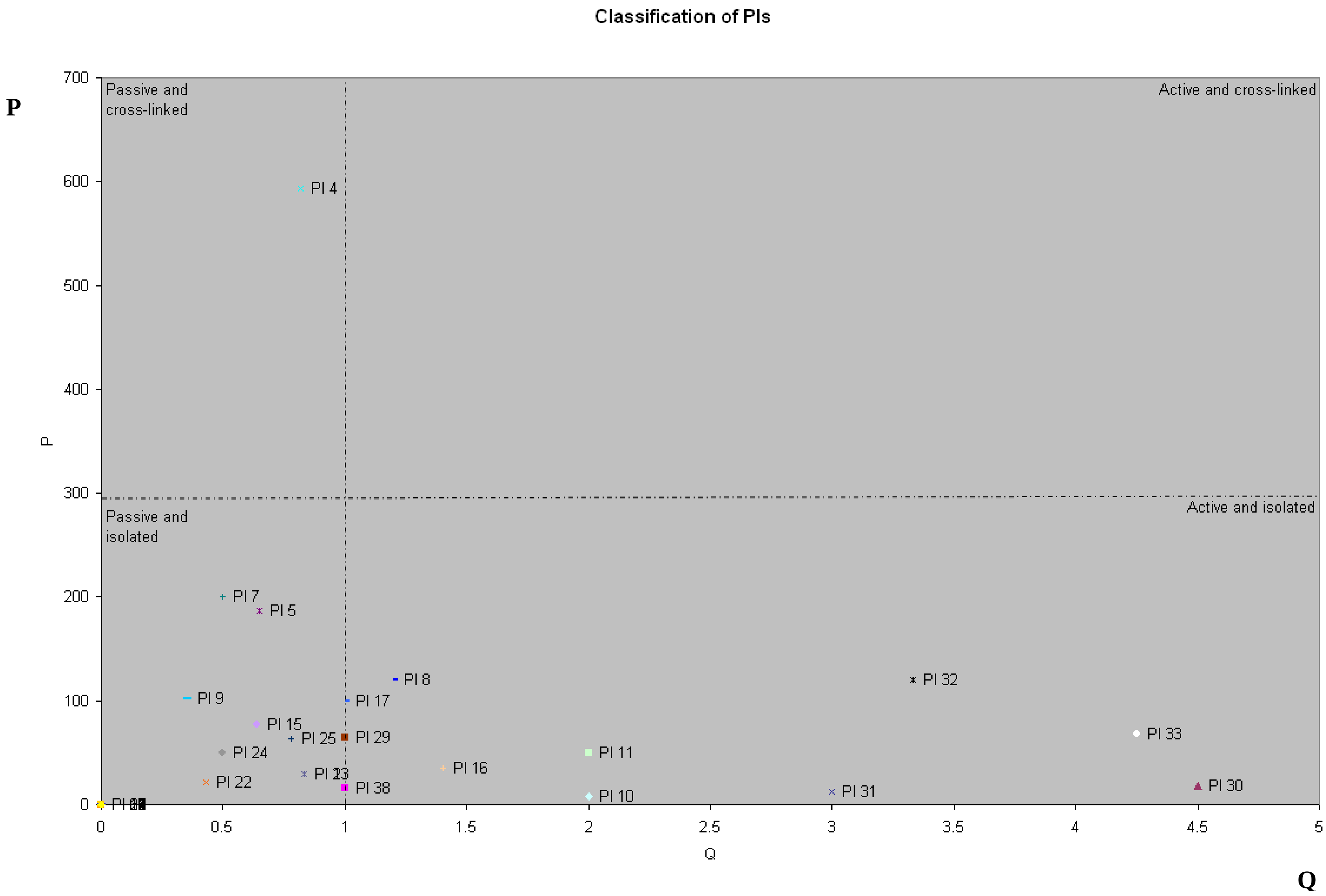

Figure 4-8: Interdependency Portfolio (IP) - Maintenance Cluster (SKF)

4.3 Maintenance Cluster (Comau)

Of the 38 Level 2 Performance Indicators (PIs), 36 (95%) were considered in this cluster. Of these 36, 17 were active, 19 passive and 14 (39%) were considered *active and isolated* with PIs 3, 4, 18 and 19 being the most notable.

Figure 4-9 shows a summary of the allocation of PI interdependency types across the 4 PI categories considered while Figure 4-10 describes each PI in turn.

	Effectiveness / Reliability	Flexibility	Responsiveness / Time	Assets / Costs	
Active and Cross - Linked	1	0	0	2	***3***
Active and Isolated	5	6	0	3	***14***
Passive and Cross - Linked	1	0	1	1	***3***
Passive and Isolated	5	2	6	3	***16***

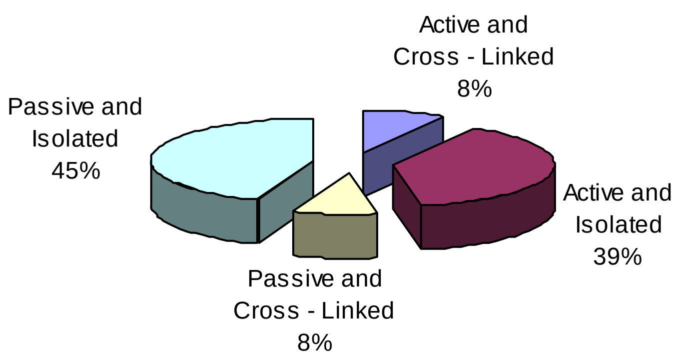

Figure 4-9: Maintenance Cluster(Comau) PI Interdependency Summary

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
1	New launches of services	✓			
2	New service performance accuracy				✓
3	Use of new technologies	✓			
4	Service interaction reliability	✓			
5	Service operating input quality	✓			
6	Service operating input quantity	✓			
7	Service operating output quality		✓		
8	Service operating output quantity			✓	
9	Service object input quality			✓	
10	Service object input quantity			✓	
11	Service object output quality			✓	
12	Service object output quantity			✓	
13	Service adapt flexibility	✓			
14	Service build flexibility	✓			
15	Service interaction flexibility	✓			
16	Service operate adaptability			✓	
17	Service operate flexibility			✓	
18	Resource adaptability to modifications of the service object production/operation process	✓			
19	Resource flexibility in service operations	✓			
20	Upside SOURCE/MAKE/DELIVER adaptability				

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
21	Service object production/operating flexibility	✓			
22	Service adapt cycle time			✓	
23	Service build cycle time			✓	
24	Service interaction cycle time			✓	
25	Service operate cycle time				✓
26	Administration time			✓	
27	Interoperation time			✓	
28	Production/operation lead time			✓	
29	Indirect/intangible costs related to activity		✓		
30	Service adapt costs	✓			
31	Service build costs	✓			
32	Service interaction costs		✓		
33	Service operate costs				✓
34	Consumables costs				
35	Maintenance costs (if not outsourced)			✓	
36	Material re-work costs			✓	
37	Production equipment charges	✓			
38	Production labour costs			✓	

Figure 4-10: Maintenance Cluster (Comau) PI Interdependencies Table

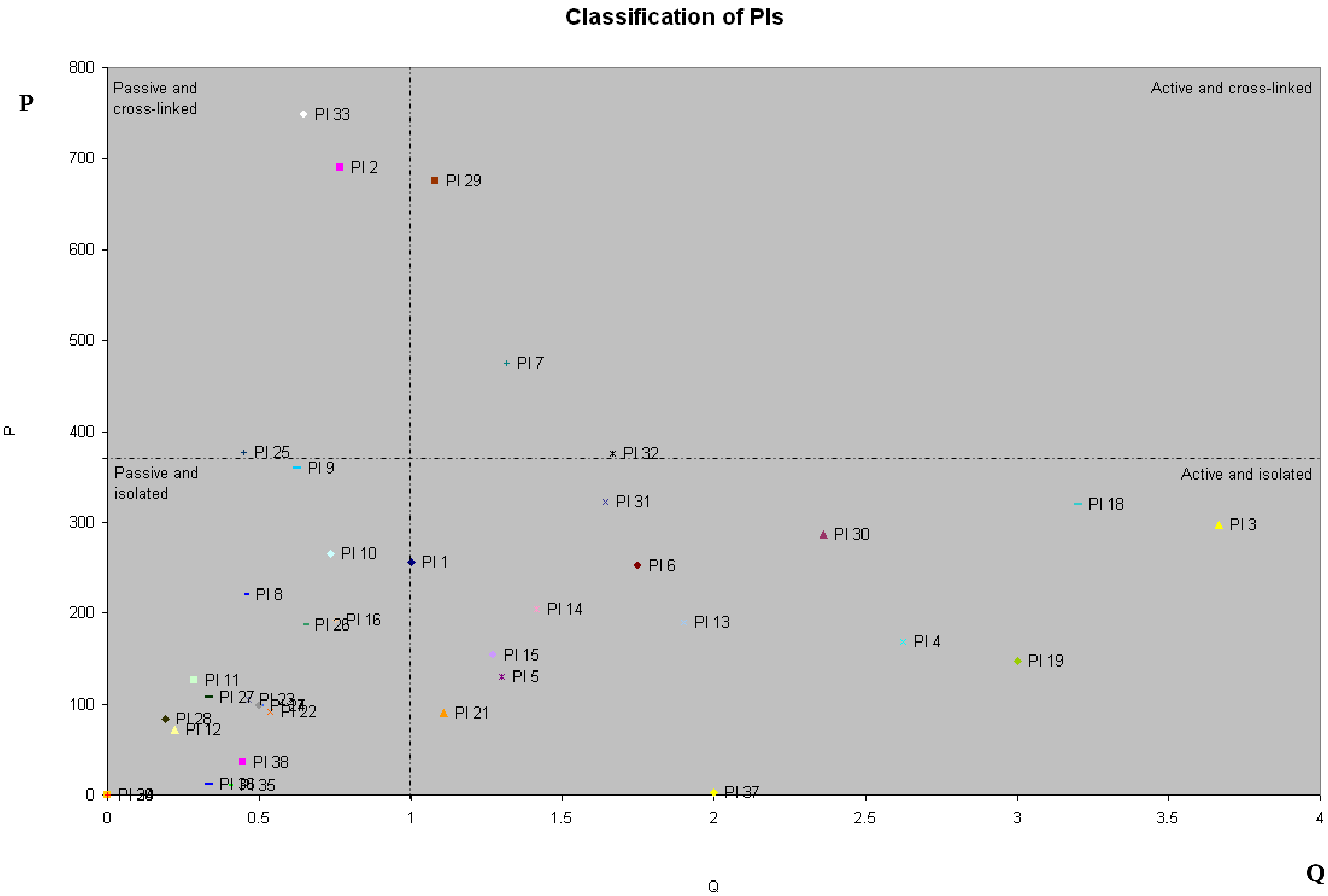

Figure 4-11: Interdependency Portfolio (IP) - Maintenance Cluster (Comau)

4.4 Retrofit Cluster

Of the 38 Level 2 Performance Indicators (PIs), 17 (45%) were considered in this cluster. Of these 17, 10 were active and 7 passive. Of this 7 only 1 (6%) PI was considered *active and isolated* namely PI 26, *Administration Time*.

Figure 4-12 shows a summary of the allocation of PI interdependency types across the 4 PI categories considered while Figure 4-13 describes each PI in turn.

	Effectiveness / Reliability	Flexibility	Responsiveness / Time	Assets / Costs	
Active and Cross - Linked	3	3	3	0	***9***
Active and Isolated	0	0	1	0	***1***
Passive and Cross - Linked	1	0	0	5	***6***
Passive and Isolated	0	0	0	1	***1***

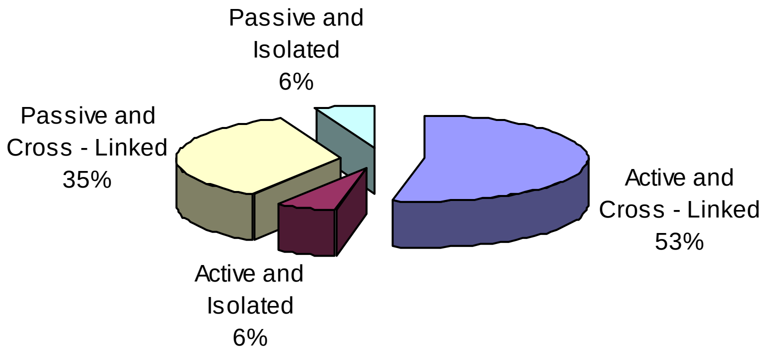

Figure 4-12: Retrofit Cluster PI Interdependency Summary

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
1	New launches of services				
2	New service performance accuracy				
3	Use of new technologies				
4	Service interaction reliability				
5	Service operating input quality		✓		
6	Service operating input quantity				
7	Service operating output quality				
8	Service operating output quantity		✓		
9	Service object input quality		✓		
10	Service object input quantity				
11	Service object output quality				✓
12	Service object output quantity				
13	Service adapt flexibility		✓		
14	Service build flexibility				
15	Service interaction flexibility				
16	Service operate adaptability		✓		
17	Service operate flexibility		✓		
18	Resource adaptability to modifications of the service object production/operation process				
19	Resource flexibility in service operations				
20	Upside SOURCE/MAKE/DELIVER adaptability				

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
21	Service object production/operating flexibility				
22	Service adapt cycle time				
23	Service build cycle time		✓		
24	Service interaction cycle time		✓		
25	Service operate cycle time		✓		
26	Administration time	✓			
27	Interoperation time				
28	Production/operation lead time				
29	Indirect/intangible costs related to activity			✓	
30	Service adapt costs				✓
31	Service build costs				✓
32	Service interaction costs				✓
33	Service operate costs				✓
34	Consumables costs				
35	Maintenance costs (if not outsourced)				
36	Material re-work costs				
37	Production equipment charges				
38	Production labour costs				✓

Figure 4-13: Retrofit Cluster PI Interdependencies Table

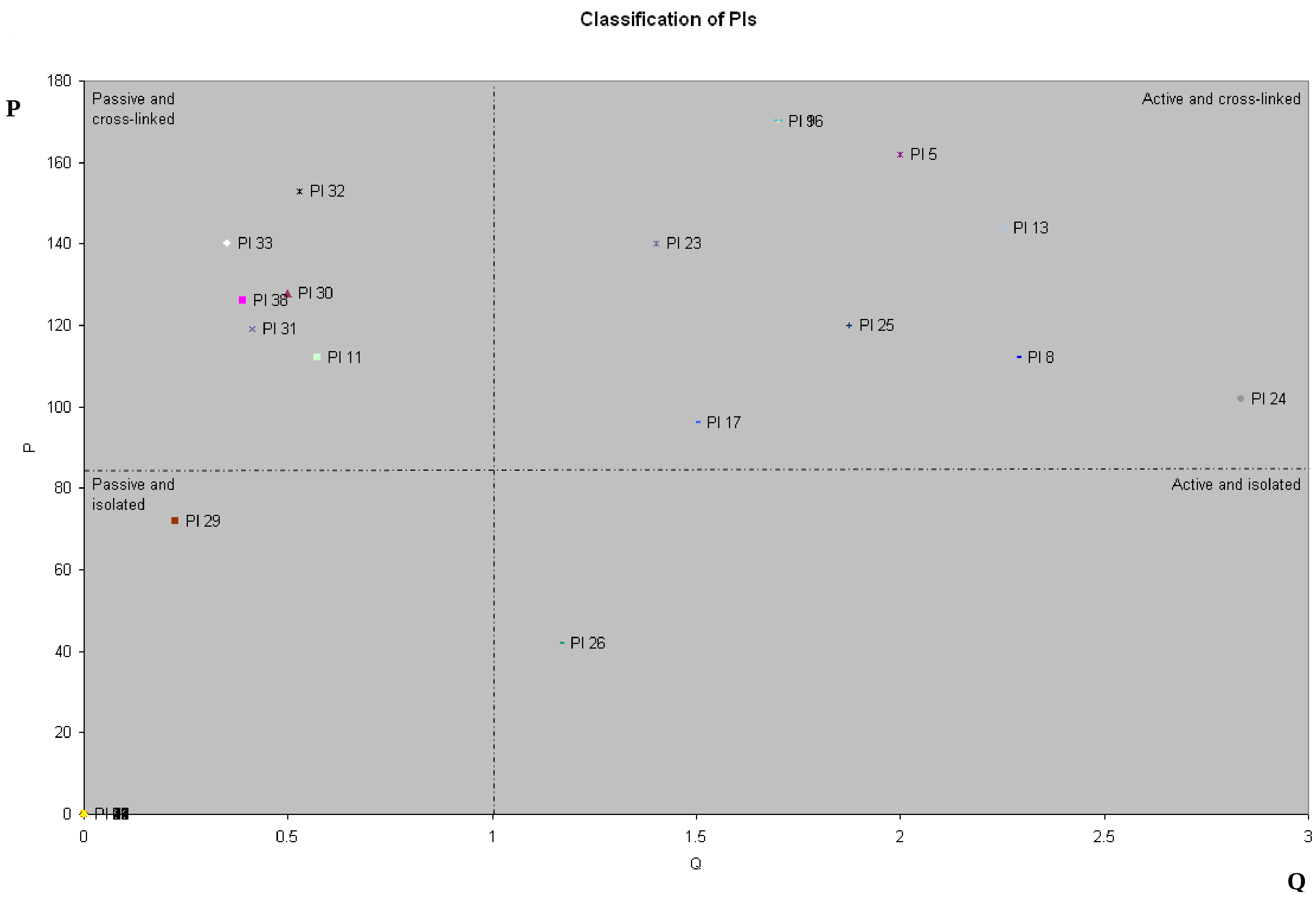

Figure 4-14: Interdependency Portfolio (IP) - Retrofit Cluster

4.5 Quality Control Cluster

Of the 38 Level 2 Performance Indicators (PIs), 28 (74%) were considered in this cluster. Of these 28, 14 were active and 14 passive. Of the 14 active PIs,13 (46%) were considered *active and isolated* with PIs 18 and 19 being the most notable.

Figure 4-15 shows a summary of the allocation of PI interdependency types across the 4 PI categories considered while Figure 4-16 describes each PI in turn.

	Effectiveness / Reliability	Flexibility	Responsiveness / Time	Assets / Costs	
Active and Cross - Linked	1	0	0	0	***1***
Active and Isolated	5	4	4	0	***13***
Passive and Cross - Linked	1	0	0	0	***1***
Passive and Isolated	4	1	1	7	***13***

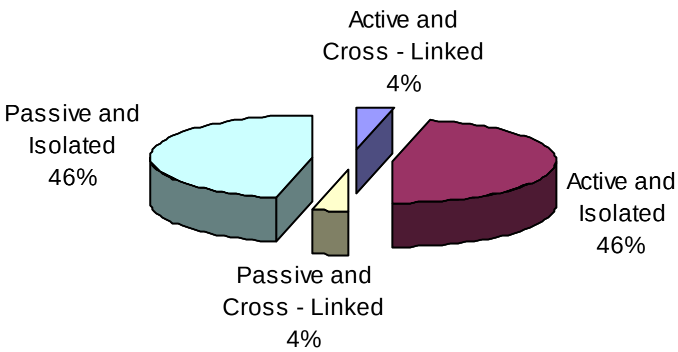

Figure 4-15: Quality Control Cluster PI Interdependency Summary

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
1	New launches of services	✓			
2	New service performance accuracy				✓
3	Use of new technologies				
4	Service interaction reliability		✓		
5	Service operating input quality	✓			
6	Service operating input quantity	✓			
7	Service operating output quality	✓			
8	Service operating output quantity			✓	
9	Service object input quality			✓	
10	Service object input quantity	✓			
11	Service object output quality			✓	
12	Service object output quantity			✓	
13	Service adapt flexibility			✓	
14	Service build flexibility				
15	Service interaction flexibility	✓			
16	Service operate adaptability				
17	Service operate flexibility	✓			
18	Resource adaptability to modifications of the service object production/operation process	✓			
19	Resource flexibility in service operations	✓			
20	Upside SOURCE/MAKE/DELIVER adaptability				

PI #	PI Name	**Active and Isolated:** *Intervention, Controlling*	**Active and cross-linked:** *Accelerators, selective interventions*	**Passive and isolated:** *Stabilizers, Monitoring*	**Passive and cross-linked:** *Indicators, Monitoring*
21	Service object production/operating flexibility				
22	Service adapt cycle time	✓			
23	Service build cycle time	✓			
24	Service interaction cycle time	✓			
25	Service operate cycle time	✓			
26	Administration time			✓	
27	Interoperation time				
28	Production/operation lead time				
29	Indirect/intangible costs related to activity			✓	
30	Service adapt costs			✓	
31	Service build costs			✓	
32	Service interaction costs			✓	
33	Service operate costs			✓	
34	Consumables costs				
35	Maintenance costs (if not outsourced)				
36	Material re-work costs			✓	
37	Production equipment charges				
38	Production labour costs			✓	

Figure 4-16: Quality Control Cluster PI Interdependencies Table

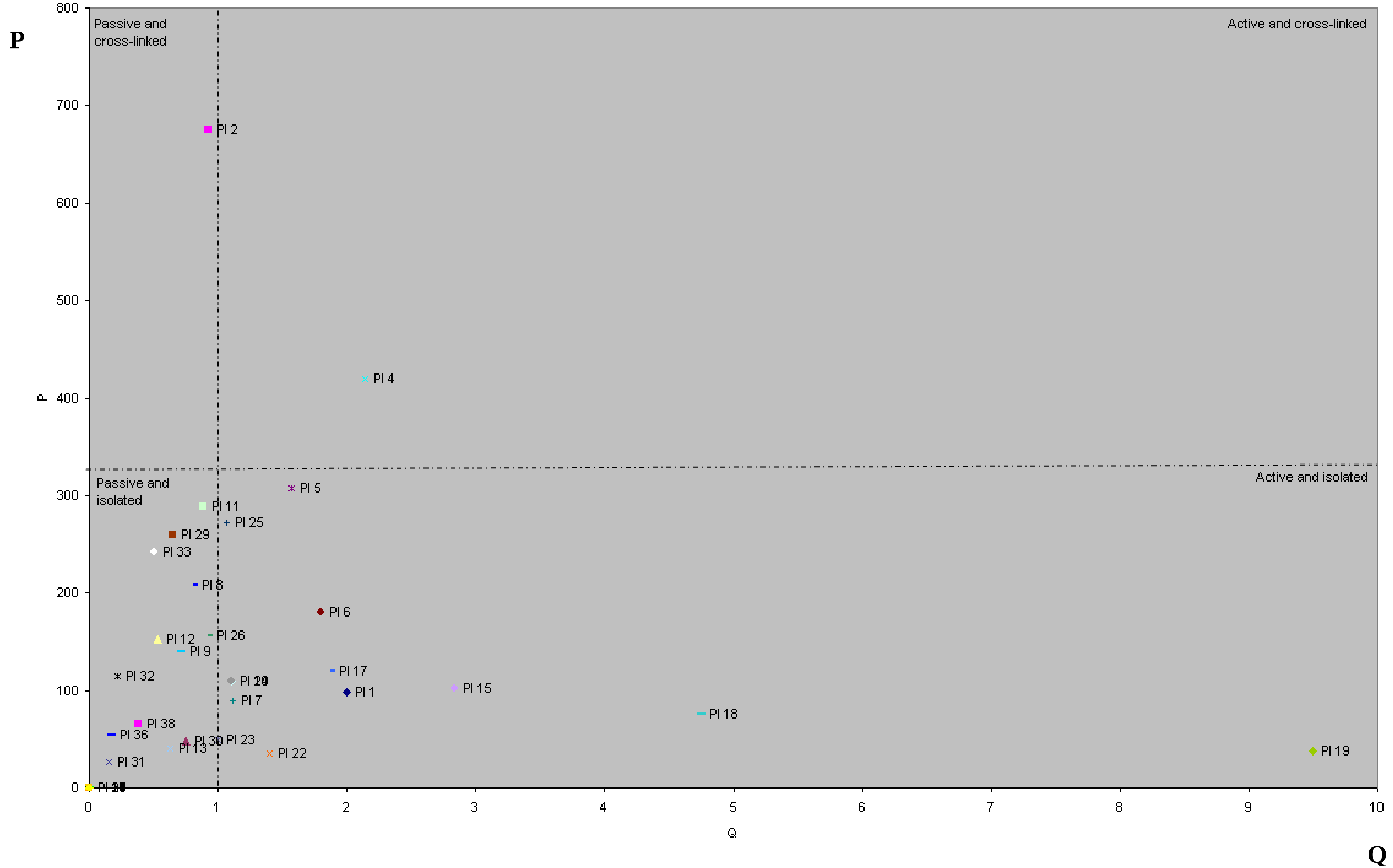

Figure 4-17: Interdependency Portfolio (IP) – Quality Control Cluster

4.6 Interpretation

This section provides an evaluation of the results of the Interdependency exercise undertaken by the cluster managers and industry partners.

4.6.1 Active Performance Indicators – Cluster Analysis

Active performance indicators are those with influence on many other indicators and, as such, can be used to improve not only the particular indicator itself, but those it influences.

Table 4-1 shows a simple analysis of *active* PIs across all of the clusters. A “1” is entered whenever a particular PI has been classified as *active* for a particular cluster, and the total number of clusters in which the PI appears as *active* listed.

Table 4-2, however, shows the results of analysing for *active, isolated* PIs across all clusters. In this case, a “1” is entered if the PI is *active and isolated.*

A comparison between the clusters reveals that they all have approximately 50% of the PIs categorised as *active*; that is, they can be used in interventions in the system (Table 4-3). With the exception of the retrofit and packaging clusters, the majority of active PIs are *isolated* and can be used in targeted improvement of the performance of the service cluster. Only 6% of the PIs in the retrofit cluster are *active and isolated*, while there are roughly equal numbers of *isolated* and *linked* active PIs in the packaging cluster.

Retrofit Cluster Intervention

The retrofit cluster contains very few performance indicators to drive process improvement without having to account for the interdependency of those indicators with others; that is, plans to improve performance of these PIs need careful attention to the likely knock-on effect on other performance areas in order to avoid unintended consequences.

	Packaging	Maintenance (SKF)	Maintenance (Comau)	Retrofit	Quality Control	Total Active
PI 1	**1**	0	**1**	0	**1**	3
PI 2	0	0	0	0	0	0
PI 3	0	0	**1**	0	0	1
PI 4	**1**	0	**1**	0	**1**	3
PI 5	**1**	0	**1**	**1**	**1**	4
PI 6	**1**	0	**1**	0	**1**	3
PI 7	**1**	0	**1**	0	**1**	3
PI 8	0	**1**	0	**1**	0	2
PI 9	0	0	0	**1**	0	1
PI 10	**1**	**1**	0	0	**1**	3
PI 11	**1**	**1**	0	0	0	2
PI 12	0	0	0	0	0	0
PI 13	0	0	**1**	**1**	0	2
PI 14	0	0	**1**	0	0	1
PI 15	**1**	0	**1**	0	**1**	3
PI 16	0	**1**	0	**1**	0	2
PI 17	**1**	**1**	0	**1**	**1**	4
PI 18	**1**	0	**1**	0	**1**	3
PI 19	**1**	0	**1**	0	**1**	3
PI 20	0	0	0	0	0	0
PI 21	**1**	0	**1**	0	0	2
PI 22	**1**	0	0	0	**1**	2
PI 23	0	0	0	**1**	**1**	2
PI 24	**1**	0	0	**1**	**1**	3
PI 25	**1**	0	0	**1**	**1**	3
PI 26	0	0	0	**1**	0	1
PI 27	**1**	0	0	0	0	1
PI 28	**1**	0	0	0	0	1
PI 29	0	**1**	**1**	0	0	2
PI 30	0	**1**	**1**	0	0	2
PI 31	0	**1**	**1**	0	0	2
PI 32	0	**1**	**1**	0	0	2
PI 33	0	**1**	0	0	0	1
PI 34	0	0	0	0	0	0
PI 35	0	0	0	0	0	0
PI 36	0	0	0	0	0	0
PI 37	0	0	**1**	0	0	1
PI 38	0	**1**	0	0	0	1
	17	11	17	10	14	

Table 4-1: Analysis of *active* Performance Indicators across clusters

	Packaging	Maintenance (SKF)	Maintenance (Comau)	Retrofit	Quality Control	Total Active
PI 1	0	0	**1**	0	**1**	2
PI 2	0	0	0	0	0	0
PI 3	0	0	**1**	0	0	1
PI 4	0	0	**1**	0	0	1
PI 5	0	0	**1**	0	**1**	2
PI 6	0	0	**1**	0	**1**	2
PI 7	**1**	0	0	0	**1**	2
PI 8	0	**1**	0	0	0	1
PI 9	0	0	0	0	0	0
PI 10	0	**1**	0	0	**1**	2
PI 11	0	**1**	0	0	0	1
PI 12	0	0	0	0	0	0
PI 13	0	0	**1**	0	0	1
PI 14	0	0	**1**	0	0	1
PI 15	0	0	**1**	0	**1**	2
PI 16	0	**1**	0	0	0	1
PI 17	**1**	**1**	0	0	**1**	3
PI 18	**1**	0	**1**	0	**1**	3
PI 19	**1**	0	**1**	0	**1**	3
PI 20	0	0	0	0	0	0
PI 21	**1**	0	**1**	0	0	2
PI 22	**1**	0	0	0	**1**	2
PI 23	0	0	0	0	**1**	1
PI 24	**1**	0	0	0	**1**	2
PI 25	0	0	0	0	**1**	1
PI 26	0	0	0	**1**	0	1
PI 27	**1**	0	0	0	0	1
PI 28	**1**	0	0	0	0	1
PI 29	0	**1**	0	0	0	1
PI 30	0	**1**	**1**	0	0	2
PI 31	0	**1**	**1**	0	0	2
PI 32	0	**1**	0	0	0	1
PI 33	0	**1**	0	0	0	1
PI 34	0	0	0	0	0	0
PI 35	0	0	0	0	0	0
PI 36	0	0	0	0	0	0
PI 37	0	0	**1**	0	0	1
PI 38	0	**1**	0	0	0	1
	9	11	14	1	13	

Table 4-2: Analysis of *active, isolated* Performance Indicators across Clusters

<table>
<tr><th>Cluster</th><th colspan="2">Active (Isolated, Linked)</th></tr>
<tr><td rowspan="2">Packaging</td><td colspan="2">52%</td></tr>
<tr><td>27%</td><td>25%</td></tr>
<tr><td rowspan="2">Maintenance (SKF)</td><td colspan="2">52%</td></tr>
<tr><td>52%</td><td>0%</td></tr>
<tr><td rowspan="2">Maintenance (Comau)</td><td colspan="2">47%</td></tr>
<tr><td>39%</td><td>8%</td></tr>
<tr><td rowspan="2">Retrofit</td><td colspan="2">59%</td></tr>
<tr><td>6%</td><td>53%</td></tr>
<tr><td rowspan="2">Quality Control</td><td colspan="2">50%</td></tr>
<tr><td>46%</td><td>4%</td></tr>
</table>

Table 4-3: Intervention PIs

4.6.2 Analysis by Performance Indicator

This section looks at individual PIs and their nature and prevalence across the clusters.

Universally *Passive* Performance Indicators

Only 6 of the 38 PIs considered in the task did not appear as an *active* PI in any of the cluster responses, these are listed at Table 4-4.

PI #	PI Name
2	New service performance accuracy
12	Service object output quantity
20	Upside SOURCE/MAKE/DELIVER adaptability
34	Consumables costs
35	Maintenance costs (if not outsourced)
36	Material re-work costs

Table 4-4: Performance Indicators *passive* across all clusters

These PIs are seen to be exclusively used for monitoring and not for intervention.

Most Common *Active* Performance Indicators

Two of the Performance Indicators appeared as *active* in 4 of the 5 clusters (Table 4-5). Figure 4-18 shows the causes tree for these two PIs.

A further 10 PIs appeared as *active* in 3 of the 5 clusters (Table 4-6)

PI #	PI Name
5	Service operating input quality
17	Service operate flexibility

Table 4-5: Performance Indicators *active* in 4 of 5 clusters

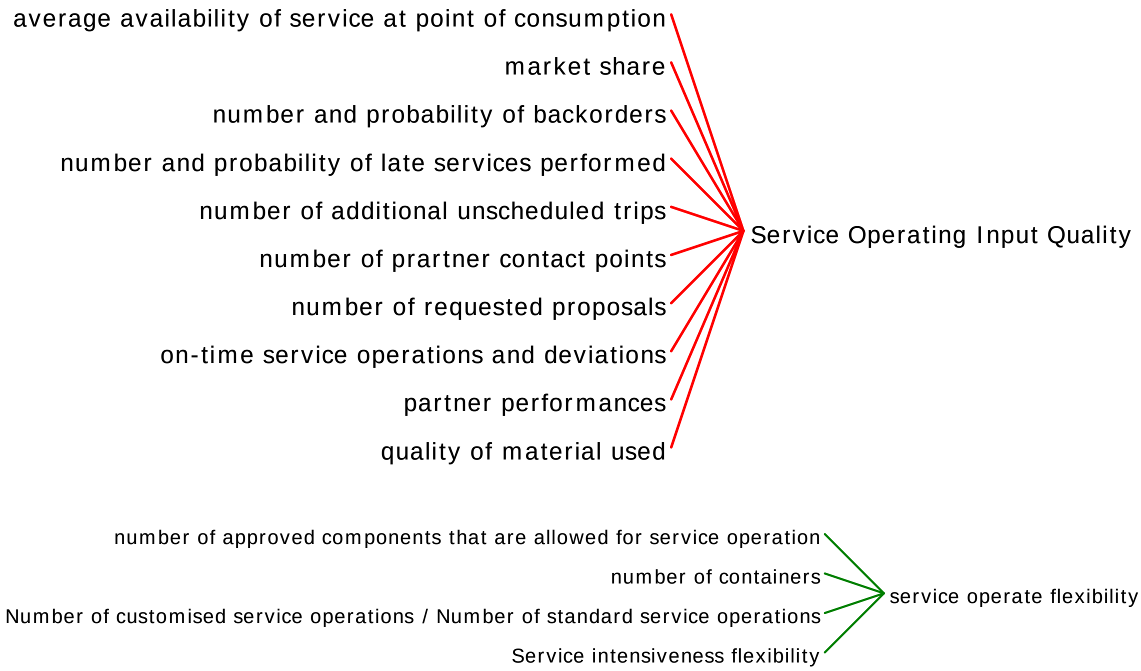

Figure 4-18: Causes trees for most common *active* PIs across clusters

PI #	PI Name
1	New launches of services
4	Service interaction reliability
6	Service operating input quantity
7	Service operating output quality
10	Service object input quantity
15	Service interaction flexibility
18	Resource adaptability to modifications of the service object production/operation process
19	Resource flexibility in service operations
24	Service interaction cycle time
25	Service operate cycle time

Table 4-6: PIs appearing as "active" in 3 of 5 clusters

Most common *Active, Isolated* Performance Indicators

Three of the level 2 performance indicators were assessed as *active, isolated* in 3 or more of the clusters (see Table 4-7). Figure 4-19 shows the causes trees for these three PIs

In the terminology of the Paper Computer, these PIs are labelled as "Intervention, Controlling". *Interventions here can have a huge impact on other PIs. Therefore, they are levers that can be used to influence a system in a targeted way. For a targeted intervention, the interdependencies should be analyzed thoroughly in order to assess its impact*

PI #	PI Name
17	Service operate flexibility
18	Resource adaptability to modifications of the service object production/operation process
19	Resource flexibility in service operations

Table 4-7: PIs appearing as *active, isolated* in 3 or more clusters

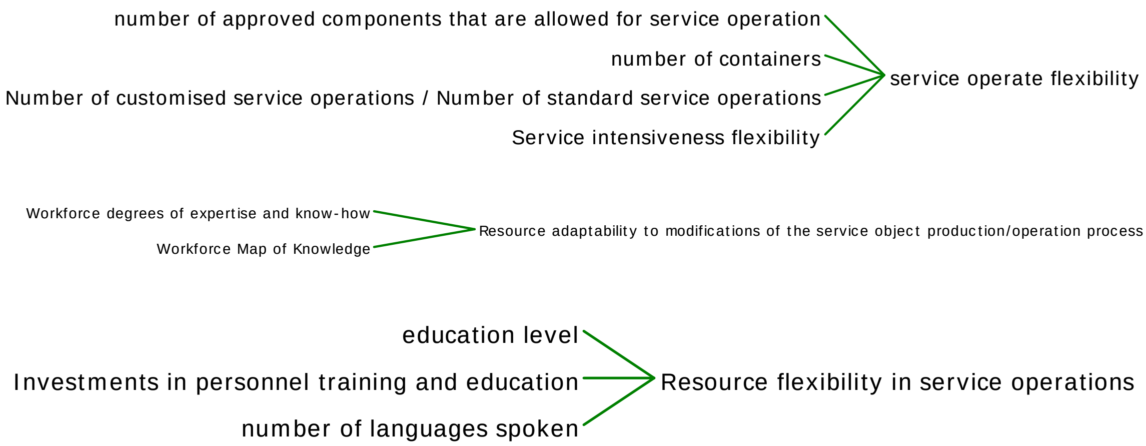

Figure 4-19: Causes trees for most common *active, isolated* PIs across clusters

As can be seen in the causal tree at Figure 4-9, improvements in the PI *resource flexibility in service operations* are influenced by such factors as *education level*, *personnel training and education* etc, obvious candidates for improvements in the behaviour of the system.

5 Conclusion and outlook

Conclusion

The methods used to elicit the interdependencies between Performance Indicators (PI) in the Service Performance Management System (SPMS) have served to highlight the strength of relationship between these measures. The results stress the importance of coordination and collaboration between service providers and their customers. Furthermore, the analysis indicates the potential for service operation improvements for service providers`. In future research activities the result will have an impact on the development of a methodology for the individual assignment (selection) of PIs to various services, as described in more detail in deliverable 4.4.

The results enable service providers to gain transparency about the influence of service activities (related PIs) on the customer benefit and show potential for service operation improvements. They enable the service provider and the client manufacturer to evaluate the potential impact of improvements, as measured by performance indicators, on other areas of their business and illustrate areas where great care should be taken to fully understand the cause-and-effect and feedback structures present in their business.

The identification of interdependencies between performance indicators is critical to the ability of two or more organisations to monitor, assess and implement improvements. The impact of interventions in one area of the business need to be understood in order to support negotiation between manufacturer and service suppliers and, ultimately, to improve perfomance of the whole system. Best practices (BP) for coordination between entities, as discussed and evaluated in Task 3.4, will have an impact on the behaviour of both the manufacturer and the service suppliers. Without this understanding of interdependence, implementing improvements in one area of a business could result in detremental effects elsewhere. Task 4.3 has highlighted the strength of interdependencies between business areas spanning both manufacturer and service provider and will, together with further work in later tasks, serve as a blueprint for understanding the coordination needs across organisational boundaries.

Outlook

The InCoCo-S project makes use of the System Dynamics (SD) approach in the understanding of complex systems. Causal Loop Diagrams (CLD) will be developed during Task 5.1 in the creation of a simulation model with the ability to analyse the relationships between elements of the service-supply system. In Task 5.2, a number of experiments with the model will be performed in order to evaluate the impact on system performance (measured using Performance Indicators) of implementing Best Practices (BP). In Task 5.3, an interactive version of the simulation model will be developed and web-enabled; providing a “gaming” or learning environment for dissemination of the key findings of the InCoCo-S project.

Further work may be required to rationalise the list of PIs, especially where there may be repetition, and to ensure that the set of relevant PIs selected for each cluster are comprehensive. The development of the System Dynamics (SD) model during Task 5.1, and its subsequent exercise during Task 5.2, will further enhance this ability to understand better the interrelationships between performance indicators spanning diverse areas of the business. The result of Task 4.3 will assist in the design, development and use of the SD simulation and further strengthen the SPMS and InCoCo-S Reference Model (IRM). The simulation model will, in turn, be used to both strengthen and validate the outcomes of this current task.

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7 Annex

7.1 Performance Indicator descriptions

PI	Name	Description	
1	New launches of services	The number of new service offers launched in a given time period.	Effectiveness / Reliability
2	New service performance accuracy	The number of accurate performances of newly introduced services, according to the service contract.	
3	Use of new technologies	The amount of services performed with using new technologies compared with the amount using commonly used technology.	
4	Service interaction reliability	The reliability of processes, where several entities take part.	
5	Service operating input quality	The quality of required resources for the service operation.	
6	Service operating input quantity	The availability of required resources for the service operation.	
7	Service operating output quality	The quality of the results of the service processes.	
8	Service operating output quantity	The number of performed services as defined in the service contract, in a given timeframe.	
9	Service object input quality	The quality of the required resources for the service object.	
10	Service object input quantity	The availability of the required resources for the service object.	
11	Service object output quality	The quality of the output of the service object.	
12	Service object output quantity	The amount of output of the service object.	
13	Service adapt flexibility	The adaptation possibility of the service offers.	Flexibility
14	Service build flexibility	The (time) flexibility in setting up a new service.	

PI	Name	Description	
15	Service interaction flexibility	The (time) flexibility in operations where several entities take part.	
16	Service operate adaptability	The (volume) adaptation possibility of service operations.	
17	Service operate flexibility	The (time) flexibility of service operations.	
18	Resource adaptability to modifications of the service object production/operation process	Self explanatory.	
19	Resource flexibility in service operations	The (time) flexibility of service resources (e.g. personnel).	
20	Upside SOURCE/MAKE/DELIVER adaptability	The (volume) adaptation possibility of a production process.	
21	Service object production/operating flexibility	The (time) flexibility of the service objects (e.g. a machine).	
22	Service adapt cycle time	The time needed for the development of a new service contract.	Responsiveness / Time
23	Service build cycle time	The time needed for setting up a new service.	Responsiveness / Time
24	Service interaction cycle time	The time needed to coordinate several entities involved in a service process.	Responsiveness / Time
25	Service operate cycle time	The time needed to perform a full service operational cycle.	Responsiveness / Time
26	Administration time	The time needed for administrating (production) processes.	Responsiveness / Time
27	Interoperation time	The time between (production) operations, e.g. waiting times.	Responsiveness / Time
28	Production/operation lead time	The time needed for producing a lot.	Responsiveness / Time

PI	Name	Description	
29	Indirect/intangible costs related to activity	Self explanatory.	Assets / Costs
30	Service adapt costs	Costs for developing new service contracts.	
31	Service build costs	Costs for setting up a new service.	
32	Service interaction costs	Costs for the coordination of all players involved in a process.	
33	Service operate costs	Costs for the operational performance of a service.	
34	Consumables costs	Costs for consumables needed during a production of a physical good.	
35	Maintenance costs (if not outsourced)	Costs for maintaining the own equipment.	
36	Material re-work costs	Self explanatory.	
37	Production equipment charges	Charges for utilizing (rented) machinery.	
38	Production labour costs	Costs for the personnel involved in production processes.	

Table 7-1: Performance Indicator Descriptions

7.2 Interdependency Matrices

This section reproduces the results of the analysis undertaken by the cluster managers supported by industry partners. An Interdependency Matrix (IM) is shown for each cluster, values in each cell denoting the strength of the influence of one PI on another. The matrices have also been colour-coded to visualise rapidly the degree of cross-influence at level 2.

Influence of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	AS
PI 1		0	0	1	2	1	2	2	2	2	2	1	1	0	1	1	1	0	1	0	0	0	1	0	0	2	0	0	1	0	2	2	1	0	0	0	0	1	30
PI 2	0		0	1	0	0	1	1	1	1	2	2	0	0	1	0	0	1	1	0	1	0	0	0	1	0	1	1	1	0	0	2	2	1	0	0	0	1	23
PI 3	0	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
PI 4	0	1	0		2	2	2	2	1	1	2	2	0	0	0	2	2	0	0	0	0	2	2	2	2	1	0	0	1	2	2	2	1	0	0	0	0	0	36
PI 5	0	1	0	2		2	2	2	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	2	2	2	1	0	0	0	0	26
PI 6	0	2	0	2	2		0	2	1	2	0	2	0	0	0	1	1	0	0	0	0	0	1	1	2	0	2	2	0	0	1	0	1	0	0	0	0	0	25
PI 7	0	2	0	2	2	0		2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	12
PI 8	0	1	0	2	2	0	2		2	2	2	2	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	2	1	0	0	0	1	25
PI 9	0	1	0	1	1	0	0	2		2	0	2	0	0	0	0	0	0	0	0	1	0	1	0	2	0	0	0	1	0	1	0	1	0	0	0	0	0	16
PI 10	0	2	0	1	0	0	0	2	2		0	2	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	1	2	0	0	2	2	20
PI 11	1	2	0	0	1	0	0	2	1	0		2	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	1	0	1	1	2	1	0	0	1	2	22
PI 12	0	0	0	0	1	0	0	2	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0	0	2	1	11
PI 13	2	0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
PI 14	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 15	2	2	0	1	1	1	0	2	0	0	0	0	2	0		2	2	2	2	0	0	1	1	2	0	1	0	0	1	1	1	2	0	0	0	0	0	0	29
PI 16	0	0	0	0	0	0	0	0	1	0	1	1	2	0	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
PI 17	1	0	0	0	0	1	0	1	1	0	1	1	2	0	2	1		1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	1	1	0	0	1	1	20
PI 18	2	2	0	0	0	1	1	1	0	1	1	0	2	0	2	1	1		2	0	0	0	1	0	1	0	0	1	1	0	0	1	1	0	0	0	0	0	23
PI 19	2	2	0	0	0	1	1	1	0	0	1	0	2	0	2	0	1	2		0	0	1	1	0	1	0	0	1	1	0	1	0	1	0	0	0	0	1	23
PI 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 21	1	1	0	0	1	1	0	1	1	1	0	2	0	0	0	0	2	0	0	0		0	0	0	0	0	1	0	1	0	1	0	1	1	0	0	1	1	18
PI 22	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	7
PI 23	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		2	0	0	0	0	0	0	2	2	0	0	0	0	0	0	10
PI 24	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2		1	1	0	0	1	0	2	2	1	0	0	0	0	0	14
PI 25	0	1	0	0	2	1	0	0	2	2	2	2	0	0	0	1	1	0	0	0	0	0	0	0		0	0	0	2	0	0	1	2	1	0	0	0	1	21
PI 26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0		0	0	2	0	0	1	0	0	0	0	0	0	6
PI 27	0	1	0	0	0	0	0	0	1	2	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0		2	0	0	0	0	0	1	0	0	2	2	15
PI 28	0	1	0	0	1	0	0	0	1	2	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	2		0	0	0	0	2	2	0	0	2	2	19
PI 29	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	1	0	0	0	0	1	7
PI 30	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	1	0	0	0	0	0	0	3
PI 31	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0		1	0	0	0	0	0	0	4
PI 32	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1		1	0	0	0	0	0	8
PI 33	0	0	0	0	1	2	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1		1	0	0	1	1	12
PI 34	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	1	3
PI 35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
PI 36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
PI 37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0		2	3
PI 38	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	2		6
PS	14	25	0	18	24	14	11	27	19	19	19	26	11	0	14	12	14	6	6	0	4	5	11	12	20	7	7	8	26	8	19	24	28	16	0	0	14	21	

Table 7-2: Interdependency Matrix - Packaging Cluster

Influence of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	AS
PI 1																																							0
PI 2																																							0
PI 3																																							0
PI 4					0		2	1	2	1	0		0		1	1	2					1	2	1	1				1	1	1	2	1					1	22
PI 5				1			0	1	0	0	1		1		1	1	1					0	0	0	2				0	0	0	1	1					0	11
PI 6																																							0
PI 7				1	2			0	1	0	2		0		0	0	1					0	0	1	2				0	0	0	0	0					0	10
PI 8				1	1		2		2	0	2		0		0	0	1					0	0	1	2				0	0	0	0	0					0	12
PI 9				2	0		1	2		1	0		0		0	0	0					0	0	0	0				0	0	0	0	0					0	6
PI 10				1	0		2	0	1		0		0		0	0	0					0	0	0	0				0	0	0	0	0					0	4
PI 11				2	2		2	2	2	0			0		0	0	0					0	0	0	0				0	0	0	0	0					0	10
PI 12																																							0
PI 13				2	1		0	0	0	0	0				0	0	0					1	0	0	0				0	1	0	0	0					0	5
PI 14																																							0
PI 15				1	1		1	0	0	0	0		0			0	1					1	0	0	0				0	0	0	1	1					0	7
PI 16				1	1		1	0	0	0	0		0		2		1					0	0	0	0				1	0	0	0	0					0	7
PI 17				2	1		2	1	1	0	0		0		1	2						0	0	0	0				0	0	0	0	0					0	10
PI 18																																							0
PI 19																																							0
PI 20																																							0
PI 21																																							0
PI 22				2	0		0	0	0	0	0		1		0	0	0						0	0	0				0	0	0	0	0					0	3
PI 23				2	0		0	0	1	0	0		0		0	0	0					0		2	0				0	0	0	0	0					0	5
PI 24				1	2		1	0	1	0	0		0		0	0	0					0	0		0				0	0	0	0	0					0	5
PI 25				1	2		0	0	1	0	0		0		1	0	2					0	0	0					0	0	0	0	0					0	7
PI 26																																							0
PI 27																																							0
PI 28																																							0
PI 29				1	0		2	0	0	0	0		1		2	1	0					1	0	0	0					0	0	0	0					0	8
PI 30				1	0		0	0	1	0	0		2		0	0	0					1	1	1	0				2		0	0	0					0	9
PI 31				1	0		0	0	1	0	0		0		0	0	0					1	0	1	0				0	0		0	0					2	6
PI 32				2	2		2	1	1	0	0		1		2	0	0					1	1	1	1				2	0	1		1					1	20
PI 33				1	2		2	2	2	0	0		0		1	0	1					0	1	1	1				2	0	0	1						0	17
PI 34																																							0
PI 35																																							0
PI 36																																							0
PI 37																																							0
PI 38				1	0		0	0		0	0				0	0	0					0	1	1	0				0	0	0	1	0						4
PS	0	0	0	27	17	0	20	10	17	2	5	0	6	0	11	5	10	0	0	0	0	7	6	10	9	0	0	0	8	2	2	6	4	0	0	0	0	4	

Table 7-3: Interdependency Matrix – Maintenance Cluster (SKF)

Influence of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	AS
PI 1		1	1	0	0	0	0	0	0	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1	0	1	1	1	1	1	1	0	1	0	0	0	16
PI 2	0		0	0	0	1	1	2	2	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	1	2	2	0	0	1	1	1	23
PI 3	1	1		1	1	1	2	1	1	0	2	1	1	1	0	1	0	0	0	0	0	1	1	1	1	1	1	0	0	2	2	1	2	0	2	1	0	2	33
PI 4	0	2	0		1	0	1	0	2	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	21
PI 5	0	2	1	0		1	2	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0	0	13
PI 6	0	2	0	0	0		1	1	2	1	0	1	1	1	1	0	1	0	0	0	1	1	1	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	21
PI 7	1	1	0	2	0	0		2	2	2	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	0	25
PI 8	0	2	0	0	0	0	0		0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	1	0	1	10
PI 9	0	2	0	0	1	1	2	2		2	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	15
PI 10	0	0	0	0	0	1	0	1	2		0	2	0	0	1	1	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	1	0	0	1	0	0	14
PI 11	0	1	0	0	0	0	0	0	0	0		1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	6
PI 12	0	1	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	4
PI 13	1	1	0	0	1	1	0	0	1	1	1	0		0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	19
PI 14	1	1	0	0	0	1	0	0	1	1	1	1	0		0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	17
PI 15	0	0	0	1	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	1	1	2	1	1	1	1	1	1	1	1	1	0	0	0	0	0	14
PI 16	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0		1	1	0	0	1	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	0	12
PI 17	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1		0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	7
PI 18	2	2	0	1	1	1	1	1	1	1	1	1	2	2	1	1	1		2	0	0	1	1	1	1	0	0	0	1	1	1	1	2	0	0	0	0	0	32
PI 19	2	2	0	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1		0	1	0	0	0	1	0	1	1	1	1	1	1	2	0	0	0	0	0	21
PI 20	1	0	1	0	1	0	0	0	0	0	0	0	1	1	1	1	1	2	1		1	0	1	1	2	0	2	1	1	1	0	0	0	0	0	0	0	0	21
PI 21	0	1	0	0	0	0	1	1	0	0	1	1	0	0	0	1	1	0	1	0		0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	10
PI 22	0	1	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0		0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	7
PI 23	0	1	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0		0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	7
PI 24	0	1	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0		0	0	0	0	1	0	0	1	0	0	0	0	0	0	7
PI 25	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	1	0	0	0		0	0	1	1	0	0	0	1	0	0	0	0	0	13
PI 26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1		0	1	1	1	1	1	1	0	0	0	0	0	11
PI 27	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		1	1	0	0	1	1	0	0	0	0	0	6
PI 28	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0		1	0	0	0	1	0	0	0	0	0	4
PI 29	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	1	27
PI 30	1	0	1	0	1	1	1	1	1	1	1	1	2	1	0	1	1	1	0	0	0	2	1	0	1	1	1	1	0		1	0	1	0	0	0	0	1	26
PI 31	1	0	1	0	1	1	1	1	1	1	1	1	0	2	0	1	1	1	0	0	0	0	2	0	1	1	1	1	0	0		0	1	0	0	0	0	1	23
PI 32	1	0	1	2	1	1	1	1	1	1	1	1	0	0	2	1	1	1	0	0	1	0	0	2	1	1	1	1	0	0	0		0	0	0	0	0	1	25
PI 33	1	0	1	0	0	0	2	2	1	1	1	1	0	0	0	2	2	1	1	0	1	0	0	0	2	1	1	1	0	0	0	0		0	0	0	0	0	22
PI 34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1		0	0	0	0	2
PI 35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0		0	0	0	2
PI 36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0		0	0	2
PI 37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0		0	2
PI 38	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0		4
PS	16	30	9	8	10	12	19	22	24	19	21	18	10	12	11	16	14	10	7	0	9	13	15	14	29	17	18	21	25	11	14	15	34	0	5	6	1	9	

Table 7-4: Interdependency Matrix – Maintenance Cluster (Comau)

Influence of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	AS
PI 1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 3	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 4	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 5	0	0	0	0		0	0	0	2	0	2	0	1	0	0	1	0	0	0	0	0	0	2	0	2	1	0	0	1	0	1	1	2	0	0	0	0	2	18
PI 6	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 7	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
PI 8	0	0	0	0	0	0	0		2	0	1	0	0	0	0	0	0	0	0	0	0	0	2	1	2	0	0	0	1	1	1	1	2	0	0	0	0	2	16
PI 9	0	0	0	0	2	0	0	0		0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	2	0	0	0	1	1	2	1	2	0	0	0	0	1	17
PI 10	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 11	0	0	0	0	2	0	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	8
PI 12	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 13	0	0	0	0	0	0	0	2	0	0	2	0		0	0	2	2	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	1	18
PI 14	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 16	0	0	0	0	2	0	0	1	1	0	2	0	1	0	0		1	0	0	0	0	0	1	0	0	1	0	0	1	1	0	1	2	0	0	0	0	2	17
PI 17	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0	1		0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	0	0	1	12
PI 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 23	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	1	0	0	0	0	0		0	0	1	0	0	1	1	2	2	1	0	0	0	0	1	14
PI 24	0	0	0	0	1	0	0	1	1	0	1	0	1	0	0	1	1	0	0	0	0	0	1		1	1	0	0	2	1	1	1	1	0	0	0	0	1	17
PI 25	0	0	0	0	1	0	0	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1		1	0	0	1	1	0	1	2	0	0	0	0	2	15
PI 26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0		0	0	2	2	1	0	1	0	0	0	0	0	7
PI 27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
PI 28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0
PI 29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	1	0	0	0	0	0	4
PI 30	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1		1	1	1	0	0	0	0	1	8
PI 31	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1		1	1	0	0	0	0	1	7
PI 32	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2	1	1		1	0	0	0	0	1	9
PI 33	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1		0	0	0	0	1	7
PI 34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0
PI 35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
PI 36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
PI 37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
PI 38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	1	0	0	0	0		7
PS	0	0	0	0	9	0	0	7	10	0	14	0	8	0	0	10	8	0	0	0	0	0	10	6	8	6	0	0	18	16	17	17	20	0	0	0	0	18	

Table 7-5: Interdependency Matrix – Retrofit Cluster

Influence of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	AS
PI 1		1	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	1	0	2	2	1	0	0	0	0	1	14
PI 2	0		0	1	0	0	1	1	1	1	2	2	0	0	1	0	0	0	0	0	0	0	1	1	2	2	0	0	2	0	2	2	2	0	0	0	0	1	25
PI 3	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 4	0	2	0		2	1	2	1	1	1	2	0	0	1	0	0	1	1	0	0	0	1	2	2	1	2	0	0	1	0	1	1	2	0	0	1	0	1	30
PI 5	0	1	0	1		2	1	2	0	2	2	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	1	1	0	1	1	0	0	2	0	1	22
PI 6	1	1	0	1	1		0	2	1	2	0	2	0	0	0	0	1	0	0	0	0	0	1	1	2	0	0	0	0	0	1	0	1	0	0	0	0	0	18
PI 7	0	2	0	0	1	0		2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	10
PI 8	0	1	0	1	0	0	2		0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	2	0	0	13
PI 9	0	1	0	1	0	0	1	0		2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	1	0	0	0	0	0	10
PI 10	0	1	0	1	0	0	0	0	2		0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0	0	1	11
PI 11	0	2	0	1	0	0	0	2	1	0		1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	1	2	0	0	2	0	1	16
PI 12	0	2	0	0	0	0	0	2	1	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	9
PI 13	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	5
PI 14	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 15	1	2	0	0	1	1	0	0	0	0	0	0	1	0		0	1	0	0	0	0	0	0	0	1	1	0	0	1	1	1	2	1	0	0	1	0	1	17
PI 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 17	0	0	0	1	1	1	0	1	1	0	0	0	2	0	2	0		1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	1	0	0	15
PI 18	1	1	0	0	1	1	1	1	0	0	2	1	1	0	1	0	1		2	0	0	0	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	19
PI 19	1	1	0	0	1	1	0	1	0	0	1	1	1	0	1	0	1	2		0	0	1	1	0	1	0	0	0	1	0	0	1	0	0	0	1	0	1	19
PI 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PI 22	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	2	0	0	1	2	0	0	0	0	0	0	0	0	7
PI 23	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	1	0	0	0	0	2	1	0	0	0	0	0	0	7
PI 24	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0		1	1	0	0	1	0	1	1	1	0	0	1	0	0	11
PI 25	0	1	0	1	0	0	0	0	2	2	1	2	0	0	1	0	1	0	0	0	0	0	0	1		0	0	0	2	0	0	1	0	0	0	1	0	1	17
PI 26	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0		0	0	2	1	1	2	0	0	0	1	0	1	12
PI 27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
PI 28	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	1
PI 29	0	0	0	1	2	0	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	1	0	0	1	0	1	13
PI 30	1	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0		0	1	0	0	0	0	0	0	6
PI 31	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0	0	2
PI 32	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	1	0	0	5
PI 33	0	1	0	0	1	2	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	1	0	1	11
PI 34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0
PI 35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
PI 36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0		0	0	3
PI 37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
PI 38	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0		5
PS	7	27	0	14	14	10	9	16	14	10	18	17	8	1	6	0	8	4	2	0	0	5	7	10	16	13	0	0	20	8	13	23	22	0	0	18	0	13	

Table 7-6: Interdependency Matrix – Quality Control Cluster

7.3 Vensim Model Diagrams

This section contains the Vensim diagrams created from the InCoCo-S Reference Model (IRM) and Service Performance Management System (SPMS) developed in earlier InCoCo-S tasks. Vensim's causal tracing tools can analyse the structure of the developed model to provide causes trees to assist in the discussion of interdependencies between performance indicators.

The Vensim diagrams display the current process flow at Level 3 in the IRM together with their relevant performance indicators (PI). The level 3 PIs have also been liked to the hierarchy of PIs developed in the SPMS and combined in the Vensim model.

These model diagrams will assist in the design of the simulation model developed in Workpackage 5, in that the process flow, connected by inputs and outputs, will help the developers understand the mechanics of each cluster. The subsequent simulation model will enable the consortium to further analyse the correlations between performance indicators and disseminate the results.

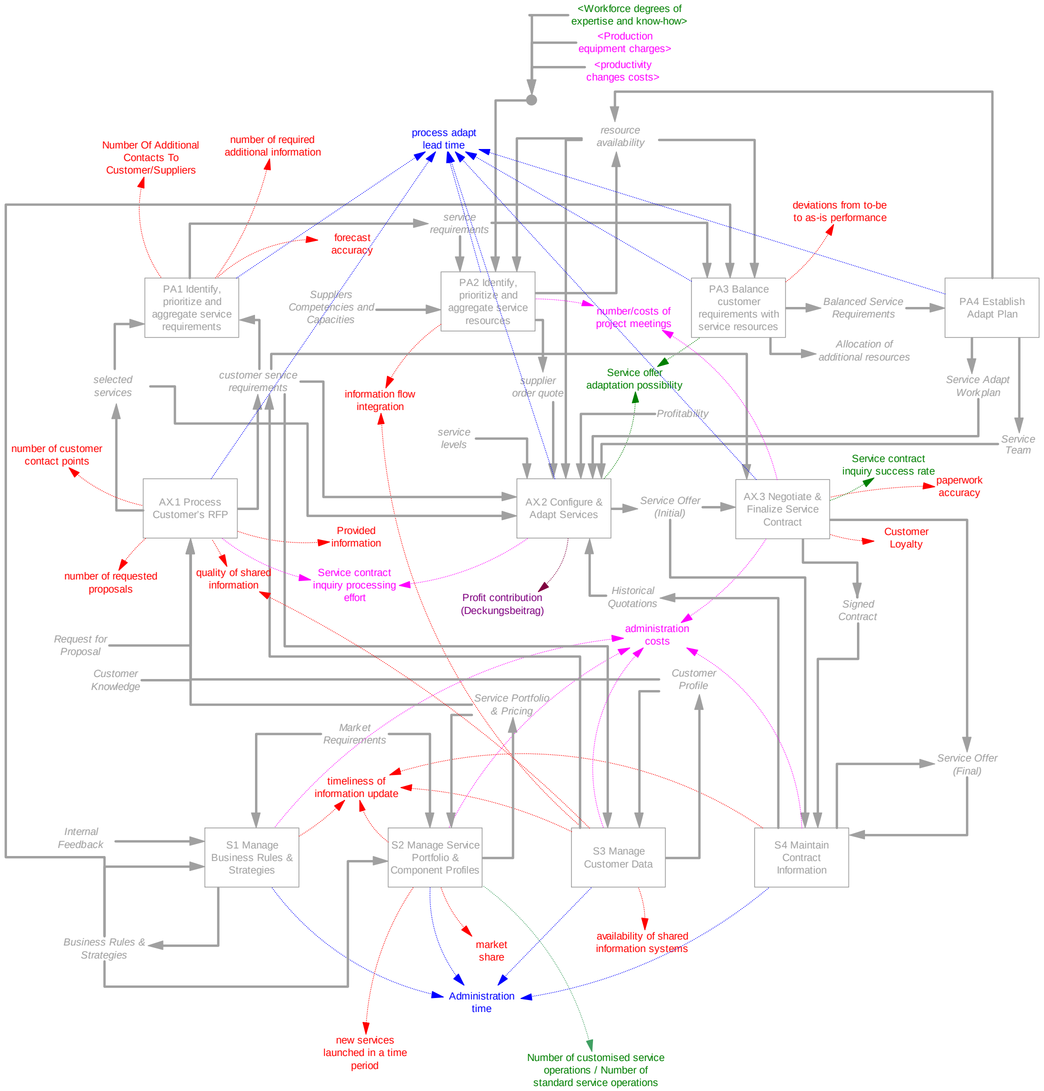

Figure 7-1: Vensim Model View; Adapt

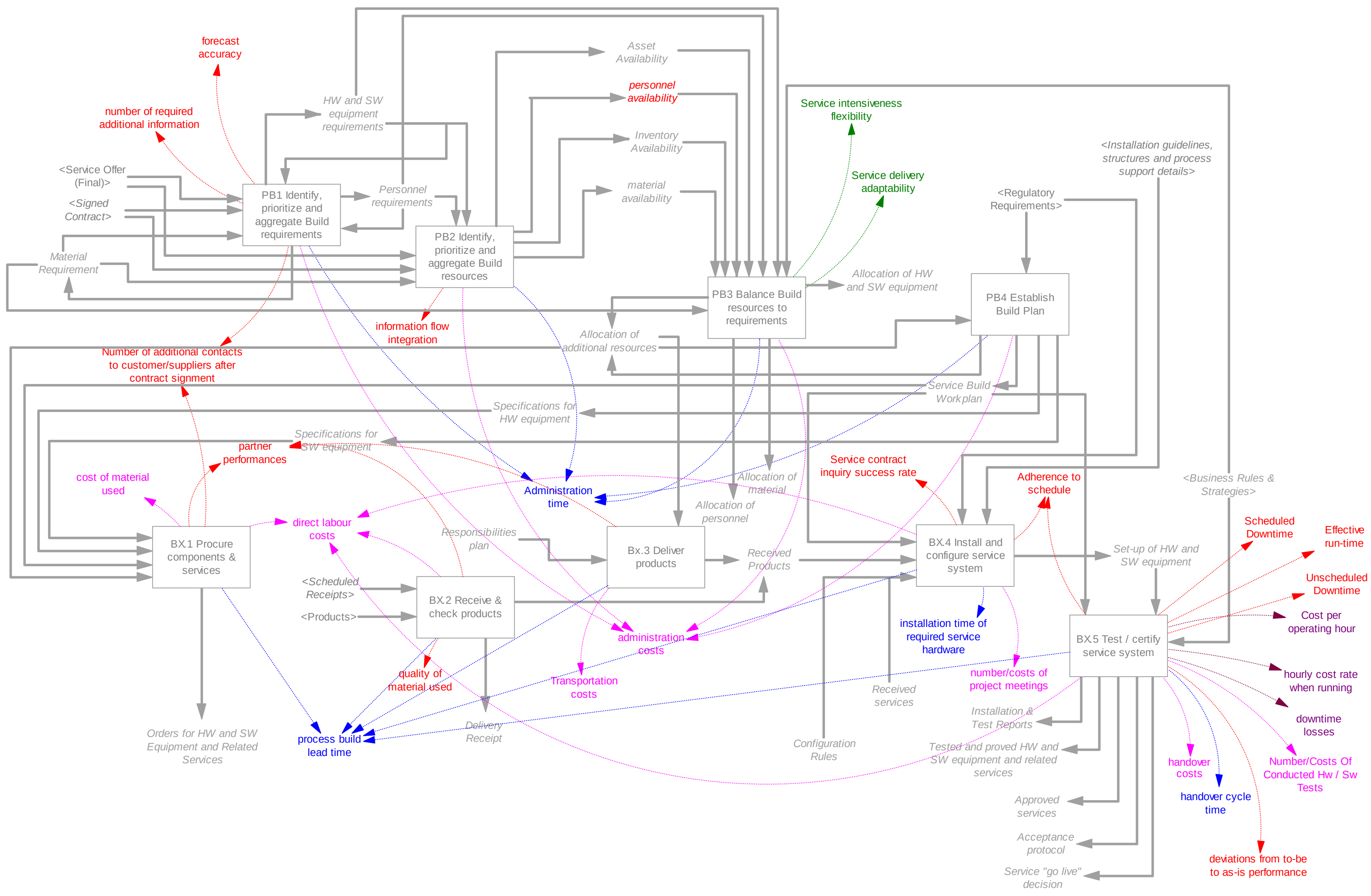

Figure 7-2: Vensim Model View; Build

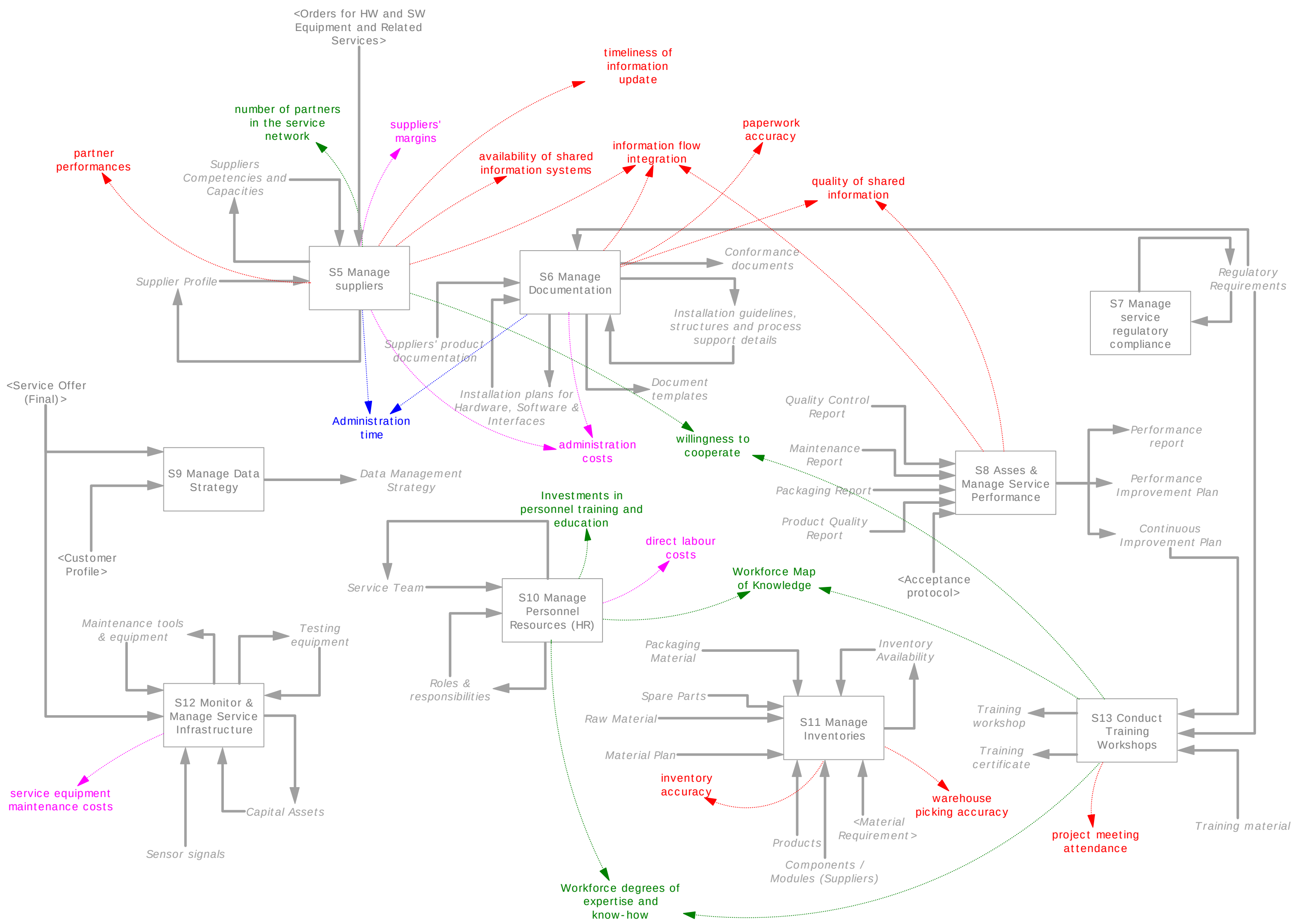

Figure 7-3: Vensim Model View; Support

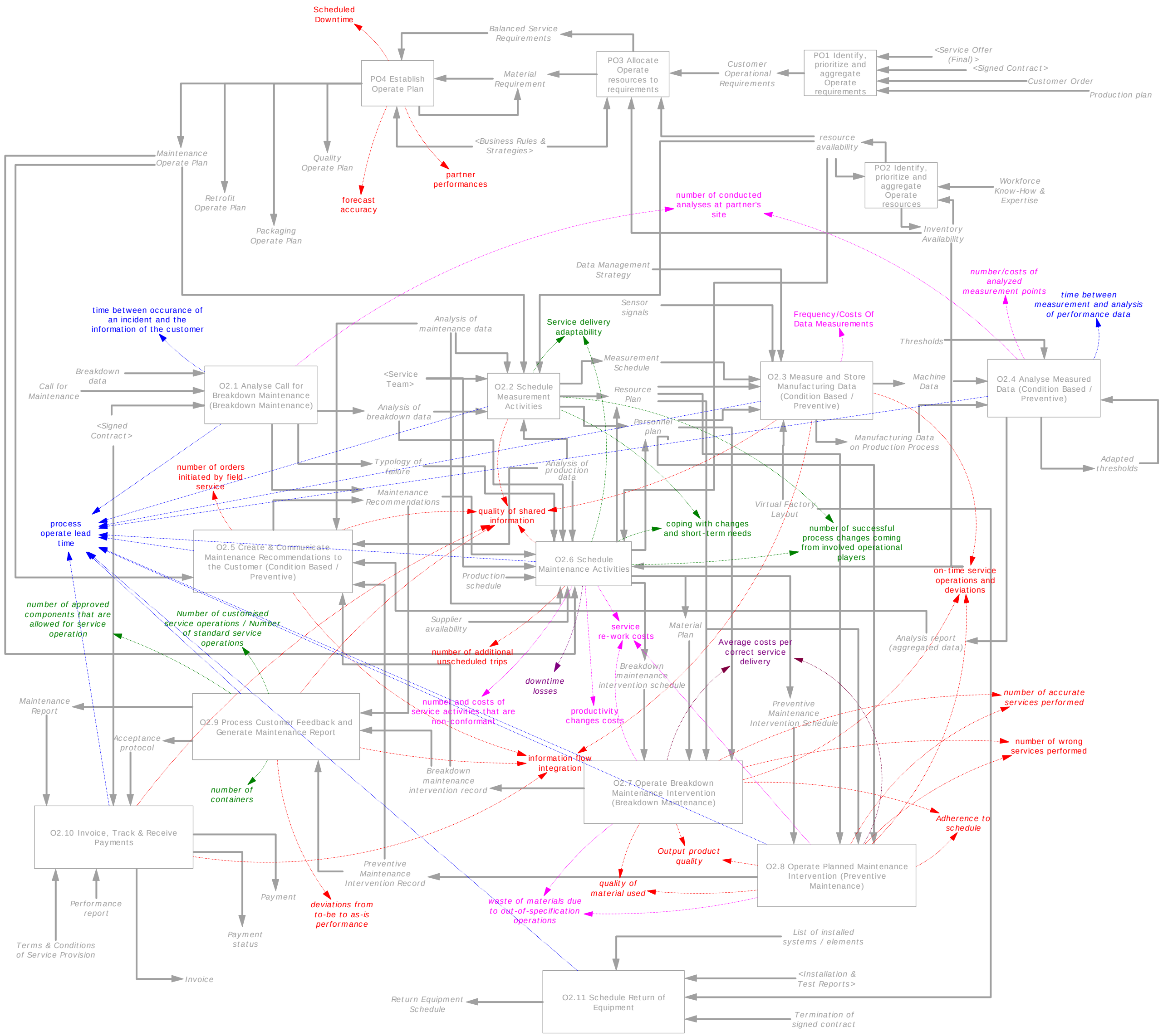

Figure 7-4: Vensim Model View; Maintenance

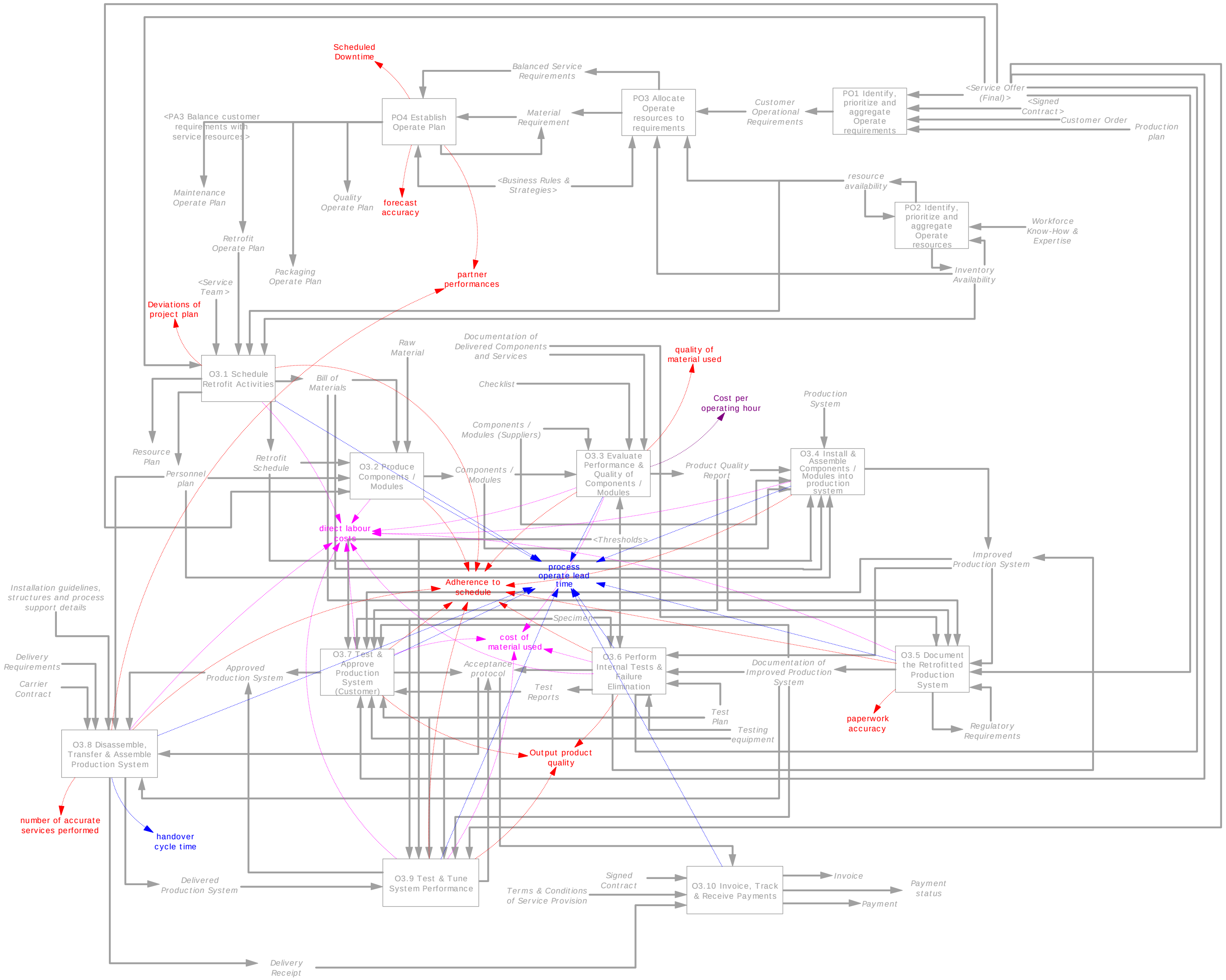

Figure 7-5: Vensim Model View; Retrofit

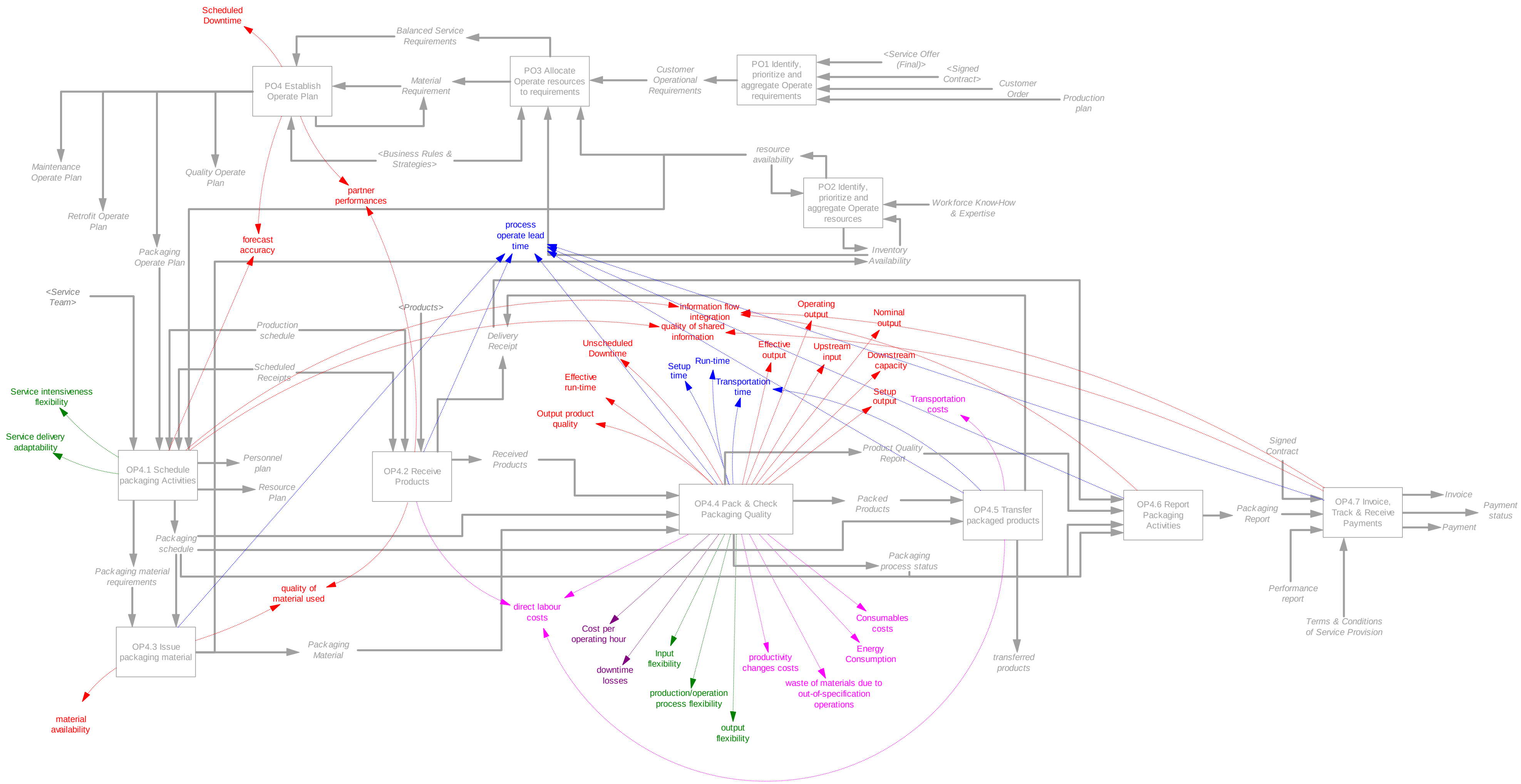

Figure 7-6: Vensim Model View; Packaging

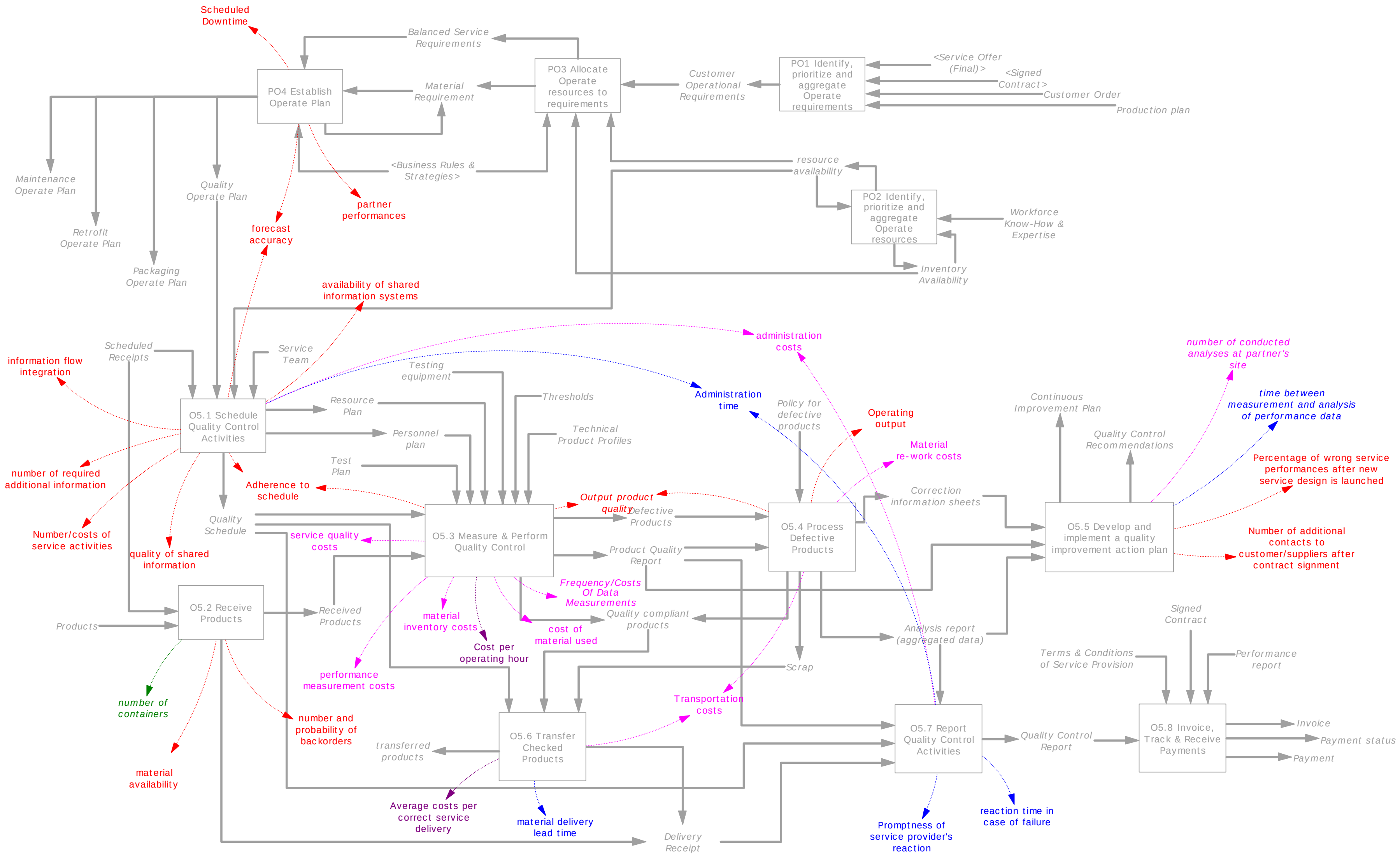

Figure 7-7: Vensim Model View; Quality Control

7.4 List of Abbreviations

BP	Best Practices
CLD	Causal Loop Diagram
DL	Deliverable
InCoCo-S	Innovation, Coordination & Collaboration in Service Driven Manufacturing Supply Chains
ID	Influence Diagram
IM	Interdependency Matrix
IP	Interdependency Portfolio
IRM	InCoCo-S Reference Model
MIT	Massachusetts Institute of Technology
PI	Performance Indicator
SD	System Dynamics
SPMS	Service Performance Measurement System