The Manufacturing Domain Ontology for simplifying interoperability of systems for Contact Lens Manufacture

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By

Hayden Atkinson

Business School

Brunel University London

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ABSTRACT

The advances in manufacturing systems and automation in recent years has been vast. The mechatronic age is apparent in any highly automated manufacturing facility. There is however, an emerging need to improve the domain model to keep pace. Much has been written regarding “big data” and the interoperability of systems, the detrimental effects of dirty data.

This research sets out to review the current state of manufacturing domain data, the options for manipulating data while an organisation grows through natural growth and acquisitions. The research adopted a design science methodology to guide through an iterative process, adding more data and creating a higher level of understanding through each cycle. This research follows using a 4D foundation ontology to model the products and processes of a test case manufacturing organisation creating a minimum viable ontology.

The accomplishments of this thesis are designing, building a foundation grounded ontological domain model for contact lenses and contact lens manufacturing process. In the final cycles of the evaluation, to empirically demonstrate the use of a philosophical foundational ontology within a legacy data conversion process enhancing the interoperability of systems by identifying and cleaning erroneous data. This research demonstrates the use of data representation, modelling using space time maps to explain both simple and complex domain data interactions within products and manufacturing processes.

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Omnium rerum principia parva sunt!

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ACRONYMS

3D: Three Dimensional (pertaining to endurantist ontologies)

4D: Four Dimensional (pertaining to perdurantist ontologies)

BFO: Basic Formal Ontology

BORO: Business Object Reuse Ontology

CVI: CooperVision Inc.

CVM: CooperVision Manufacturing System

CVMSAMM: CooperVision Manufacturing Solutions and Materials Management

DM: Data Mining

DR: Design Research

DS: Design Science

DSM: Domain Specific Model

DSRM: Design Science Research Methodology

ER: Entity Relationship (model)

ERP: Enterprise Resource Planning

IS: Information System

JIT: Just in Time

MVO: Minimum Viable Ontology

WMS: Warehouse Management System

CHAPTER 1 INTRODUCTION

1.1. Overview

Since the industrial revolution, the factory has undergone many transformations. Industrialists such as John Lombe and his 17th century silk mill made gigantic steps in transforming old and antiquated processes, reducing costs and improving England's silk and cotton exports in the 17th century. Technological advancements have often been slow to be adopted, opposition to the silk mills by the Luddites in 1811 (Patrick, 1996) depicted scenes of turmoil amongst skilled men being replaced by semi-automated machines. Today modern factories employ complex automation to reduce their manufacturing costs and improve productivity.

To create an intelligent factory or manufacturing facility, companies have extensively used computer systems to manage, schedule and process their products. Ubiquitous computing allows a more fluid, systematic approach to manufacturing. Computers are no longer tied down by power leads and network cables but are extremely powerful and use wireless technology. This technology is gradually being incorporated in the automation or mechatronic layer creating intelligent machinery, for example servos, sensors, logic controllers that are being programmed in such a way as to be in control of the product throughout the manufacturing process, scheduling and planning, part quality and optimised process control.

As more and more complex systems are introduced into the manufacturing arena, huge volumes of data are required and created by the manufacturing process. Not just the company day to day data, such as details of employees, customers and accounts, but larger datasets are available to be analysed, acted on and archived. The cost of data storage has decreased and become more reliable as technology improves. In 1980 the cost of one gigabyte of storage was over $400,000 and now in 2016 it is closer to $0.03 (Statisticbrain, 2016), allowing for more data to be stored. The use of data has become more interesting to analysts as this cost has reduced, the concept of metadata (or data about data), and in recent times the paradigm of "Big Data", a phrase coined from the book Big Data (Mayer-Schonberger & Cukier, 2013) introduces some new ideas on the reuse of data, not just in terms of our shopping habits, but making the data more useable in the systems world. Bringing systems, a step closer in converting human readable words into text understood by computer systems and aid solving interoperability issues.

In manufacturing the purpose of generated data is twofold, (1) data required to manufacture, distribute and sell the products and (2) the use of data for continuous improvement. The improvement process is specific to each manufacturer and competitive advantage can be optimised and improved with better data management and integration.

1.2. Current problem

Automated manufacturing systems have evolved over time. Since the advent of computer systems, robotics and advanced programmable logic controllers have been present on the manufacturing shop floor providing significant advances in the production processes. However, the data, with its underlying conceptual structures, that automated systems are reliant on have not evolved at the same pace. Gaps or silos tend to exist in the data structures of different systems making it extremely difficult and costly to achieve effective systems integration or interoperability, for example when merging databases of different legacy systems. Since the 1980s there has been a migration from paper-based systems to mainframe computer systems in the form of paper, spreadsheets or formatted forms and logbooks, the latter guides the user through the process steps to complete the form and gather all the information. There are numerous custom manufacturing log books from the late 1980s that are prepopulated with data and formed in triplicate. Where such data as setup and manufacturing efficiency is logged manually throughout several differing departments, such as purchasing and raw materials and the finance department to cover wages and overtime. The data would simply consist of the members of shift, the hours run, shift start reading and the shift end time, thus showing the hours run time of the machine.

There would then be the quantity of the products produced less the reject rate. The simple calculations would be indicated, the yield, the utilisation and the number of good products produced in the given time frame. This data would be passed onto a spreadsheet and the original log sheets discarded, this process was typical of data collection in the late 80s prior to automated data loggers being introduced. More commonly this manual process would introduce erroneous data, typographical errors and miscalculations that could corrupt other paper systems in the organisation if not identified.

As new products and processes are developed or the acquisition of another similar company the paper dataset must be adapted to fit the new process. Although manufacturing companies have invested in the products and manufacturing processes there has been little consideration for conceptual modelling of data and the data structures. This lack of investment in domain conceptual modelling has a detrimental effect when connecting legacy systems, making the interoperability of systems a real challenge (Chungooraa, et al., 2013).

During the acquisition or mergers of companies, there is a need to transform and migrate legacy data from one to another. There are no guidelines on how to manage this process and often critical decisions are made by junior analysts or company personnel who do not understand the importance of this company data.

1.2.1. Manufacturing Domain

Using a contact lens manufacturing company as a Manufacturing Domain example CooperVision Inc. (CVI) have been manufacturing contact lenses for over 30 years. The Cooper Companies, Inc. Is a global medical device company publicly traded on the NYSE Euronext (NYSE: COO). CVI operates through two business units, CVI and Cooper Surgical. CVI have a global distribution presence and manufacturing in the USA, UK, Budapest and Puerto Rico, with R&D centres based in California USA and Southampton UK. CVI Surgical focuses on supplying women's health clinicians with market leading products and treatment options to improve the delivery of healthcare to women.

Headquartered in Pleasanton, CA, CVI has approximately 9,000 employees with products sold in over 100 countries.

1.2.2. Contact Lens Background

Contact lenses are manufactured in single format to meet a precise patient prescription, these discrete components are often characterised by individual or separate unit of production. They can be manufactured in two different processes, high volume (Bell Curve) (Weisstein, 2012) or low volume Stock Keeping Units (SKU). This process of manufacturing can be defined as not being disassembled into its raw materials after it has been manufactured. The contact lenses are produced to correct defects in the patient's vision, they are made from monomers and polymers in a precast mould or former that has been manufactured to produce the correct prescription for the patient.

The first idea of contact lenses was thought to have come from Leonardo DaVinci back in 1508, these were hard glass, eye shaped objects that helped realise the idea. Descartes followed up the idea in the 1630s, but it wasn't until the 1950s and 60s that great advancements were made with the introduction of the soft contact lens featuring a curved shape to fit the eye better. A timeline of the contact lens is depicted in Appendix A, illustrating the development of the idea of the contact lens, to the gains in manufacturing efficiency, but noting that there is no conceptual model for the contact lens domain.

Due to the number of different prescriptions and different lens attributes, there are millions of differing combinations of lenses that need to be manufactured, along with the differing expiry dates for each product stored, leads to a complex and often costly warehouse and distribution process.

To manufacture a wide number of products, the process requires complex automation and advanced control systems. These systems help to manage change in the marketplace, for example, new products that are being introduced or changes in product volumes, help manage demand in different locations and to cope with equipment failure as these demand schedules need to be fulfilled. In this ever-changing environment, scheduling and planning negotiations are required to take place in higher level business systems and costly production time can be lost when changes are needed to the production schedule. Symptoms of this problem could include: Product type errors, labelling issues, excess inventories, obsolete stock or near obsolete stock and late deliveries, which for strategic reasons need to be reduced, excessive expediting or transport costs (Alvarez, 2007). At present there are no known domain conceptual models for manufacturing contact lenses.

Product data comes from several different areas of the organisation. Resource planning, materials and production availability are examples of such areas. Product types and brands can trace its roots back to paper datasets, or simply put a list created with a pencil and paper, detailing a list of attributes, range (or power range / prescription) and the job or batch numbers to be run. As this process evolves through time more data is added to the sheet, creating a more complex picture of the data required to manufacture the product.

A variety of characteristics and constraints related with jobs and production system, such as operation processing time, release and due dates, precedence constraints and resource availability, can affect scheduling decisions (Madureira, 1995). This combined with Architecture patchwork, which is a term used to define multiple systems integration (Meyer, et al., 2009, p. 13) amalgamating all these systems together to give, a fit for purpose manufacturing application. This leads to poor quality design of systems, often each application has its own database and predetermined data structures that are near on impossible to coordinate with or integrate to, this in turn leads to operational issues such as, excessive response time between systems and erroneous data being passed from system to system. To integrate these different business systems together successfully a great deal of forethought, time and ultimately money is required. Often this is managed badly with poor systems integration, perhaps using spreadsheet to manipulate the legacy data into the correct format for other systems to use and certainly no thought of modelling the process first.

Chapter 1

During the early years of manufacturing contact lenses, to meet the need of the regulatory bodies such as the Food and Drug Association (FDA) ISO and Conformité Européenne CE marking, there where special requirements placed on medical device manufacturers to keep control of their processes and protect the needs of the patients. To help manage this and meet the requirements, paper systems were implemented to manage batch records for devices, easier to use than expensive computer systems, but lead to large library archives and a large number of paper errors, typographic errors or typos. When contact lenses where produced as a single unit each lens would have its own device record or batch record and would consist of information pertinent to itself. Batch identification, prescription and process start and finish date stamp. As the industry has grown and automation has increased the number of lenses that can be produced at one time, the batch size has increased by not just thousands but tens of thousands of lenses, all requiring this data to be stored and retrieved at a moment's notice. The regulatory bodies also require that this batch data be stored for a period of time, which is dependent on the classification of the product to their medical device code. In common practice, this data will need to be kept for life of the product plus one year, so up to seven years with the potential that records could be called upon in time of a product recall.

Any data sets that exist currently are drawn from paper data, a manual paper documented process. This can be seen when IT developers use artefacts to mimic paper in their system creating opportunities for dirty data to migrate into automated systems. Dirty data is defined as data that is misleading, duplicate, incorrect, without correct formatting and violates business rules.

This type of data can cause issues, choices made at this basic low-level design can explode and cause larger issues further down the line for example when the interoperability between systems needs to be addressed in later years or indeed if a collection of systems needs to be replaced with one new overarching system such as ERP the choices made often make interoperability cumbersome.

1.3.Research Aim and Objectives

The aim of this research is to investigate an ontological conceptual model applied to the problem of interoperability between manufacturing systems and provide a framework to aid this approach, therefore a design science project was initiated to achieve the following research objectives.

Objective 1: Review the literature on domain modelling within the Manufacturing domain and look at where novel ideas that address interoperability have succeeded.

Objective 2: To collect and collate information on current manufacturing data within CVI, using an iterative process to design, order and reorder the data into a structured format for evaluation. Initially using the product and brands of contact lenses, understanding when a lens becomes a lens and when the brand is placed upon the lens making it a saleable product.

Objective 3: Collect data from the manufacturing business units to understand and design a model of the manufacturing process, to evaluate where products are made and how the process could be simplified and optimised.

Objective 4: To re-engineer these data sets through an iterative process, design a framework or method to aid the development and evaluation of a Minimum Viable Ontology (MVO) of the product classification brands process. Build a set of process steps or stages to allow users or analysts to convert legacy data into new systems. Identify a subset of legacy data to clean and prepare for conversion using this new approach. This evaluation will be an iterative process, containing four stages to extract, clean, load and verify the data conversion process. Figure 1 Implementation Iteration Cycle illustrates the iteration process in design science used in this body of work and described in detail in Chapter 3.

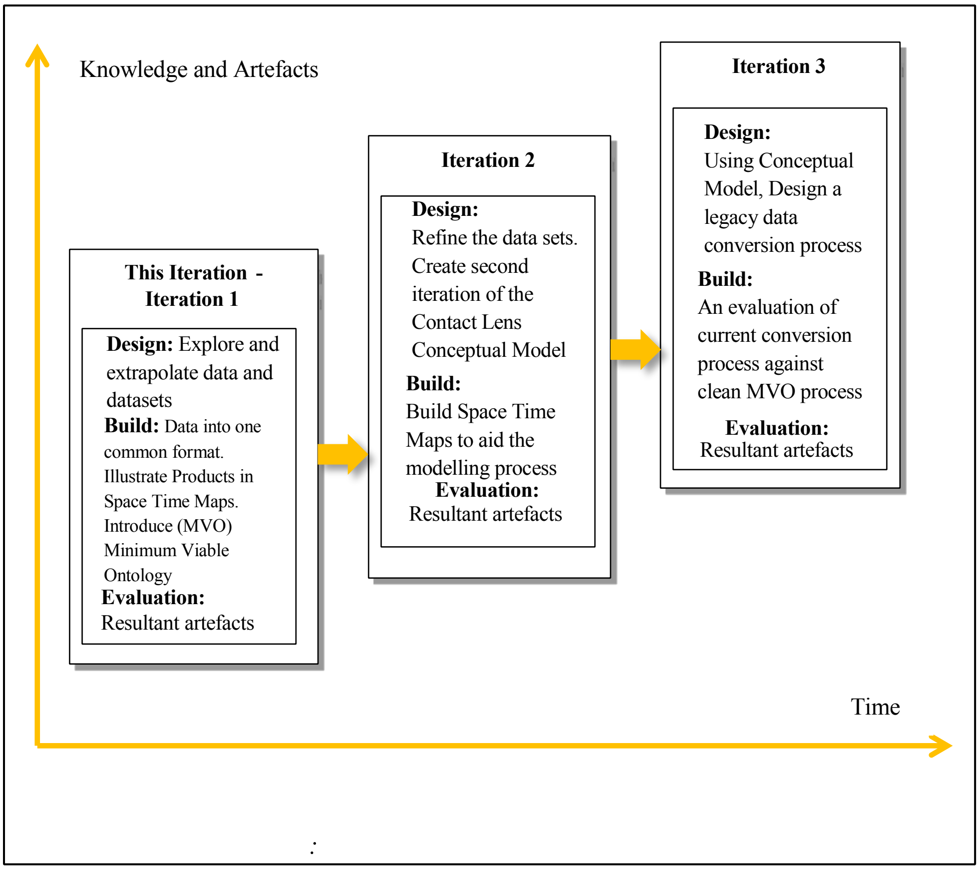

Figure 1 Implementation Iteration Cycle

1.4. Research Motivations

Understanding the way in which data and data structures have evolved in an organisation is fundamental for the larger picture. Initial research into the data gathering process within CVI, it was apparent that the organisation is multi-faceted, or in silos, defined as the same core information residing in an organisation, but viewed and manipulated by different individuals, this been more widely researched in personal informatics systems using such terms as information filtering (Jones & Kelly, 2016). Interesting to note that, not one individual will understand the whole system from a data structure point of view, which would lead to inconsistencies in future integration of systems.

In the first instance an understanding of the business objects and processes is required. This understanding can take the form of a business process model detailing the actual products and product families (Product Types) and their interactions between manufacturing components and associated data. It is also required to understand where this data and datasets have come from, whether evolved from paper and paper datasets or a merger of paper datasets.

It is more common for large business data to be stored in databases or data farms, with vast amounts of data stored, which can be of little or no use. Often there is undiscovered erroneous and or duplicate data hiding in these systems. Problems with data types and conversions of data often become unrealised and issues only become apparent when further integration or manipulation of the data is necessary. In terms of the manufacturing data, the syntax defines the structure of a language, i.e., a grammar typically provides the structure in the form of rules that govern the structure of sentences. Semantics is termed as the dealing with the aspects of meaning as expressed in the language, i.e., the sense of language elements and their combination, including the relation of these elements to the real world (Obitko, et al., 2009), Semantics is an important concept when dealing with like things or data objects. With the multi-faceted paradigm, meaning a entity that is viewed by different parts of the organisation or different people in the organisation have a different view of the semantics of the data types and further complexity is realised. For example, Lot ID, Batch, BatchID, Lot are all terms that could mean the same thing to business process owners (people) but have different data structures within systems through the organisation. The motivation for this research is to identify and clean the data structures most important to an organisation such as CVI and provide a framework or Minimum Viable Ontology (MVO) to use in the future.

1.5.Thesis Structure and Research Methodology

This thesis focuses on the current problems associated with manufacturing data, the interoperability between legacy systems issue, and the potential of utilising a foundation ontology as a basis for domain modelling, using CVI as a case study original data discovery and the benefits of: -

Chapter 1

Chapter One: Introduction of the thesis, defining the focus problem of the research and identifying possible research areas. This section provides details of the thesis structure and research motivations.

Chapter Two: Begins with a literature review of past and present work in the field of the data modelling for the manufacturing domain detailing the issues with company mergers and interoperability of legacy systems. The use, thus far of Ontologies, particularly foundation ontology and the particle choices needed to be made in terms of data, what is important, how clean the data is, and do we understand why it is important. Coupled with examples of current applied techniques, illustrating examples of failure and success.

An introduction to the BORO reengineering approach, its methods and grounding, ontological choices, 3D verse 4D debate, use of merology and why it is important to contact lens manufacturing, finally, ontologies currently being implemented in the manufacturing domain and their success.

Chapter Three: Numerous methods of researching information systems have been implemented over the past decade, Information system (IS) Design theory, Design Research and Action Research. One such method as described by Peffers *et al*. The Design Science Research Model (DSRM), illustrates a six stage process of iteration to achieve the desired result in “Design Science creates and evaluates IT artefacts intended to solve identified organisational problems” (Hevner, et al., 2004), (Peffers, et al., 2007). Phase one is to identify possible solutions and tools to fix the problem statement.

Phase two, concludes with an investigation using QFD analysis (Quality Function Deployment), listening to the voice of the customer approach to ascertain the objectives of the solution, this uses Subject Matter Experts (SMEs). Once the objectives and deliverables are understood the next gateway to pass into, is the design and development phase.

Phase three, the development phase. This is the process where the artefacts are produced and may become more of an iterative process, as better solutions are teased, tweaked and modified through the design methodology. "An artefact can be defined as models, methods or instantiations and new properties of technical, social and/or informational resources"[1]. After the artefact has been developed, it must demonstrate solving one or more of the identified problems in phase one, before the evaluation phase. To evaluate the developed artefacts requires extensive knowledge of analysis techniques and the problem being solved. Peffers *et al*. Identify in the final phase, in the works of Hevner *et al*. the need to communicate the outcomes to diffuse the resulting knowledge. This process can include publication of resultant research papers using the appropriate format (Problem identification, literature review, hypothesis development, data collection, analysis, results, discussion points and concluding remarks).

Chapter Four: The first set of artefacts in the modelling process, a data gathering exercise to establish what information exists in CVI, this can be categorised into formal and informal information and is gathered through interview and information sharing meetings with process owners and SMEs. This information is collated into a number of differing datasets for the first time to help illustrate the problem. The manufacturing process is documented and a series of initial Space Time Maps (STM) are generated to aid the design process, an initial design of the first model is created, and the data structures ordered through BORO's bCLEARer Method.

Chapter Five: The second set of artefacts in the modelling process, creating the products and brands model, extracting the data from more products and processes to and to the model. The model is cleaned and presented back to industry experts for evaluation. With the editions entered back into a new model for review creating the next iteration of the model and building Minimum Viable Ontology (MVO) for contact lenses and contact lens products and brands.

[1] Javinen,P. Action research is similar to design science . Quality &Quantity, 41, 1 2007 pg. 37-54

Chapter Six: The third set of artefacts in the modelling process, from the MVO, building the legacy data conversion process, to enable the identification and cleaning of legacy data ready for translating into another system. Objects such as products, silver stock and finished goods, raw materials and consumable goods are identified in a legacy system with their current locators. This data is extracted out of the source system into a known format. The data is then checked and cleaned prior to loading into the new system. This process consists of a manual, four stage approach to complete the conversion process. This chapter introduces this conversion process to Subject Area Experts SMEs, for completing these tasks and as review the use of an ontologically grounded method utilising the BORO bCLEARer process to define the data structures and make recommendations to the translation process. Data is staged in a temporary database and queried to review the process steps.

Chapter Seven: Conclusions, discussion, reviews the design research methodology and the artefacts built to the framework. A review of the limitations of the current form of MVO. How the contribution to knowledge in the ontology modelling field is demonstrated and a review of the contribution to industry within the contact lens manufacturing domain. A discussion on how useful the MVO can be when addressing the interoperability of systems within the domain.

CHAPTER 2 A REVIEW OF CURRENT LITERATURE

2.1. Introduction

This chapter presents the literature related, firstly to the problem of manufacturing data and how this is modelled in the manufacturing domain. Secondly review literature associated with legacy data, paper data sets and the interoperability issues that exist when merging companies by joining data together in one homogenous system. To identify the importance of clean data, the issues concerning dirty or unknown data and the tasks or cycles required to complete this cleansing work and thirdly review the potential use of a foundation ontology as a means to reengineer and modelling the data in the domain. Introducing prior work to date implementing ontologies within manufacturing. Understanding what decisions were made in the modelling process and illustrating the benefits they provide, to identify and discuss any of their limitations. Provide an introduction to ontologies in the computer science realm, a detailed review of what research has been undertaken to date and finally to review the steps by researchers and their institutes to convince organisations that modelling with a foundational ontology has unrealised benefits and can provide competitive advantage within the manufacturing domain Figure 2 outlines the literature research space.

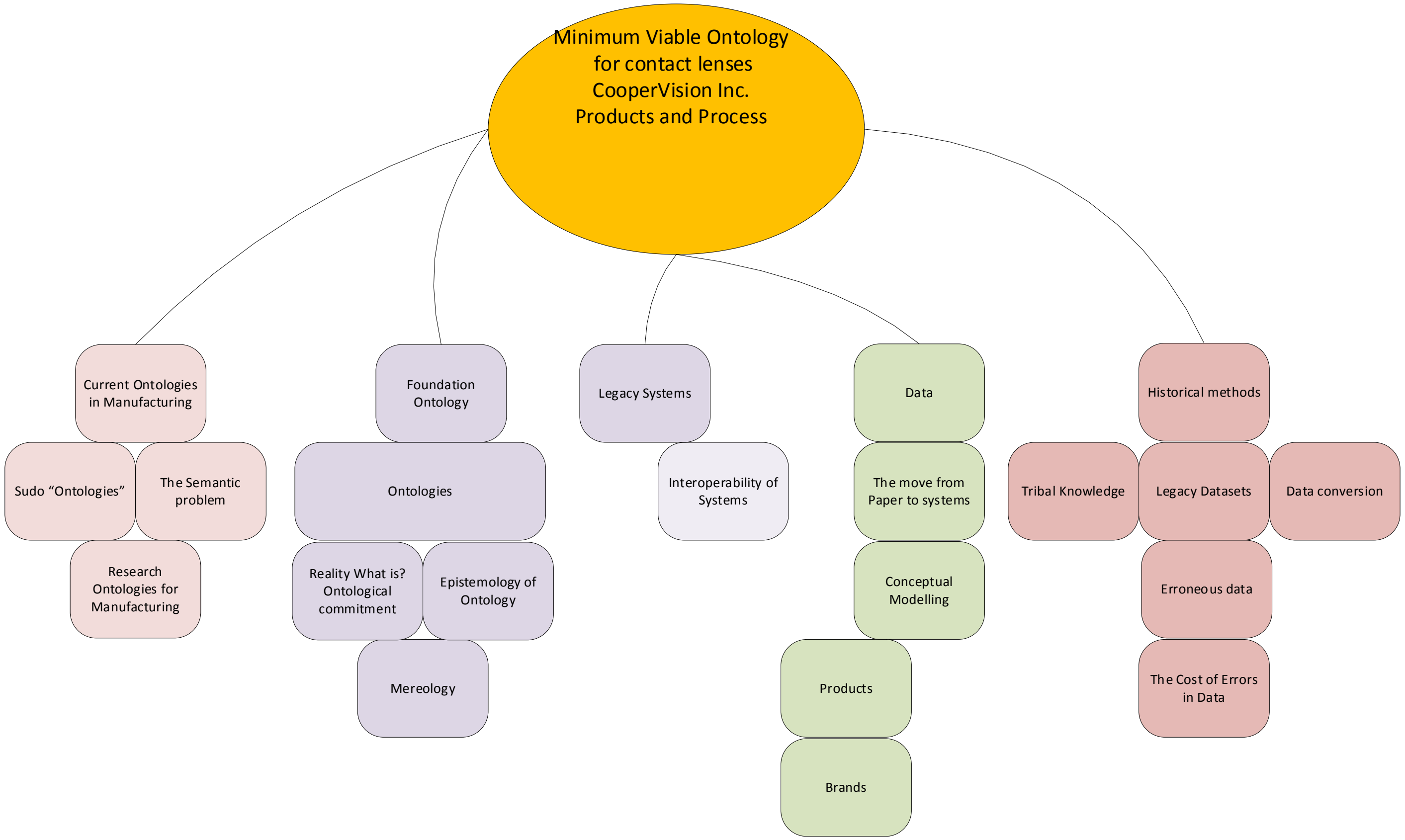

Figure 2 Taxonomy of Literature

2.2. Background

With the advent of greater competition within the manufacturing sector, companies must produce goods at higher quality and lower costs. Time to market is a crucial component to allowing a company the agility needed to meet these demands. Companies experience growth, or at least good companies experience growth, this can be either within themselves or through acquisitions and mergers.

One of the great problems facing manufacturing and the manufacturing systems, is the architecture and the interoperability between systems, issues of this type of problem appear in the literature as "record linkage" (Fellegi, 1969), the semantic integration problem (Scheuermann, et al., 1989), (Hernandez & Stolfo, 1998) or the instance identification problem (Wang & Madnick, 1989), and more recently the data cleansing problem regarded as a crucial first step in a Knowledge Discovery in Databases (KDD) process (Fayyad, et al., 1996). Business organisations call this problem the merge/purge problem. (Hernandez & Stolfo, 1998).

Companies often grow through acquisition and either attempt to interact with different legacy systems or look to integrate a newer solution. Each method suffers from the same pitfalls, there is often little consideration to conceptual modelling the process in order to understand, the "what and where" needs to be integrated and how this can be achieved. These effects of coupling two similar companies create numerous business process issues with an organisation. For example, when two companies both manufacture similar products, contact lenses, both companies have products and process that are specific to them individually, however when these companies merge the interoperability issue arises. Similar products and processes exist, but in terms of systems they are worlds apart. A central database scenario containing all the product and process data is not realistic for most companies since the necessary software adaptation would be both time- and cost-intensive (Feilmayr & Wöß, 2017).

Often a fix, will be to introduce a new system to aid the merger process, linking a multiple of data sources together integrating two or more companies with one system. Decisions need to be made on making sure the data is the same thing or not and whether which particular data subset is correct. For example, LotID, Batch number and BatchID. According to Quine, thinking of the subject of topiary[2]; two bushes can be trimmed to outwardly the same things, yet the actual configurations of the branches might be very different. In Quine's analogy, meaning people can take different pathways to get to the same result (Quine, 1960).

This information assessment can take considerable time as larger organisations can have many hundreds even thousands of databases to run the organisation. Questions are required to be asked across both merging companies' data, for example, customer details, bank accounts, pay roll, without considering the more detailed, less generic data that provides competitive advantage. Furthermore, consider two competing companies merging, a how many similar sets of data they would have? How would this data be modelling to allow for the correct decisions to be made and what tools would be useful in this process? Where has the original data come from and is it accurate for the organisation to use reliably in their decision-making process?

2.3. Data in the Manufacturing Domain

Business data is used in a number of different ways and not uncommon for large businesses to acquire scores of databases each month, with millions to billions of rows of data that need to be analysed in a number of days (Hernandez & Stolfo, 1998). Data Mining (DM) is a concept to discovery unrealised and potentially useful data (Ziegler & Dittrich, 2004). DM has been described as a manual or semi manual process used to discover knowledge from data and useful tool to extract important data. A persistent problem is the gathering of the required expert knowledge to implement these knowledge-based components (Buchner,

[2] Topiary is the art of training and pruning plants into a shape or form they would not naturally grow.

et al., 1997). To understand what data is important to the business, often first reviews of the data can become overwhelming, making the process resource heavy. To conduct a deep trawl through spreadsheets or other static layers of data held in flat files as repositories and to pull together the information useful to an organisation takes time and effort. This DM process has also lead to a rise in new research into the Knowledge Discovery from database or KDD, KDD refers to the overall process of discovering useful knowledge from large and complex data sources (Gertosio & Dussauchoy, 2004). In manufacturing often, large sets of manufacturing data exist and is held in several different systems. Before the advancement of computer systems, identifying and manipulating data was a manual process carried out by a systems analyst, by populating ledgers or log books. As computer systems came about in the 1980's spreadsheets were introduced to manipulate data. Further progression to DM has expanded with more automated approaches. Data Warehousing is one such approach that uses modern technology to report on any number of legacy operation systems and feedback key business information to the decision makers. Advantages of data warehousing include the processing of large sets of data in a relatively short period and provide an enterprise-wide view for decision support purposes (Buchner, et al., 1997). Data warehousing is a pivotal application used to manage "Big Data". Over the last 50 or so years, since computers have been conceived, they have been making more information available, this information is growing at an increasing rate. Big data is commonly characterised by the three Vs of volume of data (volume), velocity or speed of data access (velocity) and variety or types of data required (variety), representing the relevant dimensions that can be used to evaluate the nature of the data and the software platforms available to exploit them (Modoni, et al., 2016). It was sciences like Genomics and Astronomy that first experience large dataset and now all areas of life are having a large amount of information available to them (Mayer-Schonberger & Cukier, 2013). However, there are benefits in implementing DM and Data warehousing built on a structure organised data layer, as this would reduce the labour in analysing the data that is important, this is more desirable for manufacturing operations due to the vast amounts of data being produced by systems and machine each shift or production period. It is necessary to have a structured modelled based dataset, to allow complex data mining solution to acquire the correct data. Implementing a solid framework is required to aid the performance of such data structures (Cuzzocrea, et al., 2017). To lesser scale, data from a manufacturing domain can still be very unstructured and requiring following some basic rules (Venkateswara Roa, et al., 2012). The Entity Relationship (ER) Model is one such solution typically comprising of: -

The Data model; to have any form of DM in place, there needs to be a model in place, there are several different types of data model. Predominantly, the conceptual model, a summary of data in the model, used for a whole view of the business enterprise. Illustrating, products, locations, manufacturing, assets and financial business object. This is a high-level representation of the subject, containing not more than 40-50 entities. An entity is defined as a thing with a distinct and independent existence that is related to other entities (Chen, 1976). The Logical data model contains more detail than the Conceptual model with operational and transactional data being defined. The data types will be well defined with attribute structure, such as precision and data lengths. The detail of the relationships with other entities will be robust, illustrating how entities will overcome issue such as nulls between entities (nullability) and cardinality. The Physical data model is design and developed from one or more logical data models. The Physical data model is the construct to building the actual database, having the tables defined, column naming and data types within each table. The relationships will be included, showing the primary and foreign keys within the table structure. The Physical model could be used to build several different databases, SQL, MySQL, Oracle or even Access. The ER model provides benefits to an organisation, modelling the entities and the relationships that connect them in a pictorial view helps to illustrate how the company data is tether together and who owns particular entities in an organisation, according to Chen the forefather of ER, "The entity-relationship model adopts the more natural view that the real world consists of entities and relationships.

It incorporates some of the important semantic information about the real world" (Chen, 1976).

For manufacturing organisations, it is important to have clearly defined data structures to create a purposeful mechanism to report on manufacturing efficiency. The ER model and the DM tools described above are not implemented from conception. Many companies grow and merge and evolve and it is harder to apply this technology unless a greenfield site option is explored. Exposing the issues of interoperability and erroneous data within an organisations data.

2.4. Domain Data

Domain data defined as the data belonging to a particular domain, i.e. manufacturing or operational domain data would contain data specific to those areas. Manufacturing data would be product and process specific, whilst operational data would contain other areas of an organisation, such as Human Resources and Finance. A domain model is like a conceptual model, in that it contains the data necessary for that particular to domain to function. Order numbers, quantities, shipping sizes, batch quantities etc. Defining these as the conceptual level requires a far-reaching depth of domain knowledge, as models are normally the starting point in determining what the organisational structure is or how it is intended to operate. Organisational structure is not only the term used for individual roles, but also operational structure, business units for example.

Errors that are introduced in the modelling phase can be detrimental to an organisation, they are costly to fix if unidentified or if not realised, lay dormant to create other issue at a later date (Bertolino, et al., 2011). According to Boehm's paper on software verification and validation, he taunts the idea off, "Are we building the model right and are we building the right model"? (Boehm, 1984) (Bertolino, et al., 2011)After the model structure, consideration must be given to the quality, mostly checked by manual intervention, although in recent years more automated scripting of test cases to check and report the quality of data have been developed. The area of data quality is therefore open to "gaps" or erroneous data and relies on domain knowledge experts reviewing and agreeing the data structure and content (Odd Ivar Lindland, 1994). This is always a prominent issue when moving data from legacy systems into new or upgraded systems. Data from Legacy information systems (also called legacy systems) is defined as, software systems that often last many years in an organization and that are the core of its business. These systems are highly complex, and they include a lot of functionality and code; they usually mix different technologies and their maintenance is difficult and costly (Arevalo, et al., 2016).

2.4.1. Legacy Data

Managing legacy data is important to organisations, as it is often called the backbone of the information flow within an organisation (Bisbal, et al., 1997). As organisations evolve decisions need to be made on whether legacy systems need to be merged in to a newer environment, often these decisions are made by the lack of availability of aging hardware or software support. Gone are the days of individual servers running applications. Today modern datacentres can hold multiple racks of servers running virtual environments with hot swappable networked storage. These servers can be configured, removed or maintained, "On the fly" creating real advantage for data management if systems can be adapted to perform in these new environments.

The process of identifying the legacy data can be lengthy, these systems are often old and have evolved over time. It becomes a challenge when trying to update or improve these systems.

Legacy data often suffers from data quality challenges, database design and data architecture are all problems noted as pitfalls working with legacy data. Data quality issues are illustrated in Table 1 Typical Legacy Data Problems (Ambler 2016), detailing what problems exist with the data and a possible fix for them in the legacy data prior to bringing them in to a new system or application.

Problem	**Potential Database Refactoring's**
A single column is used for several purposes	Split Column (to *Notes*)
The purpose of a column is determined by the value of one or more other columns	Remove Unused Column (to remove *DateType*) Split Column (to *PersonDate*)
Inconsistent data values	Introduce Trigger(s) for Calculated Column (between *BirthDate* and *AgeInYears*) Remove Redundant Column (to *AgeInYears*)
Inconsistent/incorrect data formatting	Introduce Common Format
Missing data	N/A
Missing columns	N/A
Additional columns	Introduce Default Value to a Column Remove Redundant Column
Multiple sources for the same data	N/A
Important entities, attributes, and relationships are hidden and floating in text fields	Replace Blob with Table Split Column
Data values that stray from their field descriptions and business rules	Split Column
Various key strategies for the same type of entity	Consolidate Key Strategy for Entity
Unrealized relationships between data records	Introduce Explicit Relationship
One attribute is stored in several fields	Combine Columns Representing a Single Concept
Inconsistent use of special characters	Introduce Common Format
Different data types for similar columns	Apply Standard Types to Similar Data
Different levels of detail	Introduce Calculated Column Replace Column
Different modes of operation	Separate Read-Only Data
Varying timeliness of data	Separate Data Based on Timeliness
Varying default values	Introduce Default Value to a Column
Various representations	Apply Standard Codes Apply Standard Types to Similar Data

Table 1 Typical Legacy Data Problems (Ambler 2016)

The design of a legacy database is a factor to consider when converting data from one database to another. The original design goals are often undocumented, ineffective or no naming conventions have been used through the database. Often a database schema exists, but by design it is hard to use and modify, being only design fit for original purpose (Ambler, 2016). The interface design and development can be an area of concern when managing legacy data as any new technology will need to be adapted or a custom interface developed to facilitate this connection. It is clear to see that legacy systems are not designed but evolve, with little or no consideration for data modelling, making the maintenance and future scalability problematic (Modoni, et al., 2016, p. 4). As discussed previously in this chapter, legacy data itself is important as it is born out from what is important to an organisation, if this data was reengineered to be in a more structured format it could be more useful when migrating to a newer system

2.4.2. Born from Paper

Prior to the introduction of computer systems in the 1980s manufacturing data resided primarily on paper. This was deemed to be the technology of the time, orality and literacy were the only forms of data available prior to the computer (Ong, 2005). Information would have been written down in notebooks or ledgers as columns of data, holding information required for the purpose. As computer systems are modelled on the existing process, the design process often mirrors the paper process. For example, a simple ledger for stock control, you would expect to find unique complete entries, with all the information to complete the entry. Number, description, quantity, size, cost. This information would dictate the data types required for each item. It is important to consider this data as it is designed into a computer system as decisions made at this early inception can be hard to rectify and costly to implement the change. Consider a system design incorporating a number of paper ledgers, moving from file structure to the need of a relational database. Careful thought is required to conceptualise and approve the model prior to any code being produced. The data will need to be clean and checked, however, when the databases involved are heterogeneous, meaning they do not share the same schema, or that the same real-world entities are represented differently in the data sets, the problem of merging becomes more difficult (Hernandez & Stolfo, 1998). To manage these interoperability issues in the merging of ledgers, conceptual modelling is an industry standard tool available for this purpose (Chen, 1976). A conceptual data model is a summary-level data model that is most often used on strategic data projects. It typically describes an entire systems enterprise and due to its highly abstract nature, it is often referred to as a conceptual model. The conceptual view is a single, integrated definition of the data within an enterprise that is unbiased toward any single application of data and independent of how the data is physically stored or accessed (Y. Tina, 1999). In first using conceptual modelling techniques, the scope of the work needs to be well defined and reassessed throughout the modelling process. Coming from paper to conceptual model Ziegler and Dittrich assess data integration into six blocks or discreate processes (Ziegler & Dittrich, 2004):-

1. Manual Integration: Users manually enter data directly into the application following a process or procedure, this method is prone to input errors or typos.
2. Common User Interface: users are supplied with a common interface such as a browser to load the information in to the systems, still manual and needs to make sure the user knows what data to load in the correct fields or have controls on the browser form.
3. Integration by application: interfaces to systems, removes the human errors but becomes hard to manage as multiple system interfaces create burden on legacy systems.
4. Integration by middleware: provides a more robust solution adding a common integration platform and again removing human error.
5. Uniform data access: linking local data stores to global data stores through multiple data layers, can be time consuming and expensive.
6. Common storage: single point of storage providing a shared data store for multiple applications. In essences one source of truth for data.

The above six points detail the ways and mechanisms for data to be introduced to a data structure. Each point has increasing quality control and robustness

There are different practices in developing a conceptual information model. The underlying methodologies for the recent modelling practices are based on three renowned approaches: the entity-relationship (ER) approach (Chen, 1976) discussed earlier in this chapter, the functional modelling approach, and the object-oriented (O-O) approach (Y. Tina, 1999). The ER method is more graphical in its approach, the Functional Model views the data in terms of a process flow and the object-oriented method incorporates the use of both data structures and functions. The building blocks in the O-O model are object classes, attributes, operations, and associations (relationships.) The objected-oriented approach has the following advantages: easier modelling of complex objects, better extensibility, and easier integration with O-O DBMS and O-O programming code (Y. Tina, 1999).

In recent years the use of ontology in computer systems has become more prevalent, exploration and research into the benefits of creating conceptual ontologically grounded models on a domain has reaped rewards in aiding the interoperability of systems complexity. Several ontologies have been developed in recent years to model different manufacturing domains, Factory Domain, which specialises in OWL, Web Ontology Language with definitions related to products, processes, and production type systems (Terkaj & Šojić, 2015). The PPI ontology, an ontology that introduces the concept of Process Performance Indicators (PPI), in order to enable process evaluation also the Time ontology, which specifies the start time, end time, and time interval associated to activities and objects, reusing the representation of time proposed and demonstrated in the Time Ontology. The Logistics core ontology (Daniele & Pires, 2013), an ontology covering logistics, i.e. the set of activities that take place among several actors in order to deliver certain products at the right time, right place and under the right conditions, by using suitable resources (Modoni, et al., 2016). The non-grounded ontologies tend to promote simplicity, whereas foundation ontologies consists of very general terms (such as "object", "property", "relation") that are common across all domains and due to their design rigor handle complexity in a more robust manor (Gell-Mann, 1994). Keet, brands these simply non-foundation ontologies as "common" and do not always hold up to the rigor of cross domain use (Keet C.M, 2011). Ontological grounding needs rules at the foundation level to enable clear and decisive decisions (Jones, et al., 1998). Errors or poor choice selections in early stages of the modelling process have huge impacts to models in future versions. It is important a model has a grounding, this grounding is described as the foundation or core ontology, the choices are made through philosophical section.

2.5. Introducing the Foundational ontology

Ontology derived from a Greek word and translated from the Latin word ontologia. Defined as a sub field of metaphysics, it was used by the great Greek philosopher Aristotle to create the first naming ontology or the ontology of substance. E.J.Lowe, defined ontology as "the set of things whose existence is acknowledged by a particular theory of system of thought" (Poli & Seib, 2010) (Partridge, 2005). The existence of things has also been represented pictorially as the Arbor Porphyriana or tree of Porphyry, detailing the relationship between like things and one of the first of the first attempts to classify things. Ontology is used to answer questions of what things exist in the world and what properties can explain their existence. Foundational ontologies or upper ontologies as they are also known, define the theory of distinctions, which are applied independently of the state of the world. Foundational ontology is a system of general domain-independent ontological categories that can form a foundation for domain-specific ontologies.

Foundational ontology can be applied across several domains and aims to give a common grounding in how objects are defined (Partridge, 2005). Using a Foundation ontology gives the user broad concepts at a higher level, which in turn allows for better interoperability between like grounded systems, providing a simple and clear set of rules to be adhered to. During the implementation of the foundation objects several decisions must be made, and these decisions are not based on one particular view point. Domain ontology is primarily only for that particular domain and more often than not, specific to the individual development organisation. For example, a spectacle manufacturing facility creates a manufacturing ontology for its processes that are so unique they cannot be reused in another companies manufacturing site, hence creating a defunct ontology or creating the illusion of transparent vision. A foundation ontology however provides the grounding to be used in any spectacle factory as names and elements are defined for all the spectacle factories in this universe and all universes. In the work of Wimsatt regarding robustness and reality the authors chapter on the ontology of complex systems explains that humans are a simple entity in a complex world and that perspectives are important, everyone's view point is different, multi-faceted views of the same thing provide this prospective and this is important to understand what exists (Wimsatt, 2007). Debate on the levels of ontology, in short Sider writes this as a choice made, for example if my sock had a hole in it, all the holes belong to socks or a one to hole relationship, the ontological realist stance on this would apply a fundament sense of "there are" to the equation, so there are holes in socks and hole could exist in any other form of clothing (Sider, 2009). However, this would not be depicted in the model without this reasoning applied. The difference between descriptive and prescriptive ontology is debated in Ontology and Metaontology, a contemporary guide, discussing the world as a picture and for each individual to describe and create the names or elements from that picture, we would have very different descriptive works for the same picture (Berto & Plebani, 2015). Ontologies in the manufacturing area seem to be domain specific, with little or no thought using a foundation ontology, the semantic web or OWL based technology (Chungooraa, et al., 2013), seems to be the main flavour of "pop up" domain ontologies in the manufacturing arena. "Pop up", meaning ontologies that appear and only domain specific. None seem to start with any grounding in philosophy and with no consideration for ontological commitment in the first place. For example, in the work of Balakirsky, developing an ontology for just in time manufacturing process, utilising robot work cells to be optimised with self-learning attributes to increase the efficiency of the cell. (Balakirsky, 2015) the ontology is stand alone and not grounded, so could not be reused in all manufacturing work cells in this universe or any other. The ontology is too bespoke for the application, interoperability between similar processes would still need a degree of manual interfacing. Foundation ontology, is for any possible worlds (Lewis, 1986) (Berto & Plebani, 2015) and elements can exist through time and space, benefits of this are namespace changes and changes over time, as all can be modelled easily through Space Time Maps (STM) a useful tool to demonstrate and visualise parts of a model. Often called Minkowski diagram after being developed in 1908 to illustrate the properties of space and time and 4-dimensional physics by Hermann Minkowski (Minkowski, 2012).

2.5.1. Ontological Commitment

Ontological Commitment is a term used by Quine in his work on first order logic. Willard van Orman was a widely popular Philosopher who helped bring Ontology back as a discipline in the 1960s (Effingham, 2013). The term refers to the relationship between particular entities and the language used to describe those entities within the entity domain. Meaning those particular entities are ontological committed to that domain. An important term when grounding things that exist past present and future and helps to create an affective model.

2.5.2. Epistemology of Ontology

The term Epistemology refers to the way we know or understand things, coming from the Greek episteme meaning knowledge, and logos meaning study, so collectively the study of knowledge and ontology is to define what things are and how they exist (Inwagen, 2014). Important in terms of review of system data to establish the grounding at a higher level, i.e. lens and lens types.

2.5.3. Realism and Normalism

There are two major schools of thought, idealism and realism, which have for millennia been the subject of the debate on how the human mind can know reality. Idealist philosophers view reality as fundamentally a construct of the mind which is dependent on human perception. As asserted by Partridge et al. (2013) this leads to the erroneous conclusion that reality is nothing more than a construction built by each individual person's concept system. Thus, as each information system is designed by an individual who reflects their own view of reality, the result is a multiplicity of conceptual models and the instantiation of incompatible systems. Quine (1948), who also adheres to the realist philosophical stance, stated that what exists can be determined by observing which entities are endorsed by the scientific theories. This realist stance is also supported by Sider (2001) and Van Inwagen (1998) who all assert that what exists can be clearly recognised as the 'real world' outside the mind. This realist stance is often reflected in the context of IS system design, in the phrase 'real world models' or 'real-world semantics. Real world can be defined to two areas when considering formal ontology, formal logic and formal ontology according to Barry Smith in (Smith, 1998), formal logic being derived from set theory and formal ontology coming from mereology and part hood, both discussed later in this chapter.

2.5.4. 3D vs 4D Debate

Endurantism or 3D is defined as A three-dimensional object is wholly present at any given instant and persists by 'sweeping' through a region of space-time, while wholly present at all moments of its existence, an object preserves its identity via a set of essential attributes (for example, a person's DNA). (Sider, 1997)

Perdurantism or 4D is defined as an individual thing has a four-dimensional extension (or extent) in the universe (i.e., the region of space-time that it occupies) and it is not therefore totally present at any given instant, but instead only partially present, identity is defined by the thing's four-dimensional extension, in its lifetime an individual thing goes through states (or stages) change is explained via successive dissimilar temporal parts.

Temporal parts are important in computer systems, because using a particular method provides a richer view of data, to help resolve interoperability of systems and manage changes over time.

2.5.5. Mereology

Whole parts and the sum of all the parts etc. is a key term that is important to contact lens manufacturing. As a sum of all the parts constitute a contact lens, the lens travels through various stages of its life from initial sacrificial mould through to finished product. Mereology is the term used for stages, or part and whole part relationships. Coming from the Greek meros meaning part, Mereology is useful to distinguish parts of things, used as a complement to Set theory and can be used to explain changes or developments over time (Effingham, 2013).

2.6. Business modelling and ontology

Business Objects Reengineering Ontology or BORO is a metaphysically based foundational ontology or upper ontology, developed specifically for use with computer systems. Principally used for re-engineering legacy data as a methodology, BORO emerged from several legacy re-engineering projects that started in the late 1980s, developed by (Partridge, 2005). It is a perdurantist upper level (Foundational) ontology strongly based on extensionality, BORO was developed to retrieve data from legacy systems, create ontologically based data models to enable the design and development of a newer generation of systems (Partridge, 2005).

BORO helped influence the ISO 15926 standard and inspired the upper level ontology of the International Defence Enterprise Architecture Specification for exchange Group and has been adopted by the U.S. Department of Defence Architecture Framework (DoDAF) (Partridge, et al., 2013) Also applied in various industrial sectors including finance, oil and gas, defence and manufacturing domains (de Cesare, et al., 2013).

2.7. Manufacturing ontology

As discussed previously manufacturing systems often have issues with interoperability between systems, due to the different data models being used, often systems use different data models in the same processes exacerbating the interoperability issues further. Choices need to be made and are often made by a snap decision, an analyst or process owner of a particular model in a system may have a huge effect on upstream and downstream system interoperability. According to the classification of manufacturing systems (McCarthy, 1995) manufacturing classification amount to five categories: -

- Operational characteristics, such Lot, batch, continuous, intermittent etc.
- Operational objectives made to stock or made to order
- Operational flow structures, VAT, analysis, flow line etc.
- A detailed sub classification of the above, batch, flow line
- A combination of one of the above

These classifications are also supported by Constable and New, who stated that all manufacturing systems can be defined by three characteristics: product structure, organizational structure; (flow line, cells, functional layout, etc.); and the nature of customer orders (make to stock and make to order). (Constable, & New, 1976) the BORO reengineering approach may have great potential to improve the interoperability of manufacturing systems in the contact lens domain, however there are first some key concepts in ontology to understand.

2.8. Current ontologies used within Manufacturing

It has become necessary for manufacturing software to interoperate; however, the reality is found to be more challenging. Developing ontologies for manufacturing integration has been identified as a key area of research needed to allow for future collaboration between manufacturing systems. Ontologies are defined by Gruninger as logical theories that provide a set of terms in some formal logical language (Gruninger, 2010). Web technologies have been identified as a possible solution to link automated manufacturing systems together (Casey, 2003). Web information primarily needs to be interpreted by humans and process by machines. Ontology is pivotal for the web's automated tasks and as such provides machine process able semantics for data and information sources that can be used by agents, applications or other types of information flow. (Khilwani, et al., 2009) Utilising a combination of computer and network generated technologies can effectively supported the transfer and exchange of knowledge among companies. Ontologies are used for defining the semantics present in the concerned domain and for sharing them among people, databases, and applications, of course not all companies want to share data! But owing to this strong implication for conception of reality, it has gained much interest in artificial intelligence for defining the basic terms and relationships comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary. (Khilwani, et al., 2009, p. 908) Ontologies have been developed and used for the following purposes: - (Yoshinobu, 2004), (Khilwani, et al., 2009)

A. Share knowledge: sharing the structure of information among software agents and people;
B. Reuse knowledge: reusing it for other systems operating in a similar domain;
C. Make assumption about a domain: for easier communication

The ManuHub architecture provides a Semantic Web service-based platform for the modelling, acquisition, and retrieval of manufacturing services associated with the management of service lifecycle (Fraser, 1997). Developed by Cai *et al* (Cai, et al., 2011). Their aim is to demonstrate the natural use of Semantic Web technology to develop a ManuHub system for managing distributed manufacturing services with formal ontological support and create an easy to use graphical user interfaces.

They concluded the following points in their paper, they proved the development of a computational model to the ontology and constraint-based modelling of the distributed manufacturing services and semantic annotation of the acquired manufacturing services was indeed possible. That the development of a methodology of manufacturing service matchmaking and retrieval to facilitate efficient, accurate, and automatic retrieval of the required manufacturing services based on semantic matchmaking of manufacturing service capabilities would be required and finally the design of a test bed required to evaluate the semantic matchmaking and retrieval method of manufacturing services to test its practicality and efficiency. In particular, the experimental results demonstrate that the proposed approach out performs the existing service matchmaking and retrieval methods in terms of recall and precision rates *ibid.*

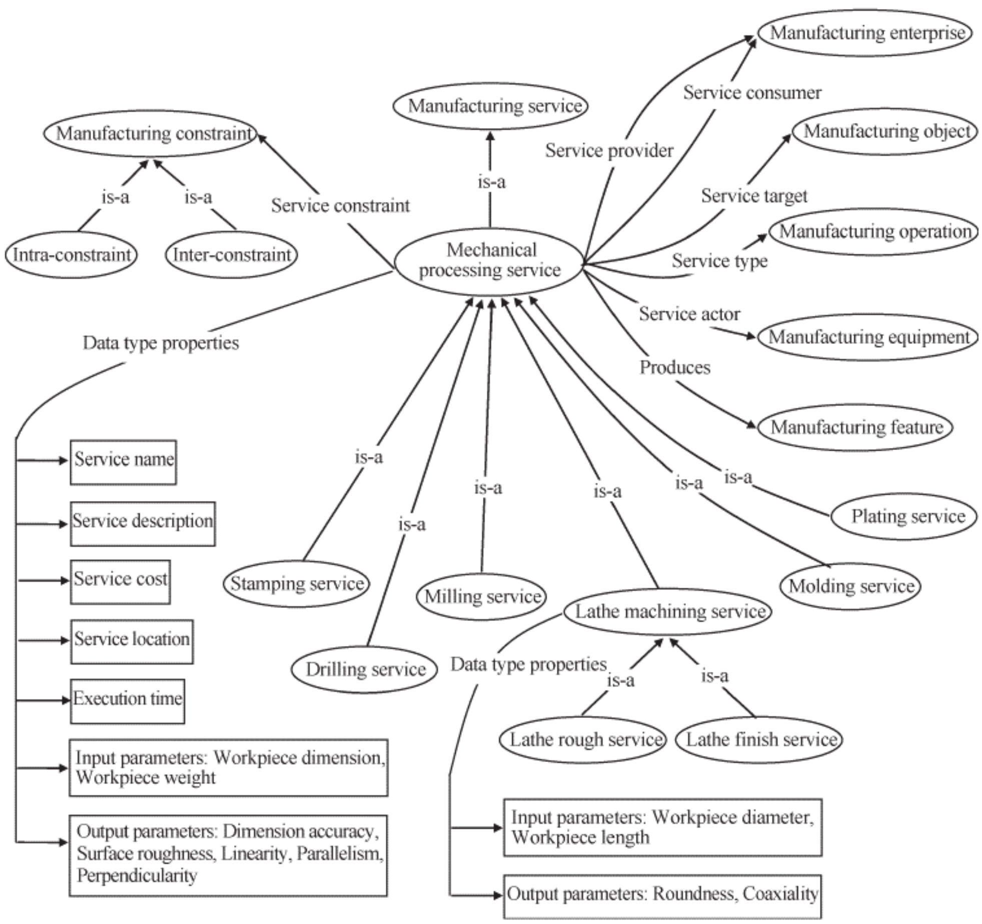

Figure 3 Manufacturing Ontology and constraint-based manufacturing service modelling process (M. Cai, 2010, p. 4)

In the medical research industry, where there is a need for standardisation amongst systems to facilitate the ability to produce reliable search patterns. Thus, could be used to identify potentially effective antibiotics against a particular strain of virus, or in this research as a method of modelling complex products and their process work stream used to schedule and manufacture contact lenses. This research is currently underway at the Buffalo University, New York with Barry Smith using the BFO Basic Formal Ontology (Smith, 1998).

2.9. Interoperability

Ontology-based reconfiguration agents use ontological knowledge of the manufacturing environment for the purpose of reconfiguration without human intervention. (Alsafi & Vyatkin, 2009). Reconfigurable manufacturing systems (RMS), a system that could be configured easily to manufacture, either different products requiring different processes or allow for an upscale in production out by halving cycle times and processing more through put of product. RMS complements the holonic manufacturing philosophy due to the very nature of individual software & hardware components rather than one centralised system. The notion of a biological manufacturing system can be defined as a distributed manufacturing system, in which each part tries to achieve its own goals and each machine tries to attract them for processing. *Ibid., measurement* of the benefits of an ontology for interoperability are difficult to qualify, (Gruninger & Lee, 2002) and define the benefits as:

– Communication between systems, between humans, and between humans and systems.

– Computational inference.

– Reuse and organization of knowledge

A key question is to identify how ontologies can be used to make the interoperability of systems more robust in terms of how to integrate products when companies are acquired.

2.10. Ontologies and the benefit to products and process

The gap model is quoted in (Burger & Simperl, 2008) as a method of measuring the influencing factors of an ontology on a specific domain. Using multiple methods, from value chain assessment to match analysis, culminating in a user satisfaction. Not ideal as everyone has a different perspective on how good or bad a particular thing works. Domain specific ontologies appear to handle situations unique to that domain, but interoperability of systems within the same domain, be it manufacturing, or distribution would still be difficult, due to grounding and naming convention. Building a domain ontology for the manufacturing factory would need to be generic in nature, however according to Feilmayr and Wöß ontologies have the potential to meet the most important requirements for a successful technology (Feilmayr & Wöß, 2017) namely, that it:-

- can save time and or money,
- is easily understood and passed on,
- is sufficiently used, and
- is, effectively, ubiquitous.

There work concludes with a precis of why in their minds ontologies fail and can be explained by (i) many existing, sometimes conflicting, definitions of the term ontology, (ii) insufficiently precise specifications of semantic technologies, and (iii) the existence of long and arduous iterative modelling processes that are very abstract and complex (Feilmayr & Wöß, 2017).

2.11. Conclusions

Interoperability of systems has always been an issue to companies, erroneous data and problems integrating shop floor data in to business mainframe without leaving gaps is a challenge. Manufacturing domain modelling has been in existence for a number of decades, but not all manufacturing can be considered generic. Ontology could provide a means of grounding manufacturing items such as products and brands or manufacturing processes. There are several domain specific ontologies, none to note in manufacturing that are grounded with a foundation ontology. The ManuHub example is introduced as a semantic integration tool, muted as the answer to reusable objects in the manufacturing domain that can be quickly propagated by manufacturing. However, there needs to be some grounding, there are some concepts in philosophy that have potential for the contact lens domain, Mereology, part and whole parts of a lens during manufacturing, grounding in 3D or 4D perdurantist stance, meaning the whole part is not in existence, but instead slices of the whole part for that instance in time. However, there is debate on what makes a good ontology and seems to be a trade-off simple verses complex. Simple meeting the reusable, easy to understand, widely used. The complexity is where the detail is hidden, abstract and complex is not so easy to use. The term deep simplicity, where something appears to be easy to understand on initial viewing, but underneath has a deeper meaning and far more complex. This is described in the Quark and the Jaguar (Gell-Mann, 1994) and we can refer to Einstein's $E=MC^2$ as an example of simple and complex, compressing the complex information into a simple expression that can be easily understood.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This chapter firstly reviews possible approaches to undertake the research. A review of the differing methods used in the Computer Science field or Design Science Research Methodology (DSRM). Secondly identifies which is the best and appropriate method for this research thesis, and thirdly outlines a plan of the actual research method used through the undertaken work during the course of this project.

3.2. Basic and Applied Research

Developing information systems; this type of research has been identified as an engineering or formulative type of research (Jay F. Nunamaker & Chen, 1990). The classification of the research type enables the correct tools to be used in order to achieve successful results. Basic research is termed as the response to intellectual interests of the researcher, rather than research for practical reasons. (Bailey K.D, 1982), (Blake S.P, 1978), (Jay F. Nunamaker & Chen, 1990). Rather expand man's knowledge than fix an actual problem with a solution. Applied research is deemed as the application of specific knowledge to solve high priority problems. In all solving research a clear and defined problem is required. The area of knowledge is often vast, and researcher can spend an age reviewing a critiquing possible methodologies to produce a solution that does not have the desired effect in rectifying the problem. For the purposes of this research, Figure 4Figure 4 Research Domain used in the Ontological modelling for the Manufacturing Domain illustrates the domain specific areas outlined in this research thesis.

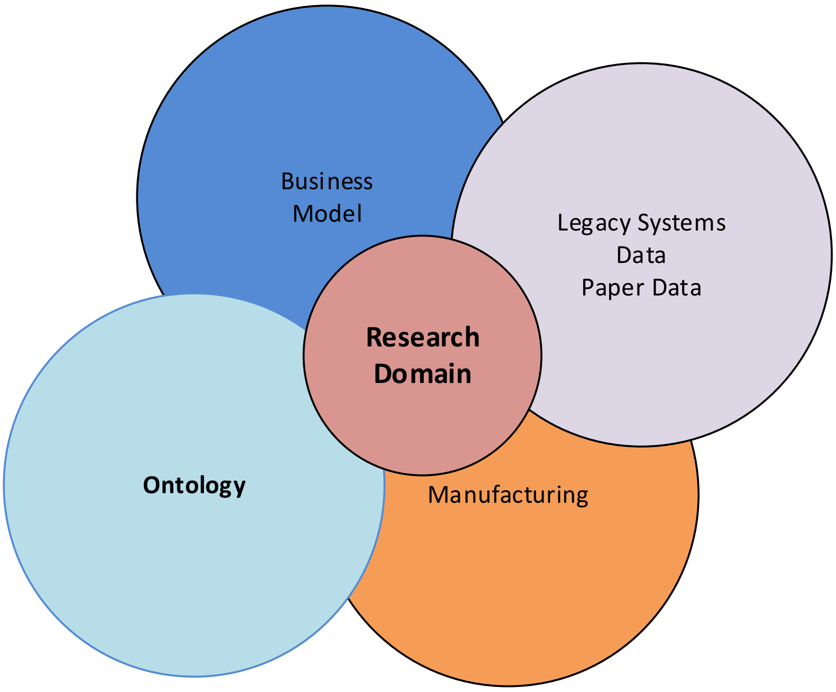

Figure 4 Research Domain used in the Ontological modelling for the Manufacturing Domain

3.3. Design Science Research Paradigm

Design research in Manufacturing Information systems (MIS) poses the same research issues and information systems (IS). Research streams have offerings from many differing disciplines, with very diverse backgrounds from engineering and mathematics. Design science can be termed as a problem-solving process, following a logical path to achieve the successful resolution of a problem (Hevner, et al., 2004)

The problem such as a model or framework rule	Description
Design Artefact	Design-science research must produce a viable artefact in the form of a construct, model, method or an instantiation.

Problem relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Design Evaluation	The utility, quality and efficacy of the design artefact must be rigorously demonstrated via well executed evaluation methods.
Research Contribution	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact
Research Rigor	Design-Science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.
Design as a search process	The search for an effective artefact requires utilising available means to reach desired ends while satisfying laws in the problem environment
Communication of Research	Design-science research must be presented effectively both to technology- oriented as well as management-oriented audiences

Table 2 Design-Science research guidelines (Hevner, et al., 2004)

The purpose of using the seven rules is to allow researchers to understand the requirements for effective design research. A framework of research depicted in

Table 2 Design-Science research guidelines (Hevner, et al., 2004)

Highlights the interaction between applying specific knowledge and "know how", to solve a known problem and this "know how" contributes to the collective knowledge let in solving the problem.

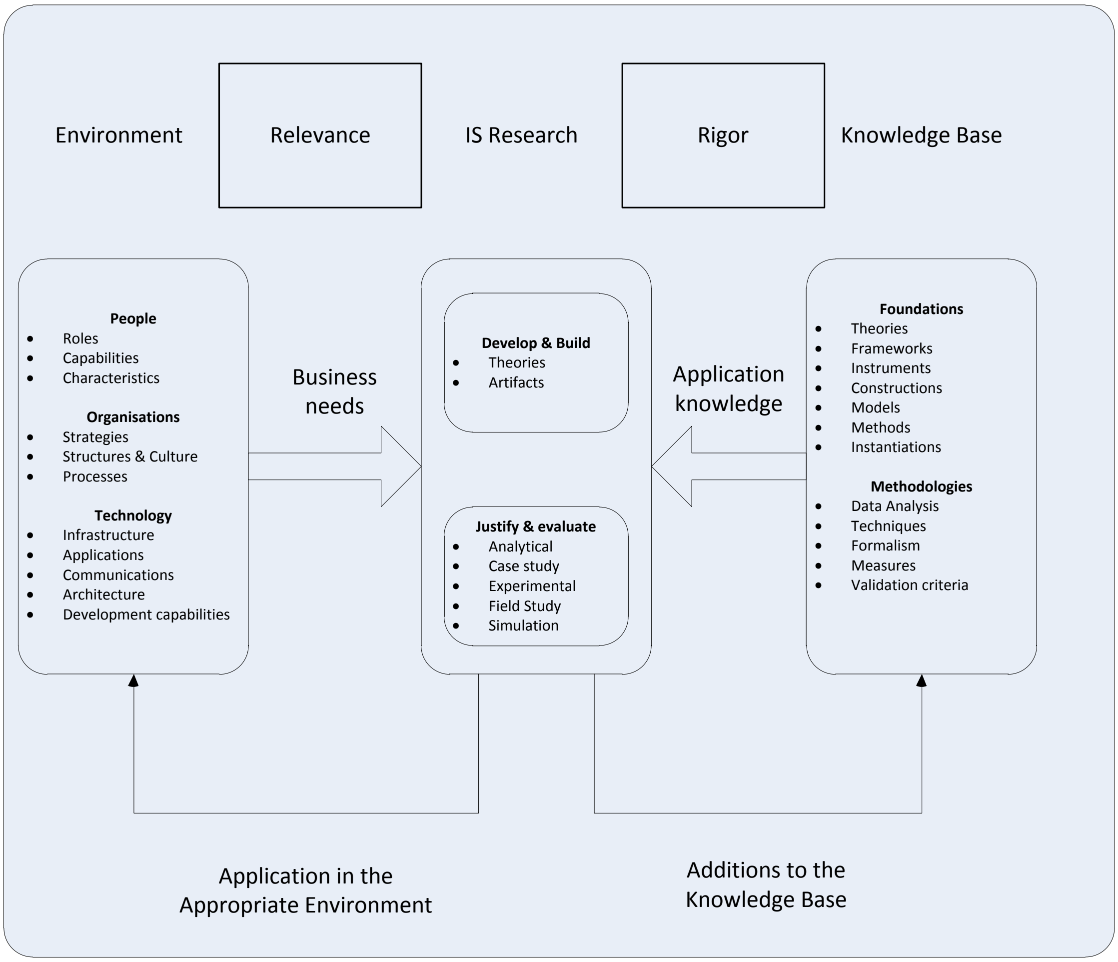

Figure 5 Framework of Research (Jay F. Nunamaker & Chen, 1990, p. 633)

Nunamaker and Chen (Nunamaker, et al., 1990) discuss and evaluate the process of systems development research methodology in creating a viewpoint. The systems building process starts by the researcher constructing a conceptual framework, encumbering not only a clear definition of the research problem, but also other ideas from different disciplines that could possibly provide a different approach and be incorporated into the overall system design, as illustrated in Figure 5.

The next phase of the process to consider is, to develop architectures to help define the system components and how these components fit together. Special consideration for communication interfaces and protocols must be considered in this phase of the research. In parallel to this, system constraints and proof of hypothesis will all be discussed. A novel approach to doing a different task can sometimes be emphasised as an innovative use feature rather than something that would be detrimental to the performance of the system.

After defining the architecture and components necessary for the system, the next step in the research process is the Analyse and Design phase, including database structures and schemas, program modules and their functions etc. During this phase there may be a need to make changes to the specification as it may become apparent that curtain designs may not be suitable as first thought. These changes can easily be implemented before the build phase without any significant delay in re-design.

The build the system phase concentrates on the implementation of the system, checking the feasibility of the design. It proves advantages and disadvantages of a system and merits of any other sub systems or alternate designs. After the system build empirical studies can take place to fully review the functionality of the system, leading to the final phase where the observation and system evaluation tasks are completed. The test results can be compared to the overall expectations of the system allowing furthering development or "tweaks" to the system to fine tune.

Peffers *et al.* considered the use of a design framework or Design Science Research Methodology (DSRM) incorporating principles, practices and procedures required to carry out research. (Peffers, et al., 2007). The model provides mechanism for presenting and evaluating DS research in IS based on the practical rules defined by Hevner *et al.* The process is categorised by six steps or rules.

- Problem identification and motivation
- Definition of the objectives for the solution
- Design and development
- Demonstration of capabilities

- Evaluation
- Communication

The DSRM paper demonstrates their model on four case studies of prior research. Firstly, a problem centred research entry point, where a problem has been identified and defined. Secondly a particular objective needs to be implemented or resolved. Thirdly a design and development centred research initiation and finally a client context initiation, where a client has a particular problem that requires a fix or solution. From the identification of the problem this approach discovers any prior theory used in similar case to aid the design and development phase of the research (Peffers, et al., 2007). Illustrated in Figure 6

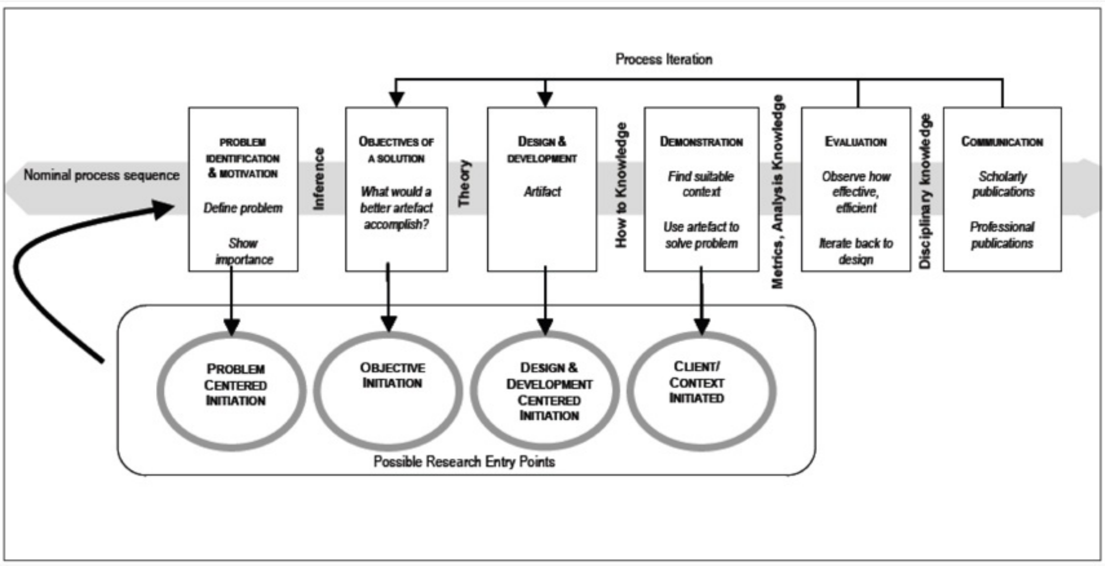

Figure 6 DSRM Process model (Peffers, Tuuanenen, Rothengerger, & Chatterjee, 2007)

They utilise a process to design artefacts that resolve the problem or at least attempt to address part of the problem. Using an iterative process to enhance the artefacts, as such many artefacts or versions of the artefact can be used to solve a specific problem. The solution needs to be tested for its efficiency and effectiveness in solving the problem. There can sometimes be another round of iteration to makes sure the artefacts solve the problem, leading often to design or model specification needing to be updated. A demonstration is required to prove the initial problem has been resolve and identify any features or bugs that exist in the solution. After the demonstration and evaluation process the findings can be published as a contribution to knowledge or academic and practical research.

3.4. Proposed Design Science Research Methodology

3.4.1. Introduction

The design science process as proposed by Peffers et al. is adopted as the overarching method for this research project. Each of the iterative stages and how they are constituted for this research are detailed in the section below.

This design science research project is focussed on retrieving data structures from the manufacturing domain, to evaluate and re-engineer using a foundation-based ontology, in order to improve interoperability between legacy systems and create a common understanding of Product and Brand data throughout the organisation.

3.4.2. Design

The design phase is intended to identify the artefacts necessary to provide a solution to the problem. Within industry the design phase is used to help the company build new artifacts or systems for sale and create revenue and often subject to cost and time constraints. Within research the design phase has a differing purpose, to research new ways to solve a given problem (Hevner, et al., 2004) and have a positive effect on the research field.

3.4.3. Build

The build phase of a DSRM project infers that artefacts will be produced as part of the process to fix the defined problem, such artefacts classified as four types by March et al. (March & Smith, 1995) Are potentially constructs, models, methods, or instantiations / constructs (Hevner, et al., 2004).

3.4.4. Evaluation

The evaluation process is required to ascertain the artefacts effectives of solving the given problem. Therefore, clear measures must be put in place to ensure the correct quality is attend and if iteration or “fettling”, is required on the artefact. The evaluation method and metrics employed should be carefully matched with the artefact that is the subject of research according to Hevner *et al*. (Hevner, et al., 2004).

3.5. Evaluation and Selection of Methodology

3.5.1. Overview

In Figure 7 below, provides a view of how each phase of the DSRM is addressed in each chapter of this thesis, illustrating how the iterative process of the DSRM is used to correlate back to the problem being solved using the design, build and evaluate stages

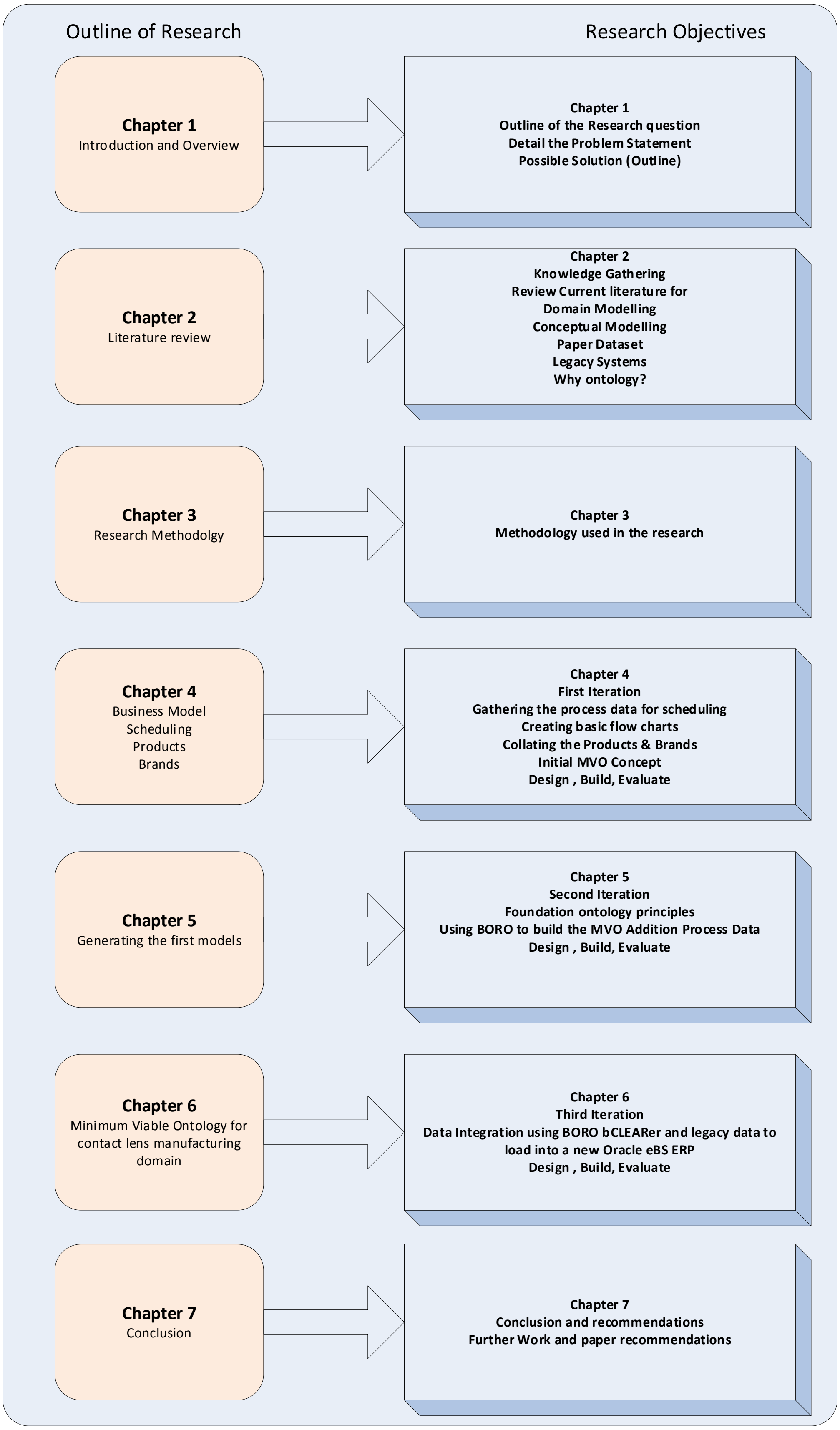

Figure 7 Design Science Framework for this research

3.5.2. Preliminary Phase

The research question was introduced in Chapter One, outlining the problem(s) to be solved. The introduction also moots possible solutions to be explored as part of this thesis. A literature review of pre-researched issues with extracting data from paper data sets, the importance and the structure of legacy data and data mining techniques, illustrating how they have been used before to provide knowledge and understanding of prior work in this research area. Introducing a possible solution through using foundation based ontology to re-engineer the raw data sets, to build cleaner data models in the manufacturing domain, creating the Minimum Viable ontology for contact lens manufacturing illustrated in Figure 8 for products and brands in the contact lens manufacturing domain.

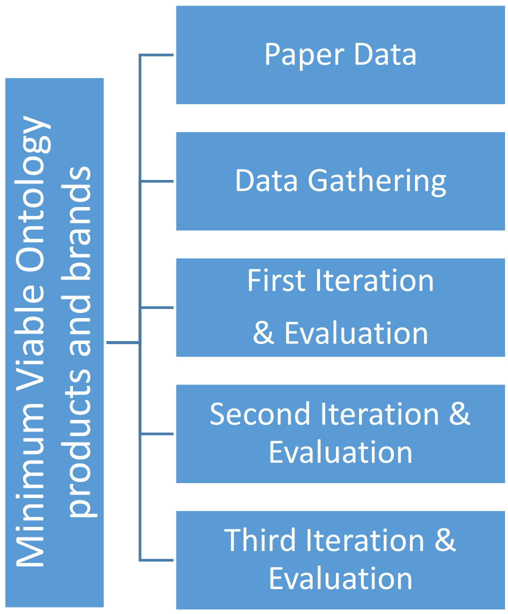

Figure 8 Proposed modelling framework detailing the Minimum Viable Ontology (MVO)

3.6. Design Build Evaluate Cycle

The DSRM framework define by Peffers et al. (Peffers, et al., 2007) is used to define the problem being solved and identifies the entry point. For this research the entry issue is that there are no defined conceptual models for the manufacturing of contact lenses. The supporting data structure is varied across manufacturing systems making the interoperability troublesome and complex. The quality of the data, completeness of the records also has inconstancies making data analysis time consuming.

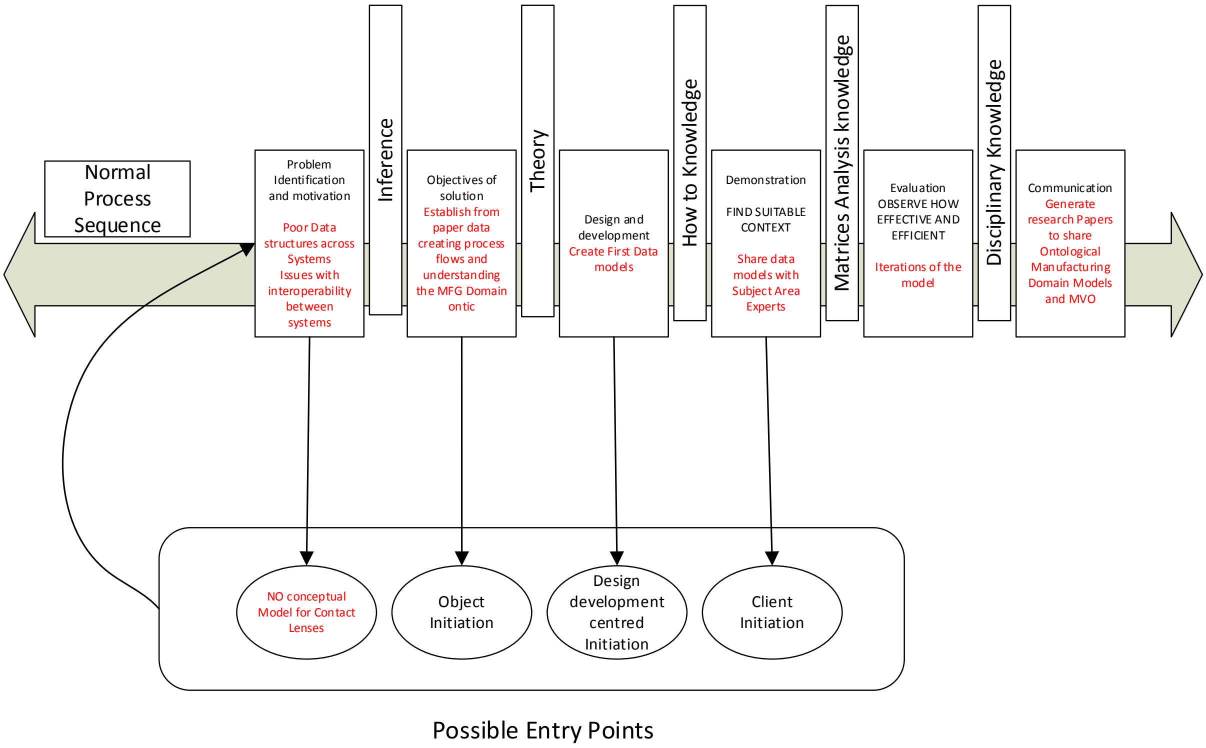

Figure 9 Design Science Research for the Manufacturing Domain based on (Peffers, Tuuanenen, Rothengerger, & Chatterjee, 2007)

3.6.1. Artefact management: Generation Framework

The proposed framework by March and Smith shows the first dimension of the framework is based on design science research outputs or artefacts: constructs, models, methods, and instantiations. The second dimension is based on broad types of design science and natural science research activities: build, evaluate, theorise, and justify. (March & Smith, 1995) The bare framework is shown in Figure 10

	Build	Evaluate	Theorise	Justify
Constructs				
Model				
Method				
Instantation				

Figure 10 Research Framework (March & Smith, 1995)

The constructs, models, methods, and instantiations are each artefact that address some task. The research activities related to these artefacts are: build, evaluate, theorise, and justify. Build and evaluate are design science research activities aimed at improving performance. Theorise and justify are natural science research activities aimed at extracting general knowledge by proposing and testing theories. Ibid.

3.7. Conclusion

This chapter details how the research within this thesis is to be executed. Adopting a design science methodology based on the work of Peffers et al. and using other framework tools from March and Smith to plan and critic the research journey.

The prior literature will provide the knowledge necessary to undertake this research. A full review will provide the areas of prior research in managing data within the manufacturing domain, some insight in to how paper data was used prior to computer systems to manage, record and manipulate manufacturing data.

The process of data mining has evolved in computer systems regarding storing of large volumes of data, how this data on data or metadata is and can be used. Introduce the aged problem of legacy data integration or interoperability, moving data from old legacy systems to a new environment or new system.

Provide some knowledge and understanding into ontology, to determining the correct foundation for the manufacturing domain and what choices are needed to be made to affect the manufacturing process.

Table 3, details the stages of the research and the actions and outputs of each iterative stage, there are three stages in total.

Stage	Purpose	Action	Output	Evaluation process
Iteration One	To collect manufacturing data in manageable sections: - Scheduling and Planning data Products Brands Manufacturing Processes	Extract Manufacturing data From Business units Interview Scheduling and planning department to establish the process from tribal knowledge	Process flow charts Unstructured Manufacturing data in tabular format. Initial Space Time Maps (STM) Initial concept of Minimum Viable ontology (MVO)	Clean the data Check with Subject area experts Re format data to make clear and readable Feedback from Subject Are Experts (SMEs) Evaluate STMs with SMEs
Iteration Two	Build Initial Models Classify products into families Type and sub types Set and power sets	Iterative process of quality checking Build initial models in Kumu (Graphical modelling tool) Translation from Kumu to foundational ontology model	Visual data models Initial patterns First iteration of Foundation ontology Generation of Minimum Viable Ontology (MVO) for contact lens manufacture	STM Feedback from Subject Are Experts (SMEs) Error Correction and re-evaluate

Iteration Three	Prove the model works Interoperability issues Data quality	Adapt the first ontological models through iterative process. Clean data, data types Update and provide clear data constraints	Prove the fundamental concepts from the MVO by practical application to legacy data conversion. Load data from Legacy into new system and evaluate the results	Evaluate Legacy load through BORO bCLEARer process Feedback from Subject Are Experts (SMEs)

Table 3 Research Activity Plan

CHAPTER 4 FIRST ITERATION

4.1. Introduction

This Chapter details the first execution of the first iteration of the research-design-build cycle defined in Chapter 3. The aim of this iteration is to extract and review the current datasets used in the manufacturing domain and document these for use in building the first conceptual model for the contact lens domain.

To improve any manufacturing process the first stage of the process is to understand how the operation works currently. For this practical approach the current architecture and business process must be first documented in a flow chart format to understand the business interactions between systems. Understanding what data is important to which particular part of the process. The second stage is to increase understanding of these processes with all of the experts or SMEs (Subject Area Experts). Products are an output of processes and in terms of manufacturing, Business Process Modelling (BPM) is used to define and optimise these processes. Products that been manufactured over time or a significant number of years often constrain as computer system, stifling the introduction of enhancements because the products either don't require it or its too complex to systematically implement. All products have their own required data needed to manufacture them. Before computer systems this was paper based data, written data detailing the specifications and components of products and a log of their journey through an iterative process of improvement over time, meaning changes to the manufacturing process were documented, each small improvement noted and recorded for future use, each iteration having its own set of data associated with it. The timeline in Appendix A illustrates the birth of the contact lens idea, back in the 1500s the timeline shows the incremental improvements over time and although technological advancements have happened through the time period to now, an important item to note is that there has never been a conceptual model produced for this domain.

In the natural design phase, we make one, improve the design then we make many, then families of product, to extended families of products etc. This is part of the Product Lifecycle Management (PLM). For example, car manufactures Ford, making one family of cars with the same components, a hatchback, saloon, minivan etc. (Ulrich & Eppinger, 2016). Each part of the manufacturing process has its own product dataset associated with it, this data resides in either, several isolated systems or held in paper. This data extraction exercise requires a high-level understanding of the manufacturing process.

4.2. Design Science Research - Iteration One

The activities within this iteration serve to explore the research problem and are planned and executed in accordance with adopted design science research methodology. A diagrammatic overview of the first iteration and how it relates to the subsequent iterations is provided in Figure 11.

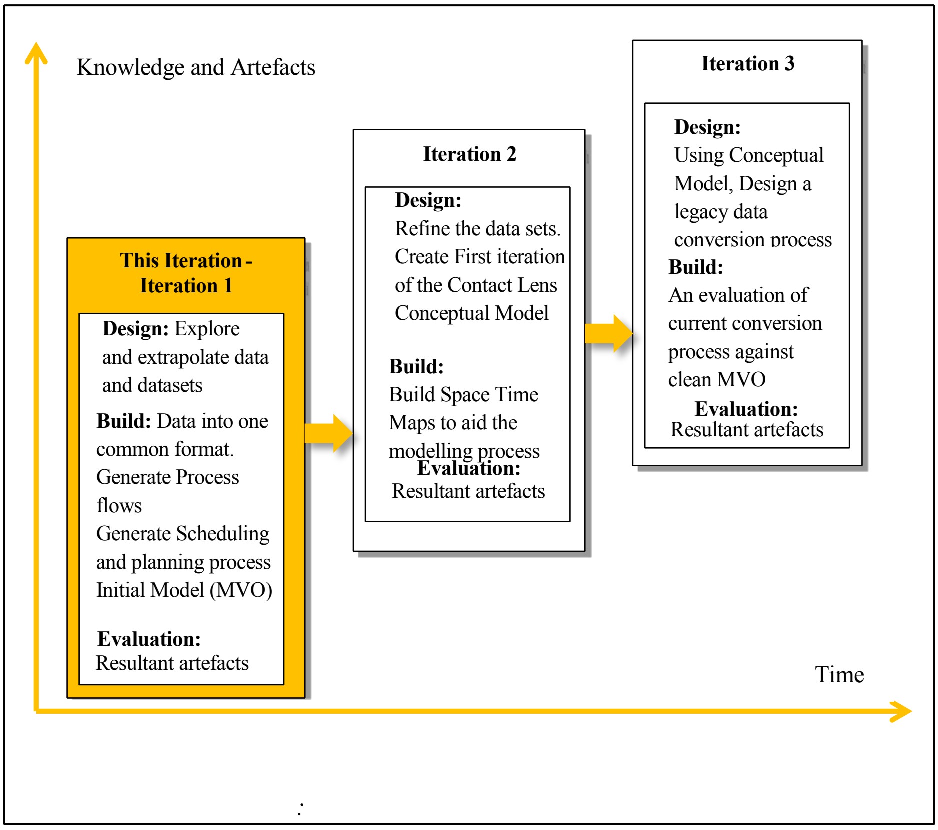

Figure 11 First Iteration Design Sciences Research

4.3. Objectives of the First Iteration

The objectives of the first iteration are to extract and compile all of the manufacturing data including, product and brand data and scheduling and planning data from all of the disparate legacy systems. This data is held in a number of locations and no one person knows or understands or has a view of the current data structure. The products are manufactured using several differing processes, these are to be explored, drawn up and analysed as part of iteration one. The possibilities of using the ontology re-engineering method and associated tools is to be explored. A foundation ontology or 4D ontology may have potential to remodel the data piece by piece and be beneficial to the manufacturing domain. Reviewing data into Simple and Non-Simple datasets and determining the size of data to reengineer in the first instance is dependent on the gains. Products and Processes appear to hold the largest and dirtiest set of legacy data and therefore the biggest potential for reengineering. Figure 11 shows the artefacts per phase and the location of the evidence.

Stage	***Activity***	***Objective***	***Section Reference***
Design	1	Gather the data with reference to the planning and scheduling of contact lenses.	4.5
	2	Gather the process steps from a manufacturing process and over lay the data to this process.	4.6
	3	Gather Products and Brands data	4.7
Build	3	Build a process flow for the planning and scheduling events and data.	4.6
	4	Build process flows for the manufacturing work streams, overlay the manufacturing data and which part of the process indicating which system hold this data.	4.11

Evaluate	5	Review process flow with subject area experts and make changes were necessary. Using bCLEARer to Clean, Load, Evolve Assimilate and Reuse	4.12

Table 4 Framework for first Iteration

4.4. Background

CVI acquired Sauflon Pharmaceuticals Ltd during 2014. Sauflon were a European manufacturer and distributor of soft contact lenses and solutions, CVI acquired Sauflon for a purchase price of approximately $1.2 billion. Established in 1985, Sauflon Pharmaceuticals Ltd is a privately-owned British company and a global manufacturer of contact lenses and aftercare solutions. It has three manufacturing plants, sales offices in over 10 countries, and products sold in over 50 countries.

The process of bringing together two similarly sized established companies is extremely complex. Both companies have a similar portfolio of products, often they will have the same customer base, similar purchasing partners and so on. The businesses are run by two different enterprise resource planning systems (ERP). CVI use a middleware system to manufacture contact lenses and Sauflon use paper-based forms to capture their manufacturing information. Middleware applications manage the resources required to produce products, primarily, Bill of Materials (BoM). As both companies are regulated by the FDA and the European Union as well as other global regulatory bodies, the manufacturing data must be kept on record for a number of years, typically five years after the expiry date of the product. Meaning if the expiry is five years then the records (regulatory data) must be on hand for retrieval for a minimum of ten years (FDA Food and Drug Administration,, 2017).

4.5. The Process Introduction

A contact lens manufacturing process is used as an example as this includes made to order and made to stock products. Making to order, means there is a patient waiting for an order and the fulfilment needs to be with a 24hr period. Making to stock is equipping the warehouse with the correct amount of each individual SKU to satisfy the sales forecast. The process of gathering this data is by interview with various members of the Supply Chain group to understand the process. This is a process of business steps, which are procedural not system based often termed as Tribal Knowledge, bespoke business processes that are known and not documented by individuals or business group and often described as “Know How” (Bertain & Sibbald, 2012) These business processes were never written down in any prior order within CVI and had to be gleaned during the interview discussions with SMEs. These are to be the first understandings of the business process and data flows to manufacture contact lenses.

4.6. Scheduling and Planning Data

Starting with the scheduling process to understand the concepts and terminology in the contact lens manufacturing domain, the initial scheduling process commences with a long-range strategic plan (LRSP) typically a 5-8-year plan that outlines the companies forecast for growth and how it will meet the demand. A steering committee, compromising of key stakeholders in an organisation, such as financial controller, manufacturing directors and senior business leads meet to agree the actions of the LRSP. A budget is produced from the LRSP and typically reviews a small-time period of 12-18 months. This budget is derived from information received from the sales demand forecast, which is the predicted sales forecast for the coming period. This sales demand is made up of information based on current sales forecast and historical trends. See Figure 12 for illustration of this process.

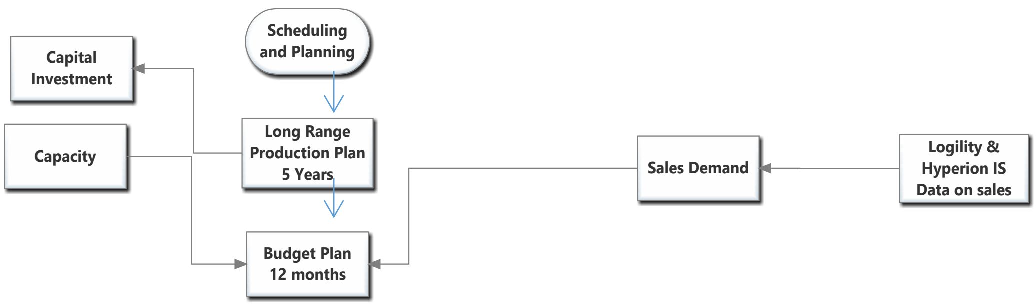

Figure 12 Long Range Strategic Plan & Budget

The budget process aligns the current manufacturing capacity with the sales demand and identifies any shortcomings in production due to capacity issues. From this information the steering committee can deliberate to increase capacity by purchasing more automated production equipment, expanding the business capacity. The data in the budget plan is used to create a global sale and order planning schedule, which holds data our current inventory levels for all the stock held in the warehouse as well as the predicted demand from historical data and the actual net demand seen through the organisation.

The demand planning is then spit into local entities, such as European or the Americas manufacturing. Each local site manages the plan on monthly / weekly bases, using a Purchase Order Sales Order (POSO) program to make production orders. Local level planners work in smaller business units and create a schedule from the plan. This process is detailed in Figure 13, this depicts the complete process and in Figure 14. The Local Planners employ an iterative process to schedule and reschedule the lenses based on machine availability and being able to produce the product to the correct quality specification in a timely manner.

Although this data discovery of how this process is currently working in manufacturing is a useful exercise, the data is not useful enough for a larger scale re-engineering project due to its simple data flow. There is greater potential for gains in the products, brands and process areas of data collection as this domain is a constantly interrogated during times of mergers or acquisitions. The process of collecting and collating the data is in itself an interesting exercise, the groups involved in the scheduling process are located in different countries and work for different parts of the organisation. Discussing this data was the first occurrence of collaborative work on this data.

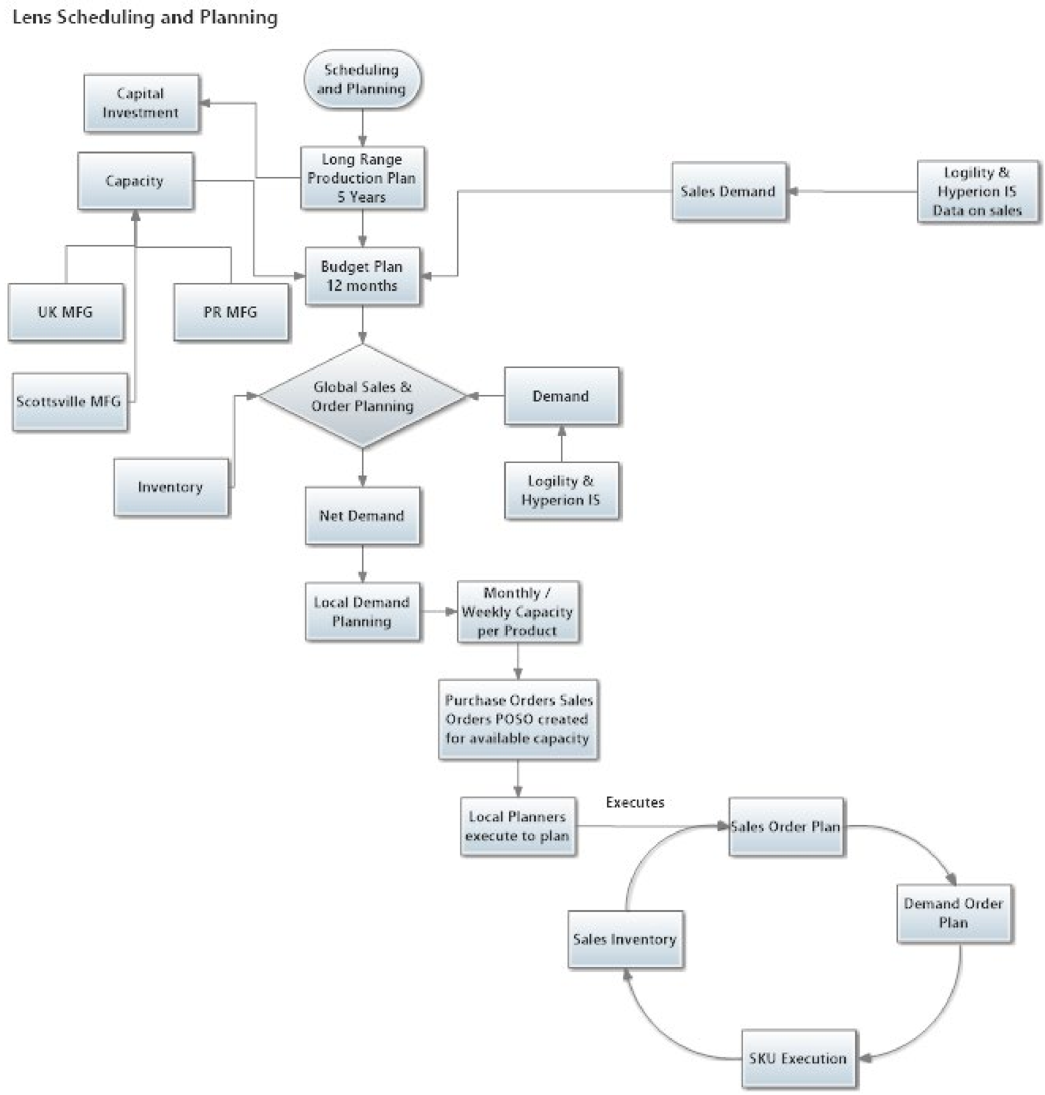

Figure 13 Global Sales and Order Planning Process

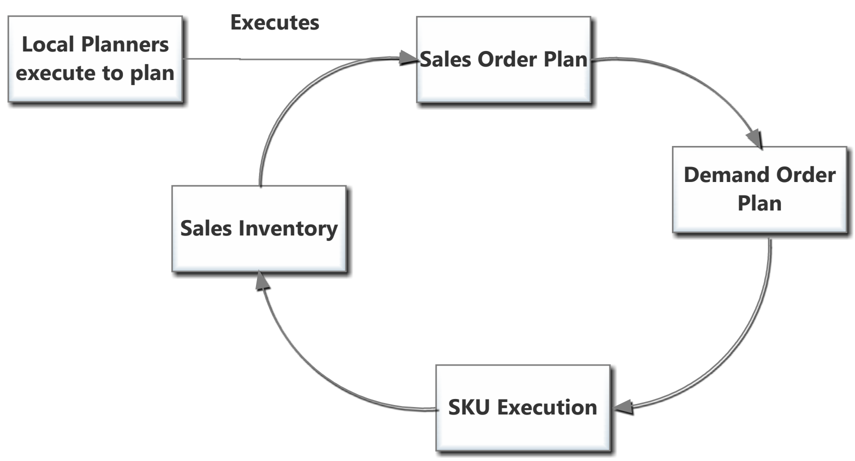

Figure 14 Local execution of the planning Schedule

4.7. Products and Process Data

The process of data gathering starts collating manufacturing data on the products workflows. For this initial data gathering, a sub set of business product and process data was collected. The manufacturing process is split into business units, each one responsible for manufacturing their products to a planner's schedule. The data is split across a few disparate systems, with little or no apparent need for interoperability between systems. The sharing of data between legacy systems was not a requirement in the early years of manufacturing, as the complexity was always fit for purpose for the task in hand. As the demand for products increases the company grows in capacity, but often fails to increase its IT infrastructure capabilities or systems requirement to meet the needs of the ever-changing demand.

Initial datasets are extracted from key business systems, CVI utilise an in house-built manufacturing Execution System (MES), built in the late 90's and maintained by an in-house group of developers. The system is a collection of relational databases connected by a front-end thick client application. The application is written in a mixture of C# and VB.net. The CVM (CooperVision Manufacturing) application contains all the data needed to manufacture the products for all of the brands in the UK. Including Bill of Materials (BOM) through to resources to manufacture the products. CVM also controls the manufacturing process. The contact lenses are manufacture in two parts, Dry and Wet processes. After the Wet process the products are sterilised, packaged and either stored or shipped to customers.

4.7.1. The Data Collection Points

The Dry process consists of a pair of injection moulding machines male and female, which have the necessary inserts or tools to produce the required prescription being demanded by the planning department. The inserts produce plastic (Polypropylene) moulds or casts that are used it inject the correct amount of Monomer (material used to manufacture the contact lens. The monomer is in liquid form and the precise dose is administered, typically 60 to

70µl to several cavities, which is dependent on the number of inserts in the mold tool. After the dispensing process has been completed the male moulds are placed on to the female moulds and closed to a predetermined force in a closing machine. This is an important part of the process to ensure there are no bubbles present between the two moulds. The presence of bubbles will not produce a full lens to the correct thickness, causing a reject. After the filling process, the closed moulds are cured in an oven and bagged as Work in Progress (WIP) to await an official release by the Quality Assurance group. Figure 15 illustrates the Dry manufacturing process. Data is gathered at the beginning, during and at the end of the process. The initial setup to product type, the in-process data and the finished dry lot data are all stored in the relational tables within CVM Dry application. Families of products are stored in their own data tables and related to other parts of the database through linked queries. This provides another short fall and an opportunity for data integration errors.

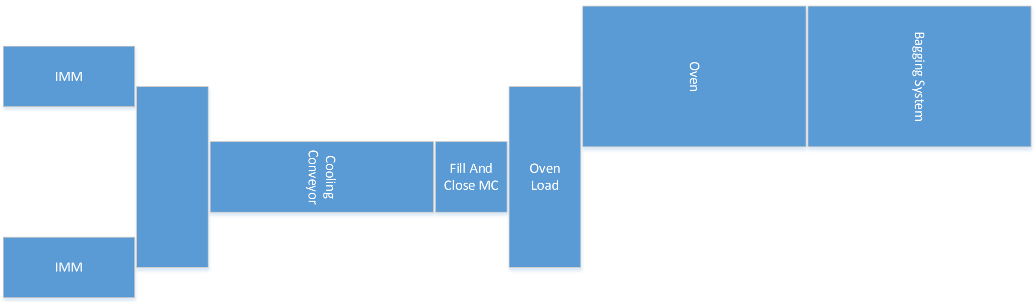

Figure 15 Dry Process Diagram

WIP consists of several dry lots held in bags that are stored in Gaylord[3] containers. CVM Wet systems contains a list of available dry lots to manufacture a particular SKU or prescription. As well as dry lots, there is another BOM for the wet process. blisters, foil and saline are required to make a finish product or Silver stock item. The Blisters are the carry a contact lens is packaged in, often referred to as a primary pack. The saline is used to hydrate the lens from its dry form into a soft contact lens and the foil is used to seal the

[3] Gaylord containers: In the U.S. and Canada, the term gaylord is sometimes used for triplewall corrugated pallet boxes; this is due to the first bulk bins being manufactured by the original Gaylord Container Company of St. Louis, which was acquired by Crown Zellerbach of San Francisco in 1955

saline and lens into the blister pack. The Wet process manages this automated process with data from CVM Wet. The finished Blister packs are then sterilized in an autoclave to kill of any bacteria and bugs and make the lenses sterile.

The data stored in CVM Wet is held in relational data tables consisting of all the available bill of materials to make the required products. The raw materials have an active shelf life, meaning they need to have their expiry managed carefully to avoid any issues with non-conforming products being produced. The Wet process uses output from the dry process to manufacture the contact lenses, illustrated in Figure 16.

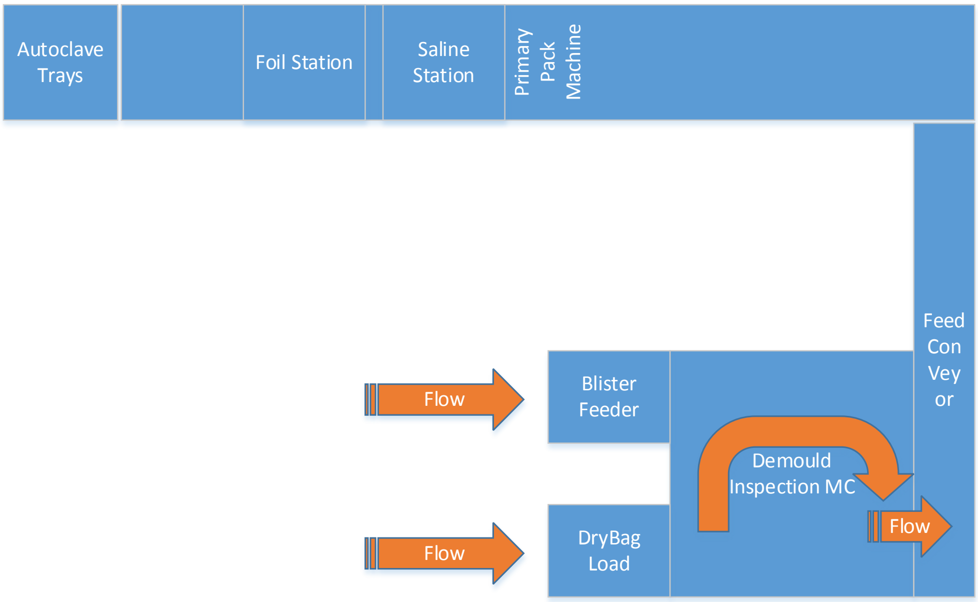

Figure 16 Wet Process Diagram

After the Wet processing has concluded, and the lenses are sterile, they are shipped out to distribution centres for final packing in the brand boxes and patient leaflets inserted. From here they are sent out via standard or expedited post to customers worldwide.

4.8. Products and Brands: - Preparing the Data

Companies manufacturing contact lens, more often have many SKUs in their systems they can call upon to manufacture at any one time. The large number of different product types with several key attributes that make up the lens SKU. These attributes can be categorised into two distinct groups, comfort or lens comfort the patient experiences while wearing the contact lens and the vision correction group, where the lens power correction and the user's sight is regained through wearing the lens.

4.9. Contact Lens brands and their transformation from Silver stock into Brands

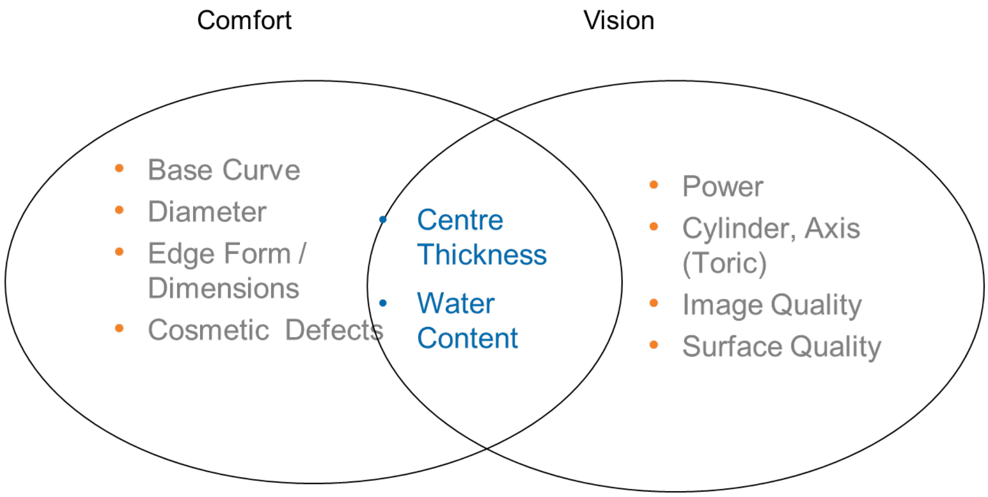

Figure 17 Attributes of Contact Lenses

The varied number and type of SKUs in process at any one time depends on the demand planning for the product. The Gaussian curve of popular prescriptions for each product is predominately a made to stock product and is scheduled through the demand process. The lower demand lenses are manufactured in a different process, more labour intensive and usually manufactured in singular format specifically for the individual patient. The product type SKU is read, and the attributes of the lens retrieved from lookup tables that define the specification of the lens. Figure 17 illustrates the common parameters that are included in a patient's prescription.

CVI have 8.5 million different combinations or prescriptions to meet patients eye correction needs, of these the largest distribution of lenses falls within approximately 5.5 million lenses. As CVI grow through acquisition there are several duplicate products, or different brands competing in the same market sector. This can be a problem as Opticians like to keep to their particular brand names that they are happy with and are sometimes reticent to move over to other products. When this happens over a twenty-year period, with companies merging and CVI growing in terms of volume and product diversification this lens SKU number is ever increasing.

The initial stage of the data gathering cycle is to understand what products are currently being manufactured by CVI, these products need to be understood in terms of their specification and their origins. This process takes place in the form of mapping the production using common data gathering methods and as product knowledge increases updating the data sheets with the information. CVI's products are listed in Appendix B.

4.10.Design: Extracting the Model Data

The Extracted data from Products and Processes (Appendix B) is used in conjunction with the BORO Unified Modelling Language (UML) a framework for re-engineering legacy data (Partridge, 2005). And based on a 4D ontological model, the Business Object Reference Ontology (BORO) Foundation provides the fundamental ontic categories of Elements, Types and tuples.

To identify all of the elements and their interactions with other elements, space time maps are generated and reviewed for correctness. The four key types of things are identified in the BORO approach defined as: -

- Particular things,
- General types of things,
- Relationships between things, and
- Changes happening to things.

The introduction of BORO in CHAPTER 2 a review of current literature provides some background as to why a grounding using a foundation ontology is beneficial the table below details the attributes of the BORO process with a description of each model element and its reason why it is essential in the reengineering process.

Super-Sub Type	A super-sub type is a set theoretic basic relationship, the pattern establishers a relationship between two types that asserts that one type is a specialisation of another type.
Types Instances	Asserts that an Element, tuple or Type is a member of a Type
Power Type Instances	Asserts that a Type is the Power Type of a Type (set of all possible sets).
Power Types	A Powertype is defined as the set of all subsets that can be created from a set of either individuals or sets. PowerTypes, are represented within the Ontology however, they are never fully instantiated rather they provide a method of modelling higher order objects – such as Types containing instances of Types (second order). A powertype can also have a powertype instance, this allows third order, forth order (ad infinitum) objects to be modelled. Thus, powertypes can be employed to model the structures that form classification systems.
Whole-Part	The whole-Part tuple asserts that one (part) Element is a part of another (whole) Element. Object semantics supports both abstract concepts of; whole-part relation where the whole can either be a proper part or an improper part, i.e. a part of itself.
Temporal Objects	Object semantics physicalizes time; thus, a time period becomes a physical Element – an spatio-temporal object. The time dimension can be measured as a time-period, for example a day. It has a spatial dimension that is all of space between the start and end of the time period.
Event Temporal Objects	Under object semantics the distinction between a time-period and an event is that events do not persist through time and are defined as slice of a four-dimensional extension with zero thickness along the time dimension. Consequently, the distinction between physical bodies such as a period of time and an event is that the former, as it persists through time, is a four-dimensional object and the latter, as it does not persist through time is a three-dimensional object. a four-dimensional world.
Temporal Whole-Parts	As object semantics physicalizes time we can apply Mereology in the same manner as the spatial whole-Part relationships. Therefore, the Temporal Whole-Part tuple can assert that one (part) Element is a part of another (whole) Element.

States	A state is a temporal part of an individual that persists through time. States (and elements in general) are bounded by events. A state can have further temporal parts such as sub-states and events.
The happens–at (whole–part) tuples	The happens–at (a time) pattern provides a relationship between an event object and the spatiotemporal object that it is a part of. Object semantics proposes that an event a three-dimensional object
The happens–to (whole–part) tuple	An event - can be associated with the object that the event happens to by the happens–to' tuple. The event that is associated with object by the whole part relation. This is a temporal mereological relationship, the event is a temporal part of the object that it effects. In object semantics, the 'happens–to' tuple is an extension (a composite of the two member extensions) and so an object within the scope of the paradigm that forms a connection between the extension of the event that is a part of the extension of the object that the event happens to.
Names **NameSpace**	Within BORO 'Names' are physicalised; they are considered to have spatio-temporal extension and as they are defined by the fact they name something (one element within the ontology) they are a defined type. To provide clarity within the ontology, 'names' have a separate structure from the things they name. BORO also provides representational, symbolic based structures.

Table 5 Foundation ontology patterns (Partridge, 2005)

The decision to use BORO over other foundation ontologies is made primarily due to its handling of elements over time, which makes the modelling processes more accurate for any given time slice. Another positive benefit is the classification of things, ideal for managing families and families of things, through type and powertypes Table 5 shows the foundation structures of BORO.

4.10.1.Initial Data sets

The extracted data needs to be checked for errors and classified, for the first instance products are group together by family types or modality, meaning their usage either daily lenses or extended wear lenses, two weekly and monthly and then sub classified into SKUe. For example, the range of products contain spherical and aspherical product types, these are the base set that contains the sub categories of the product families. Proclear and Biofinity are such product families, the materials to manufacture these are different and therefore require different BOM to create the products. Figure 18 illustrates an example of the extracted data for BOM, with the material type on the left hand column, the ERP BOM number, in this case iBAAN, by INFO Systems[4] and the Lot or sequence of that particular material type, this is important in lot traceability, so final shipped products can be recalled if there is an issue with any of the materials used to manufacture that product.

Material	BAAN No.	Lot Sequence No.
TAIC	DP-3066-01	60422
IBM	DP-3067-02	61422
2-HYDROX...	DP-3068-02	61156
VMA	DP-3160-05	58463
NVP	DP-3070-01	61935
FMM	DP-3060-01	59601
M3U	DP-3062-01	60254
TPO	DP-3071-01	58170
AOT	DP-3159-01	60025
M3U BLUE	DP-3061-01	61507

Figure 18 Extract of BOM

To continue the data extraction process, all of the common process activities used for manufacturing contact lenses are defined in a process map Figure 15 and Figure 16.

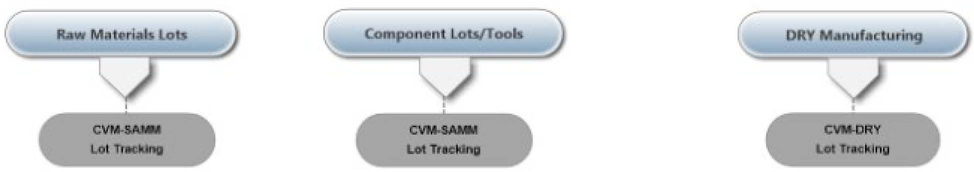

Figure 19 Primary Stages of Manufacturing Contact lenses illustrating Data required

Different systems manage each individual elements of the data, CVMSAMM, (CooperVision Manufacturing Solutions and Materials Management), manages as expected the materials and solutions required to manufacture the products, this system, contains the inbound receiving process to accept raw materials into the organisation, and contains records for quality control checks on all products received. The association of

[4] iBAAN is part of the INFO Systems portfolio of Enterprise software solutions https://www.infosystems.biz/

manufacturing runs or Lots to raw materials and sub raw materials is held as part of the lot tracking genealogy.

The raw materials are consumed in the manufacturing processes as defined early in this chapter and depicted in Figure 19. The final process steps, the serialisation, the final packaging and shipping to customer utilise different system.

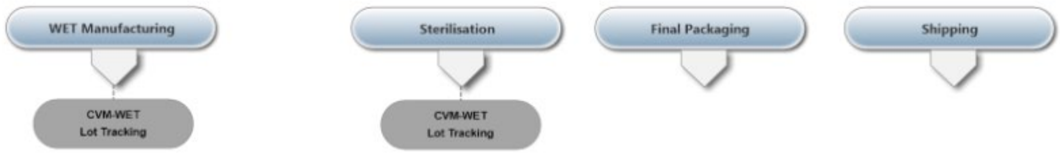

Figure 20 Secondary Stages of Manufacturing Contact lenses illustrating Data required

4.11.Build: The initial data for the Conceptual Model

To begin to model and reengineer these current processes, the process flows need to be analysed, for correctness, as each aspect of the process can be interrupted differently by different individuals working across the process. Processes are multi-faceted, meaning there are many differing view-points (García-Barriocanal, et al., 2012) and as such there is no real master of the other all process or ontic (Chalmers, 2014).

4.11.1.4D Foundational Ontic Categories

BORO contains at the highest level of the ontological architecture, the Business Object Reference Ontology (BORO) Foundation provides the fundamental ontic categories of Elements, Types and tuples.

4.11.2.Initial concept of Space Time Map

Based on the work of Minkowski, a Minkowski diagram or a Space Time Map or STM is a graphical representation of a 4D fragment of the world (Minkowski, 1908) (Minkowski, 2012) Used in the conceptual modelling world to understand and document areas of the process definition. Use of the STM can help to identify areas or boundaries where there is potential for errors. The life of a contact lens, when does a lens become a lens, process stages and the handling of reject parts are all considerations of the data. To model the life of the lens in terms of STM involves reviewing the stage of the lens during the manufacturing process. STMs help identify several small-time slices, similar to Zeno's conjecture (University of Notre Dame, n.d.) where there are an infinitesimal number of steps between two points.

The process is reviewed, documented and discussed with SMEs with the knowledge of their area. The levels of understanding are increased between silos of knowledge, brought together by the collective understanding of the STM.

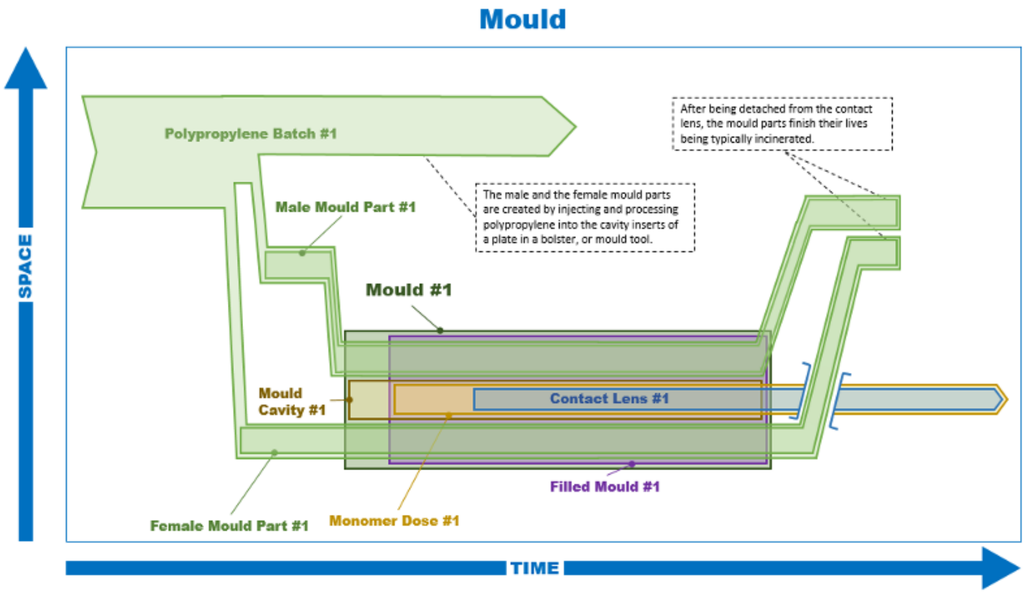

Figure 21 Space Time Map of a Contact Lens

In Figure 21 Space Time Map of a contact lens illustrates where polypropylene is used to manufacture the male and female parts of the contact lens mould, the polypropylene occupies space and time past present and future and a small amount of polypropylene is used to make the parts, the cavity is filled with the lens monomer material and cured, the mould is removed and although exists is no longer part of the lens. The lens will exist indefinitely until destroyed or reprocessed into something else. This pictorial view of a lens is useful as throughout the organisation not everyone is aware when a lens becomes and lens and what process steps are involved. One particular issue within this STM is the fact he male mould has to be removed out into a different space while the monomer material is injected into the female bowl, the male is then replacing on top of the female to a given force, the STM has omitted that particular event and temporal part of the lens life. Other BORO tools are used to identify and create clearer understanding of the data and the processes using this data. The bCLEARer process a foundation tool from BORO helps to provide a framework to extract and manage data.

4.11.3.bCLEARer Process

The bCLEARer process is a custom tool for collecting the legacy data, loading the data, evolve or clean erroneous datasets, Assimilate or understand the data being used and finally reuse the data. These five process steps are part of the method of the foundation ontology BORO. The data issues the bCLEARer method is identifying for example are issues with collations between databases. Sometimes these are not consistent from database to database and there may be issues with foreign language, which do not correlate from one database to another. Blank spaces, unique characters may all be translated and have a different meaning. The legacy data can be introduced from several different sources or domains. In the initial data gather the source systems were from manufacturing execution systems. Not all the data is in the same system, so charts are created to illustrate the process steps and the data associated with each process step. The difficulty arises when there are different products using the same or very similar process steps.

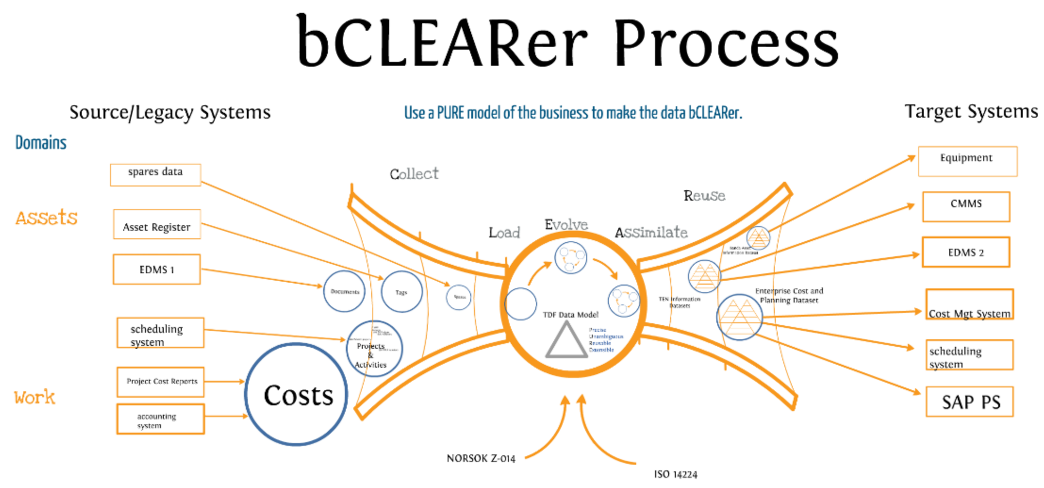

Figure 22 bCLEARer process[5]

In Figure 22 illustrates the basic principles of the process steps, in its simplest form, firstly taking in legacy data from disparate systems or paper datasets, loading into a base repository and secondly, checking the data for both cleanliness to data types and against any potential standards that may exist for that type of data, for example ISO 14534:2011 (ISO, 2018). Ophthalmic optics contact lenses and contact lens care products have the specifications required for safety and performance requirements for contact lenses and related products, such as the need for risk assessment, specifications for design, materials, clinical evaluation and manufacturing, microbiological requirements, packaging, shelf-life and discard date and product labelling. Other sources of data include manufacturing machines, the assets used to make contact lenses, these must be maintained to keep manufacturing within capable limits, and they have a maintenance system asset tags associated with elements of the automation process. When an asset requires a service, or a maintenance change an element of the machine is changed and logged in the system, this data needs to be collected and retained for the regulating bodies. The data is of interest to the maintenance team and the schedulers and planners as the can begin to identify single point of failures and expected component life or the particular “sweet spot” of any given piece of machinery. All of this

[5] Copywrite of BORO, diagram to illustrate BORO internal process

data must be collected and analysed in the Collect and Load phase of the bCLEARer process, it is the primary tools used in the first iteration.

4.12.Evaluation

During the data gathering phase several observations were noted, firstly the classification of things, mixing up of brand names and processes. People, users of the data had made assumptions mixing brands and product types, locations and processes as a way of distinguishing and classifying products and brands. Erroneous data in datasets were plentiful, typos from different systems caught up in alias tables to make translations were apparent. These errors came across from a number of legacy systems. Issues in reviewing the dataset proved to be an issue, as benefit can be seen in having the data in a relational database to make it more useable and be able to query the data. As the manufacturing datasets relating to products are so large there is a need to visualise the data in a friendlier format. For this purpose, Kumu was used. Kumu is a powerful data visualization platform that helps you organize complex information into interactive relationship maps (Kumu, 2017). The Kumu maps illustrates areas of interest in a more user-friendly way. It makes data clear and visible when handling several data objects. The core lens data for all contact lenses sold is held and published by Tyler's Quarterly (Tyler's Quarterly, 2016), this publication holds all of the specifications of all the lens families sold from different companies other sources of this flat paper set of data on contact lens specifications are OD Specs (OD Specs, 2016) ,the Eye Doctor website (The Eye Doctor, 2016) and the Contact Lens database (The Contact Lens Database, 2016).

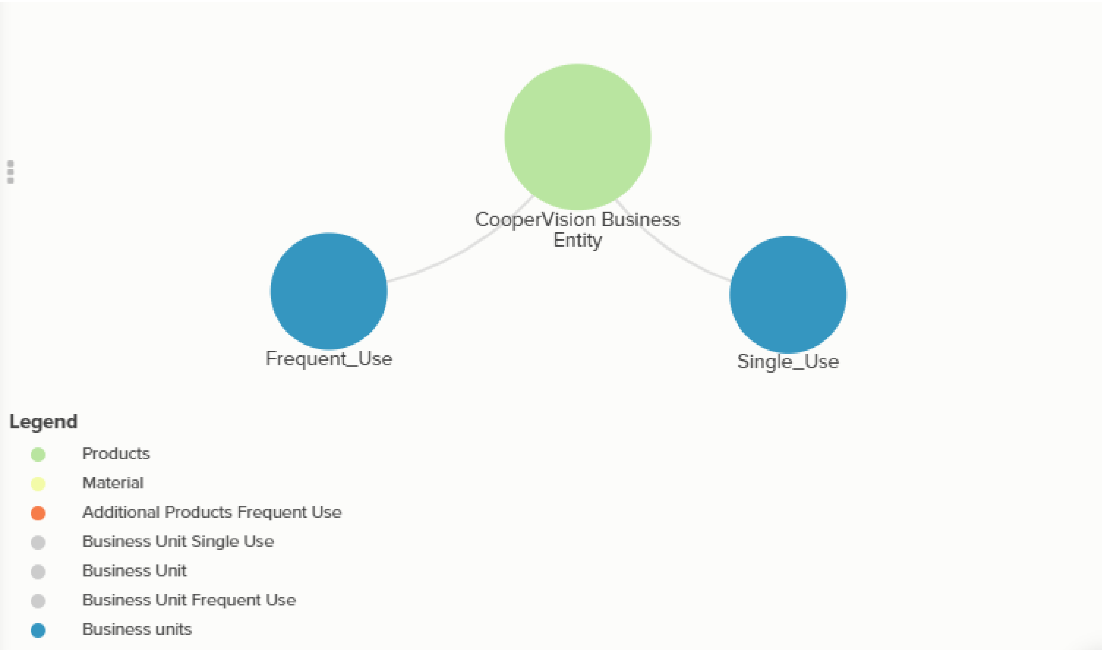

Figure 23 Kumu Map Showing Use Type

The Use type illustrated in Figure 25 using Kumu to show the type of lenses families based on lens type usage. The raw data from legacy source systems is collated on to an excel loader sheet ready for importing into Kumu. The spreadsheet has been ordered by lens usage and contains all the product range from CooperVision. The data is scalable and has several different views available. In Figure 25, the core CooperVision Business entity is shown with the product type by usage or deemed usage. The data in the loader has several errors and is only cleaned for illustrating in Kumu. The full Kumu model can be found at https://kumu.io/marribo/cvi-products and the presentation of the data can be found at https://marribo.kumu.io/cvi-products. This base Kumu model is the initial concept of the Minimum Viable Ontology for contact lenses and will be expanded upon in Chapter 5, taking into consideration a larger set of data and using the BORO foundation ontology to ground or formalise, elements, types and tuples into the first conceptual model. The data is cleaned using the bCLEARer method to extract and clean data.

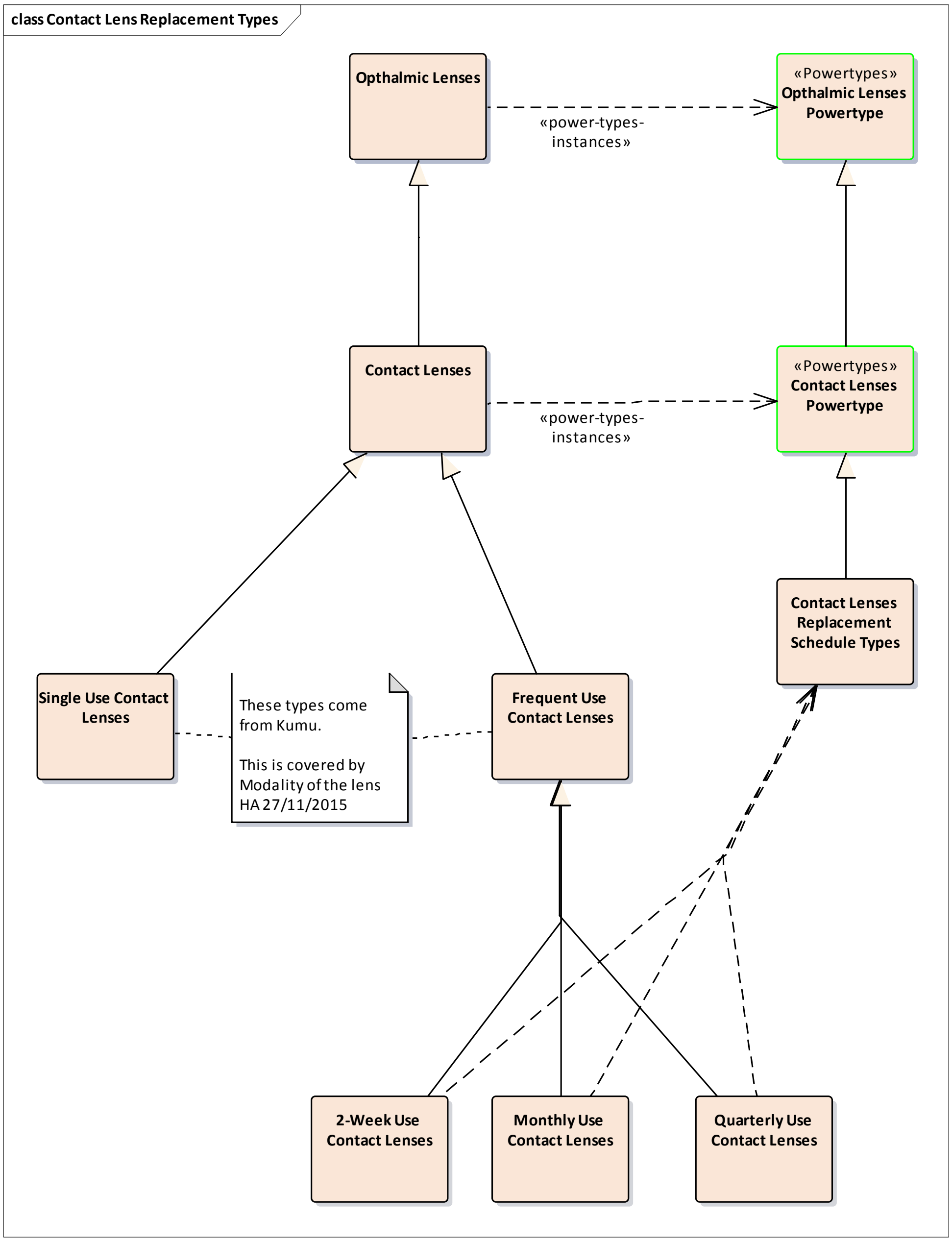

Figure 24 Kumu Use Type represented in EA

The Kumu use types or modality of lenses is depicted in Figure 24 and is one of the founding models for the MVO. This model is built in EA from the data extracted and populated from the initial spreadsheets. The spreadsheets are built based on information received from the SMEs and checked against the corresponding systems, the bCLEARer method is used to check the data for errors. The contribution from the first iteration with the artefacts, method and contributor is detailed in Table 6.

New Contribution **Artefacts produced**	**Methods**	**Contributors**
• Lens Scheduling model • Planning Schedule Execution model	• Identification of systems used in Scheduling • Review Visio drafts with SMEs	Built in Visio by researcher and ratified by SMEs
• Process diagram Dry • Process diagram Wet	• Review new Visio drafts with SMEs	Built in Visio by researcher and ratified by SMEs
• Systems Map	• Review new Visio drafts with SMEs	Built in Visio by researcher and ratified by SMEs
• Initial product and process data sets	• Review new Excel drafts with SMEs	Built in Excel by researcher and ratified by SMEs
• Kumu Products visualisation	• Import new Excel product and process information into Kumu	Built in Kumu by researcher and ratified by SMEs,

EA Kumu Model, Initial Model for MVO	• Work with BORO minimal core to create first draft of Kumu data set and basic MVO	Built in EA by researcher and ratified by SMEs,

Table 6 Contribution table for first iteration

4.13.Summary and Conclusion from the First Iteration

This iteration of the design science design build evaluate cycle frames the process of knowledge gained in extracting manufacturing data from products and process manufacturing steps. When looking for manufacturing data from an organisation that has grown from a number of acquisitions over a number of years, it is difficult to build a complete picture or ontic of what exists. Data must be identified based on what is deemed to be important, in this chapter we review the process of manufacturing and identify the Product base and the modality or usage of particular products. Introduce the base process of manufacturing contact lenses and the core data required for the manufacturing domain and the regulatory bodies. Company acquisition merges a great deal of manufacturing data, normally linked not through designed systems but people and a plethora of spreadsheets. Issues arise with naming convention and data types when trying to build one holistic view of a manufacturing company's domain data. The introduction of BORO foundation ontology and its associated tools as a potential solution to reengineering the legacy data with a view to building a more robust data model for the domain. The initial concept of MVO is established and enhanced upon in Chapter 5, with the conceptual idea of the MVO held in flat data or excel workbook, or the beginnings of visualisation in Kumu. Table 6 illustrates the artefact produced with the method and the contributors. Work will continue the MVO utilising the BORO foundation ontology core model in Enterprise Architect (EA) and the domain ontology for contact lenses will progress with more product datasets being added to enhance the model.

CHAPTER 5 SECOND ITERATION

5.1.Introduction

In the previous chapter was detailed extraction of data in preparation for reengineering the model and the introduction of the MVO, a basic concept of a model for the contact lens domain. In this chapter the focus is on using the prepared data in the previous chapter to build a basic domain ontology for contact lenses using the BORO foundation ontology tools and process steps.

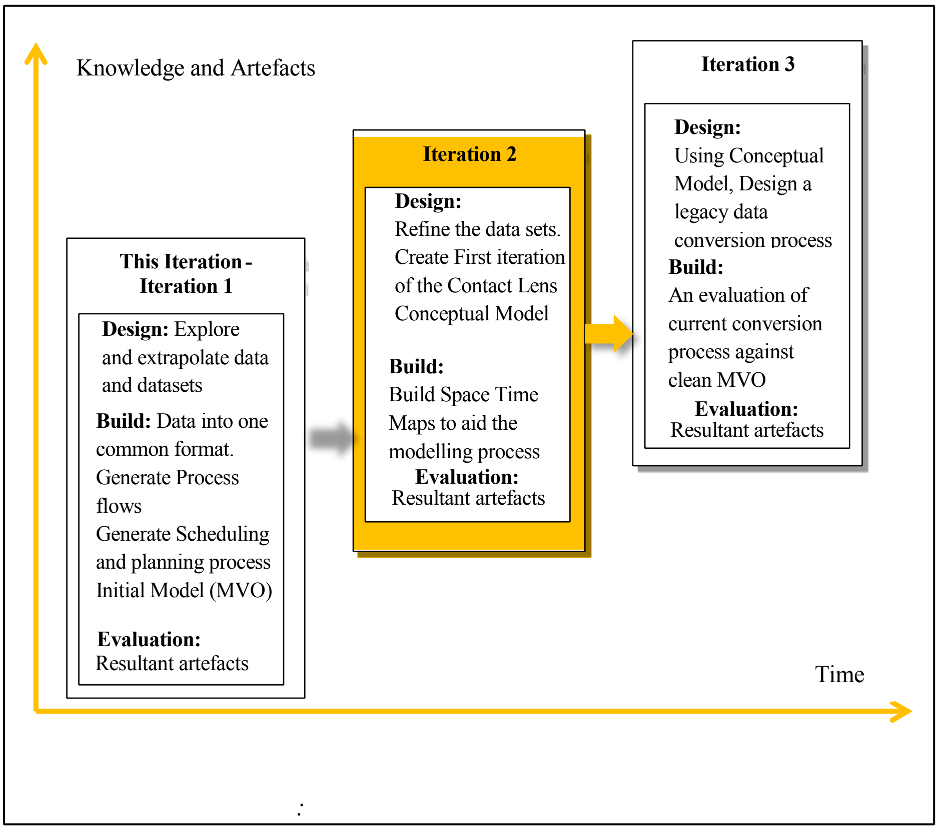

Figure 25 Second Iteration Design Sciences Research

After reviewing the scheduling process and documenting the artefacts, it is deemed that the greatest area of learning is with the Products, brands and the manufacturing process. To begin by defining the lens and types of lenses that can or could exist is the first step in generating a base model to allow lens type to follow. Figure 25 and Table 7 shows the next iteration of artefacts to be produced using the design science methodology.

5.2. Objective of Second Iteration

The objectives of the second iteration are to demonstrate a simple domain model for the contact lens domain using the BORO foundation ontology to reengineer data sets discovered in iteration 1, chapter 4. The initial product and process data sets, Kumu products visualisation and the initial MVO model born from the Kumu model are used in the detailed enhancement of the MVO and generation of the STMs.

The model focus is twofold, products and process, using EA to model the products and STMs to pictorially reproduce the interactions through space and time. For this, guidance is taken from the work of Wimsatt, ensuring robustness when dealing with things or concepts this is follow on work from Levins (Levins, 1966), when dealing with things they are considered robust if they are detectable, measurable, derivable, definable, producible (Wimsatt, 2007). Moving from paper and independent systems with SME tribal knowledge to a conceptual model grounded with a foundation ontology this robustness approach is important and only things that meet this criterion are added to the model. Each snippet of data gathered is reviewed by SMEs and documented becoming part of a base model.

Stage	*Activity*	*Objective*	*Section Reference*
Design	1	Improve the initial data sets, checking for errors in data quality and data types	5.3
	2	Using Enterprise Architect and BORO foundation ontology to design the Minimum Viable Ontology (MVO) for the contact lens domain.	5.3
Build	3	Minimum Viable Ontology for the contact lens domain	5.4.1
	4	Space Time Maps of Production and Factory	5.4.2
Evaluate	5	MVO Review STMs SME Evaluation Ontological Evaluation	5.5 5.5.1 5.5.2

Table 7 Framework for second Iteration

5.3. Design Using BORO

The BORO foundation model describe in Chapter 2 is used to help identify objects into three categories, Elements[6], Types[7] and Tuples[8] these are the top-level patterns for BORO and called the ontic categories, the BORO metaphysical choices are defined as: -

- Endurantism: bodies are typically temporally extended through time.
- Eternalism: no privileged present
- Space-time: a single space-time continuum

[6] Elements don't have instances

[7] Types, are defined as types of things, if they have an instance then they are a type

[8] A Tuple is a data structure consisting of multiple parts.

- Modally flat: modality managed through counterparts in possible worlds
- Higher Order Universals: universals can be instances of other universals
- Universals – Nominalism: (member) extension is the criterion of identity
- Particulars – Extensional Identity: (spatio-temporal) extension is the criterion of identity Materialism no abstract objects
- Linear Time: Time does not branch.

The representation of spatio-temporal events, top level patterns and whole parts can be modelled pictorially to provide representation that is easier to examine. Space Time Maps (STMs) introduced in Chapter 4 are used to identify and depict the ontology of a domain in a way that is accessible to ordinary people (and experts in the domain) - people without ontology expertise - and so are a natural tool for illustrating the domain ontology. STMs use techniques of two-dimensional (2D) graphical depiction that assume the elements exist in a 2D universe consisting of one space dimension and one-time dimension. This enables a simpler illustration of their spatio-temporal extent and so an easier understanding of the domain. BORO tools are first used with lens and types of lenses, Figure 26 is used to show the workflow of the process. Datasets from the first iteration are used to enhance the model.

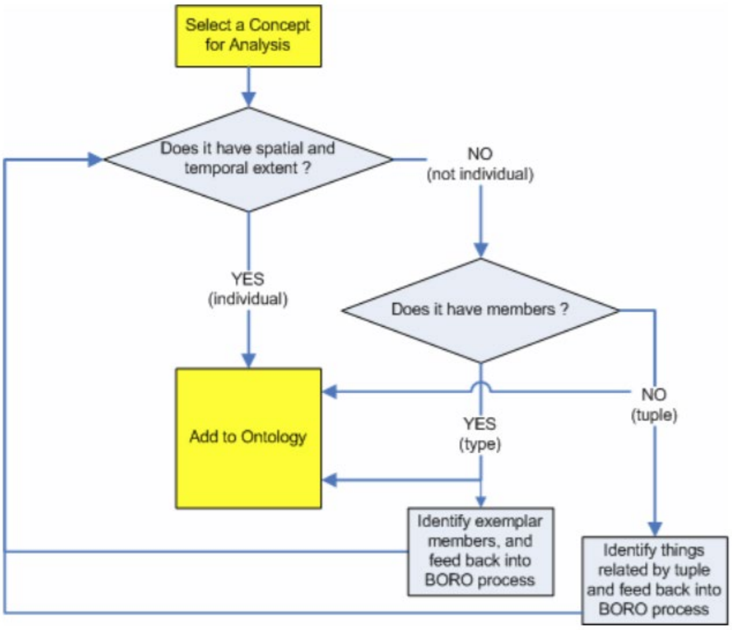

Figure 26 BORO Simplified Grounding Workflow (Partridge, 2005)

From chapter 4 moving from paper into Kumu, then into the BORO foundational ontology, the lens is added to the ontology and the first initial part of the model is created. For this project Enterprise Architect (EA)[9] was chosen as the tool to build the initial model. Primarily because the 4D community, such as IDEAS use EA to develop their models and BORO have adopted this tool for all their base models and model. Figure 27, illustrates the core components of BORO.

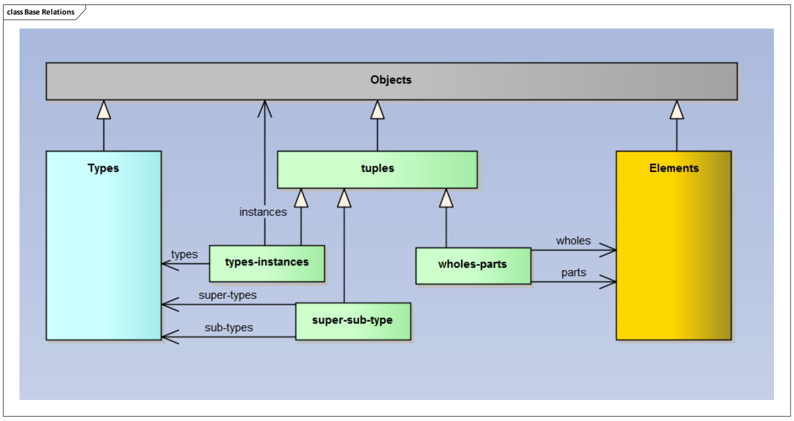

Figure 27 BORO Base Relations Model (Partridge, 2005)

[9] Sparx Systems Enterprise Architect is a visual modelling and design tool based on the OMG UML https://www.sparxsystems.eu/start/home/

5.3.1. Lens Types Model

Applying BORO to the initial lens conceptual model, the primary layer is the lens and types of lenses. Lenses are Elements and have the follow lens types, ophthalmic lenses, used in eye care correction, crystalline lenses are an in vivo lens meaning in the body of a living thing, so an eye lens. Objective lenses are man-made in optical engineering for use by scientists and engineers alike. Similar but different to optical microscope lenses and telescopic lenses, they are man-made but have different uses and therefore classified differently. Figure 28 are shown from the EA model with comments on their purpose.

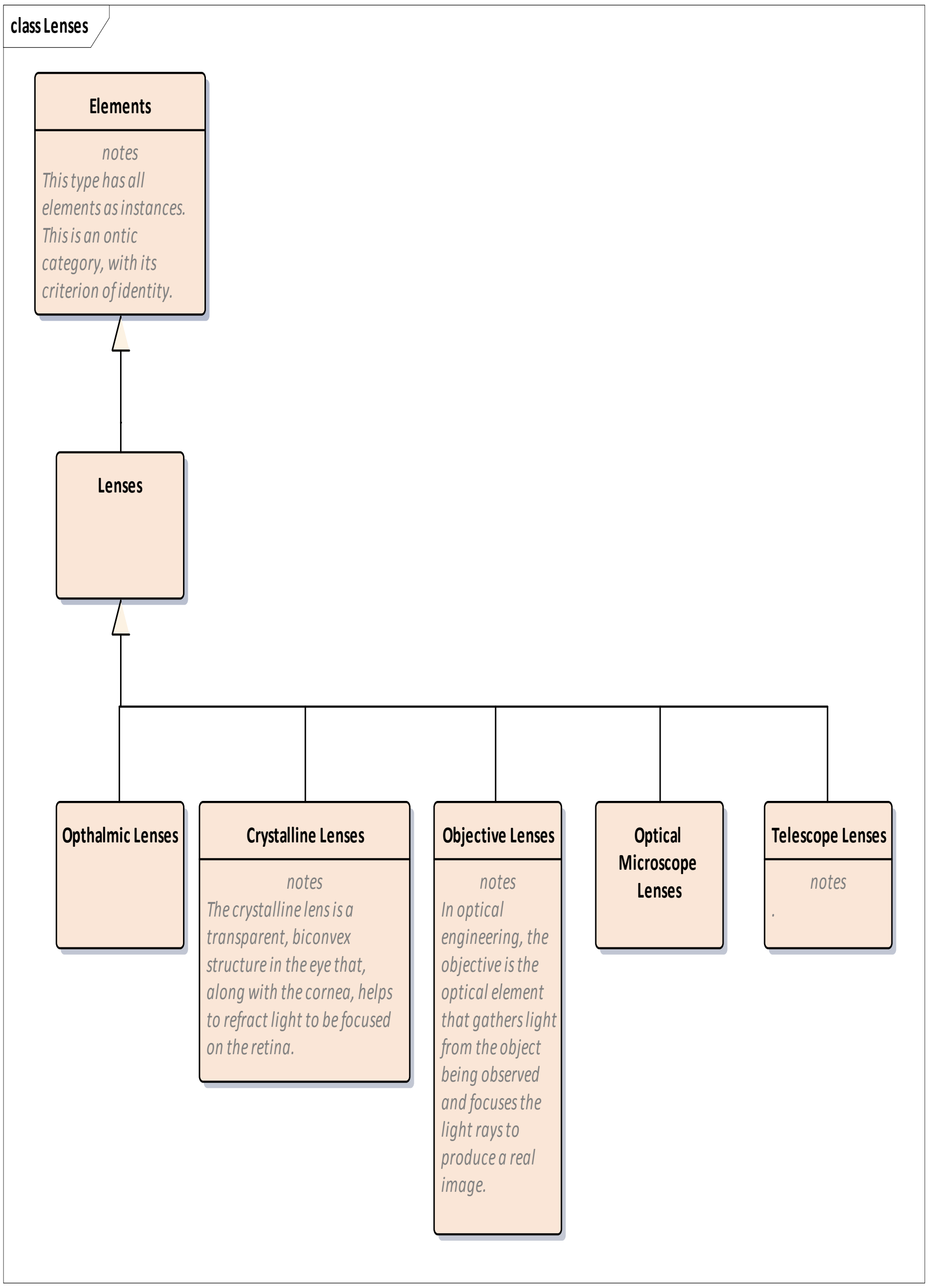

Figure 28 Lens Elements

In Figure 29 the model illustrates next layer down of the relationship between lens types, contact lenses and spectacles and the inclusion of intra ocular lenses. Intraocular lenses are used as a replacement for cataract patients and are a hard-plastic lens replacement to allow patients to have a non-clouded view, intraocular lenses are also used with patients existing lens to reduce the effects of myopia[10] or near-sightedness.

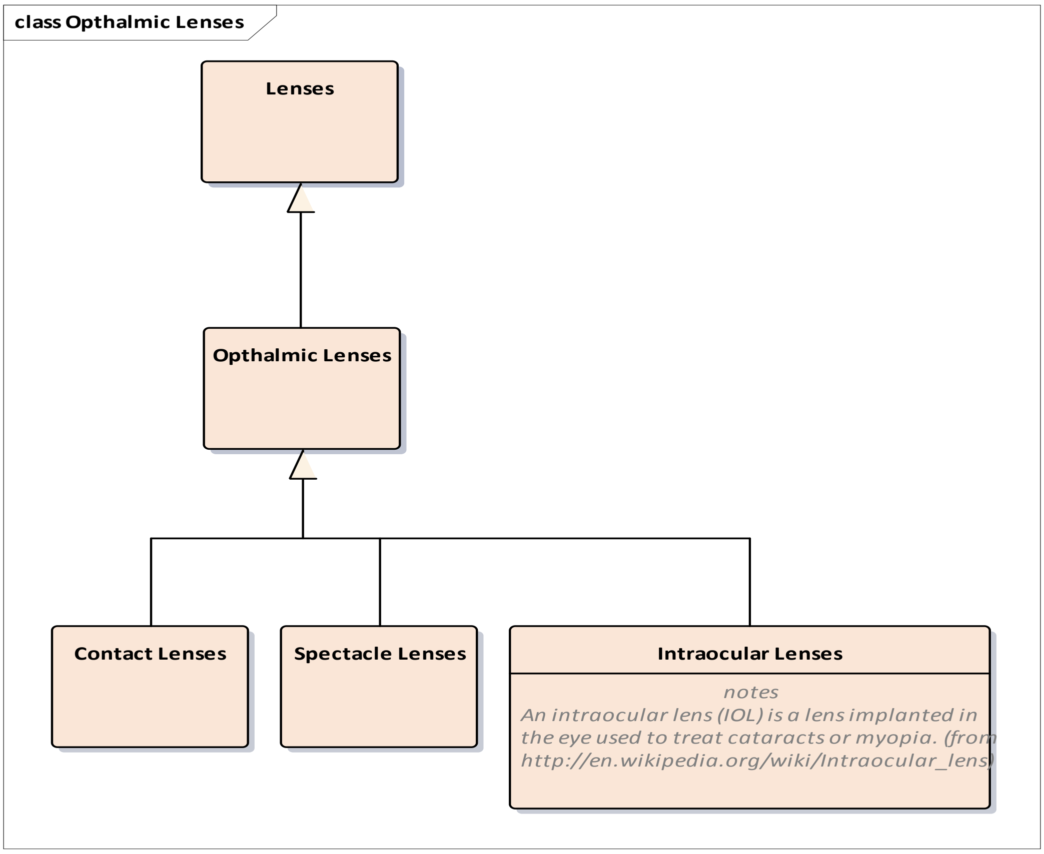

Figure 29 Types of Lens

Classification of lenses provides base grounding for lens types in the model, contact lens types can be classified in a number of ways, the frequency of use, brand and family type, type of target eye correction etc. within CooperVision this is not clear within their current datasets gleaned in iteration 1.

[10] Myopia, or near-sightedness, is a refractive error, which means that the eye does not bend or refract light properly to a single focus to see images clearly.

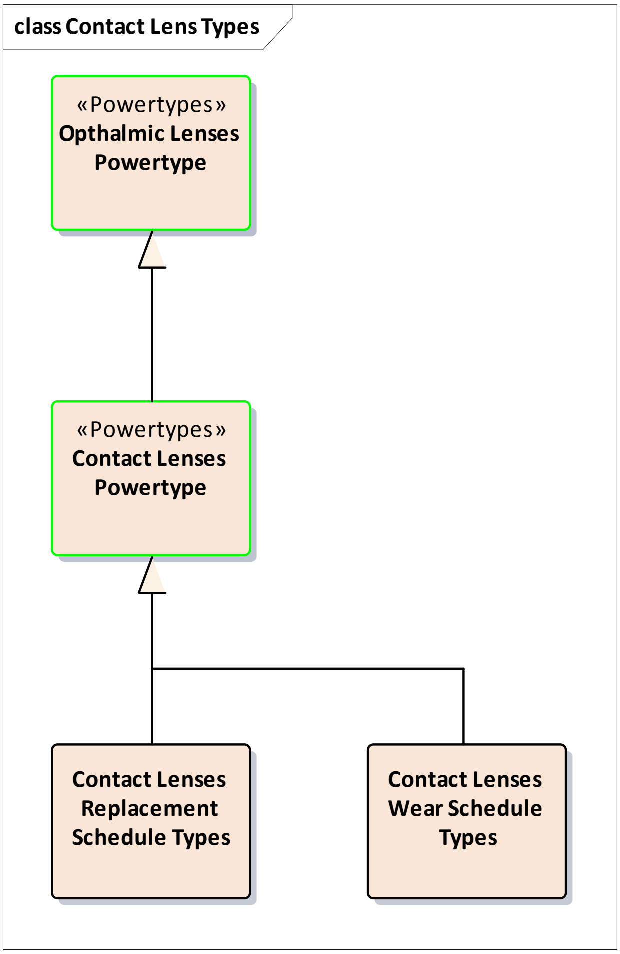

Figure 30 Lens PowerTypes by Classification

Classifying lenses by replacement types or wear schedule types, grouping product families by replacement method, either daily, two weekly or monthly verses their brand types. In terminology they amount to the same thing all based on their replacement type as shown in Figure 30.

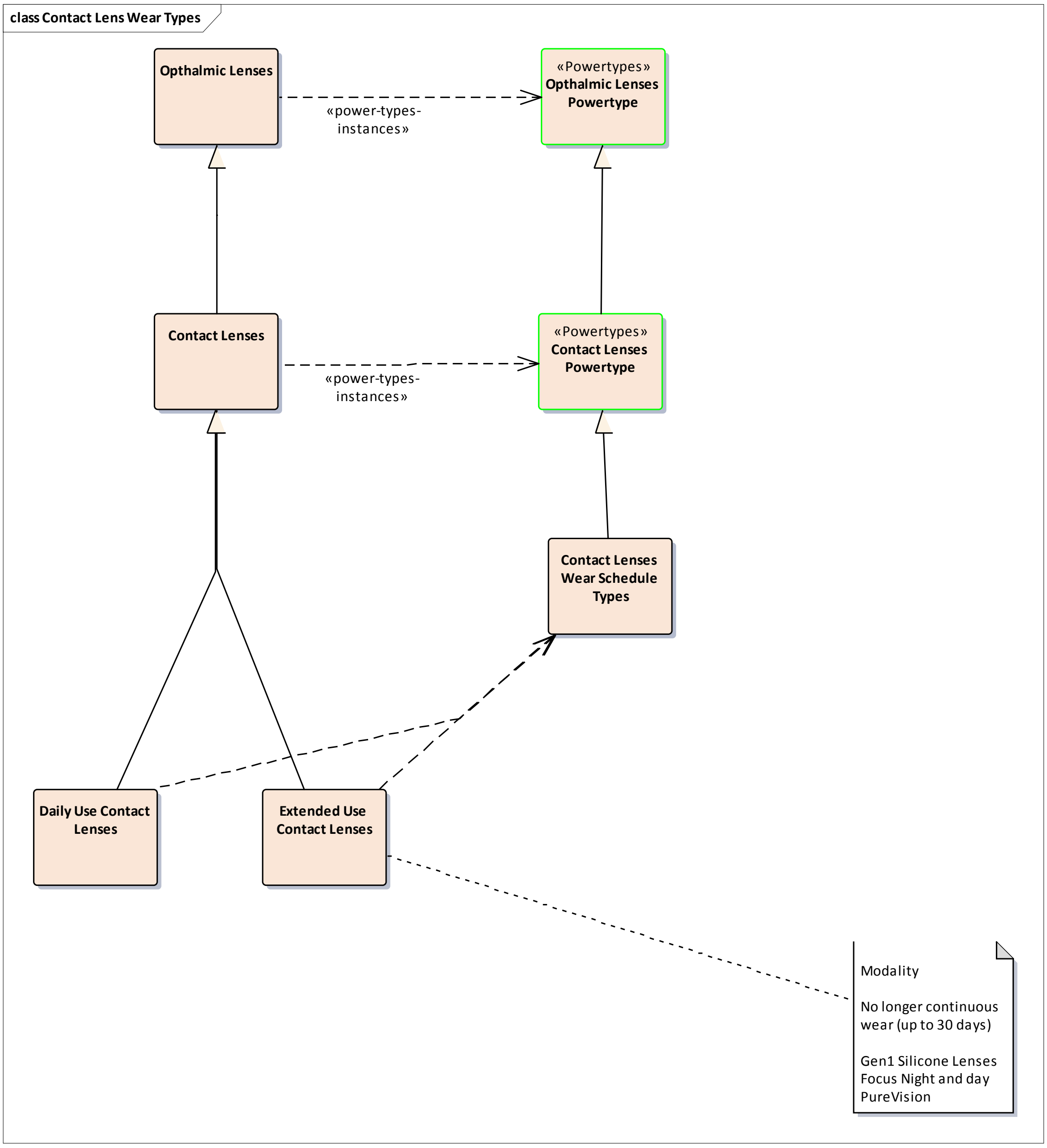

Figure 31 Types of Contact Lenses with wear schedule PowerType

The wear type classification models the intended use of the contact lens, verifying with SMEs, how contact lens brands and wear types is often confused as a means of classification. This error in classification was noted during the extraction of data from paper data (Excel sheets). The spreadsheets detail the usage type for the products being manufactured, but not consistent in their terminology. This error was also translated over into a number of manufacturing sub systems, where the lens use had been used instead of the lens type or brand of lens or the terminology was different in other systems.

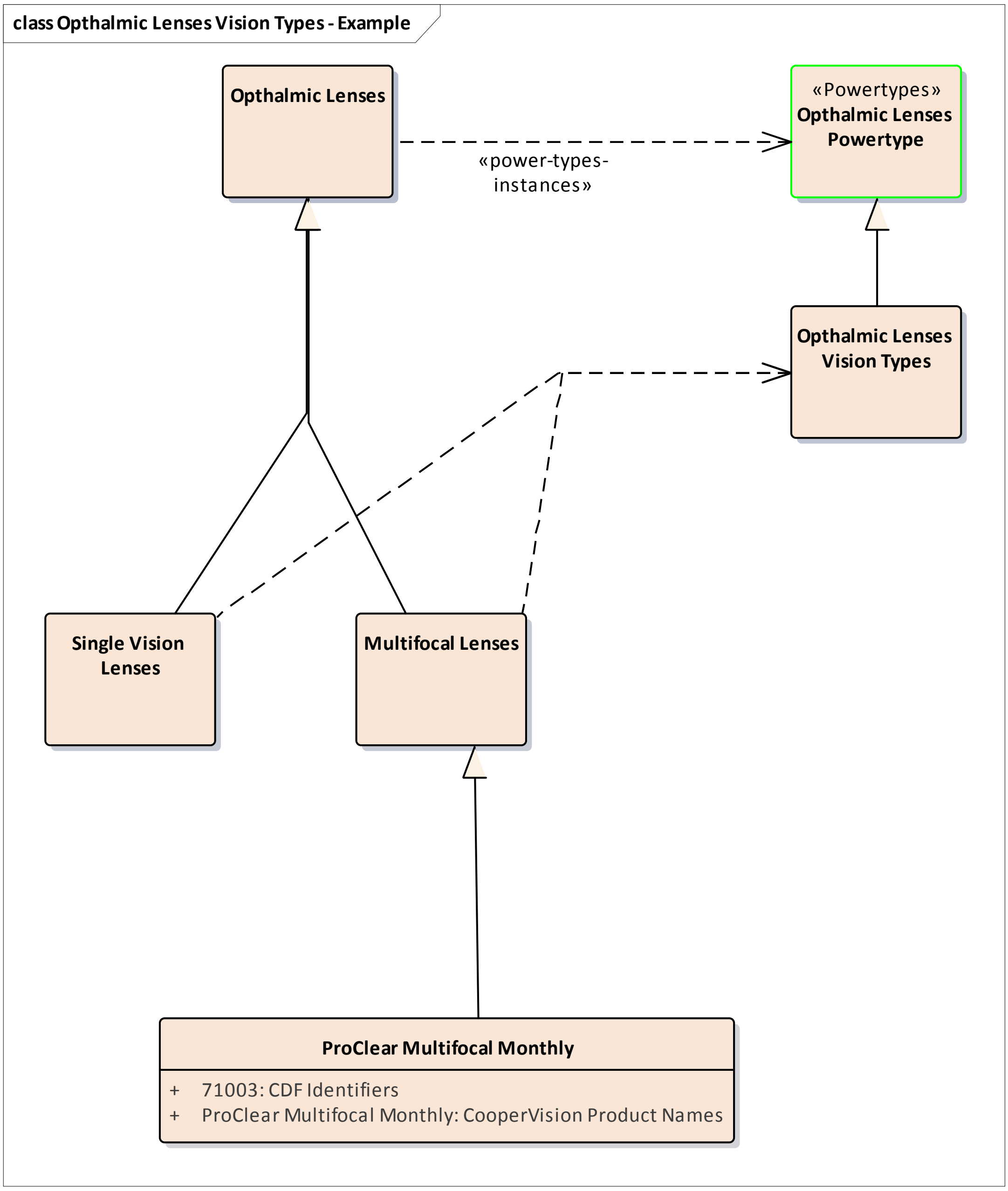

Figure 32 Single verses multifocal vision corection

Modes of eye correction depicted in Figure 32 illustrates the use type of contact lenses. A single vision lens is used to correct single axis vision correction meaning one particular power of lens correction.

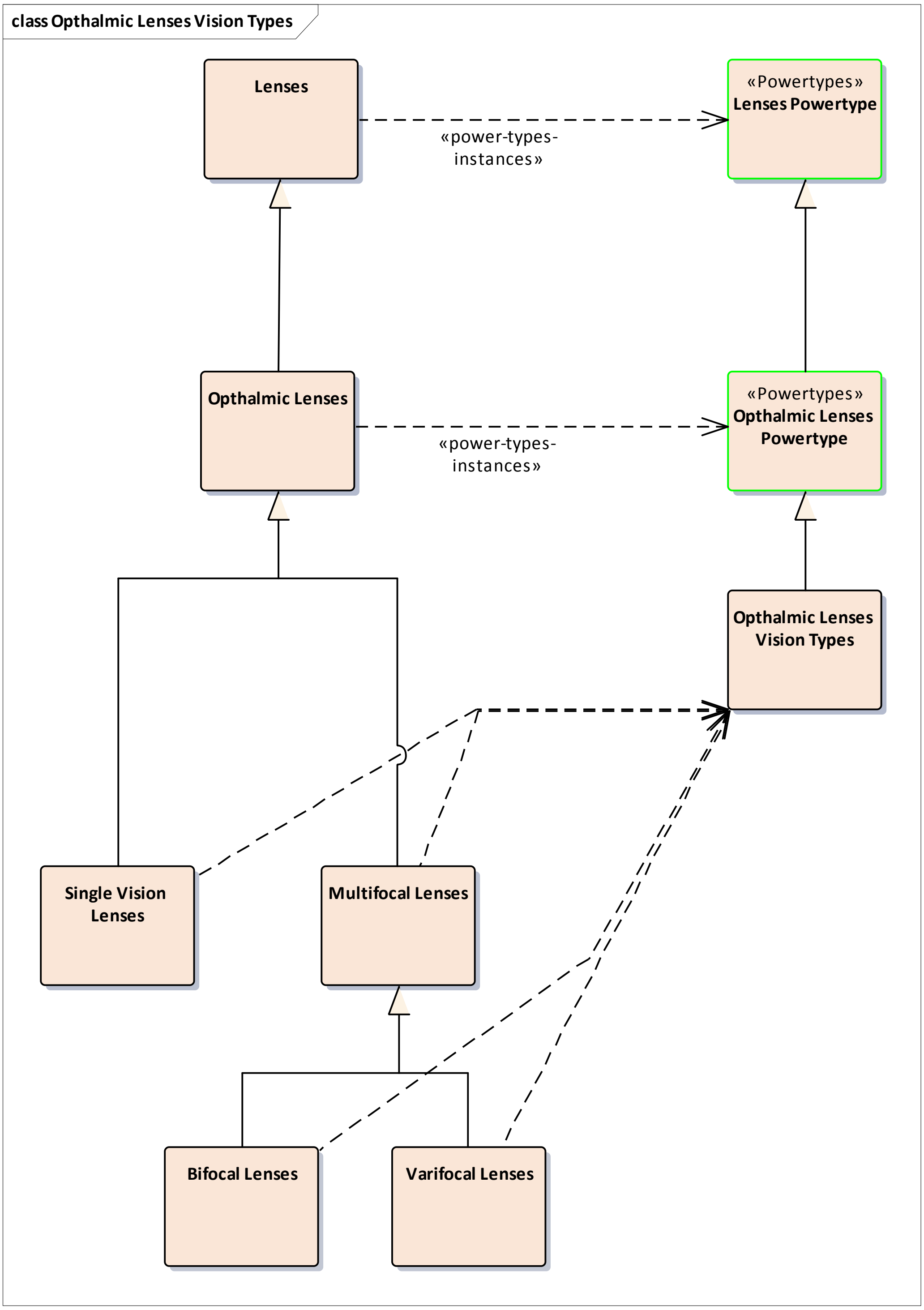

Figure 33 Lenses Powertype Hierarchy

With lens types expanded within the classification, multifocal lenses type has bifocal and multifocal sub types, which are all types of ophthalmic lenses. The term multifocal refers to the eye correction process, using multiple power correction types in a single lens. In its simplest form creating multiple tangents across the optical surface of the contact lens.

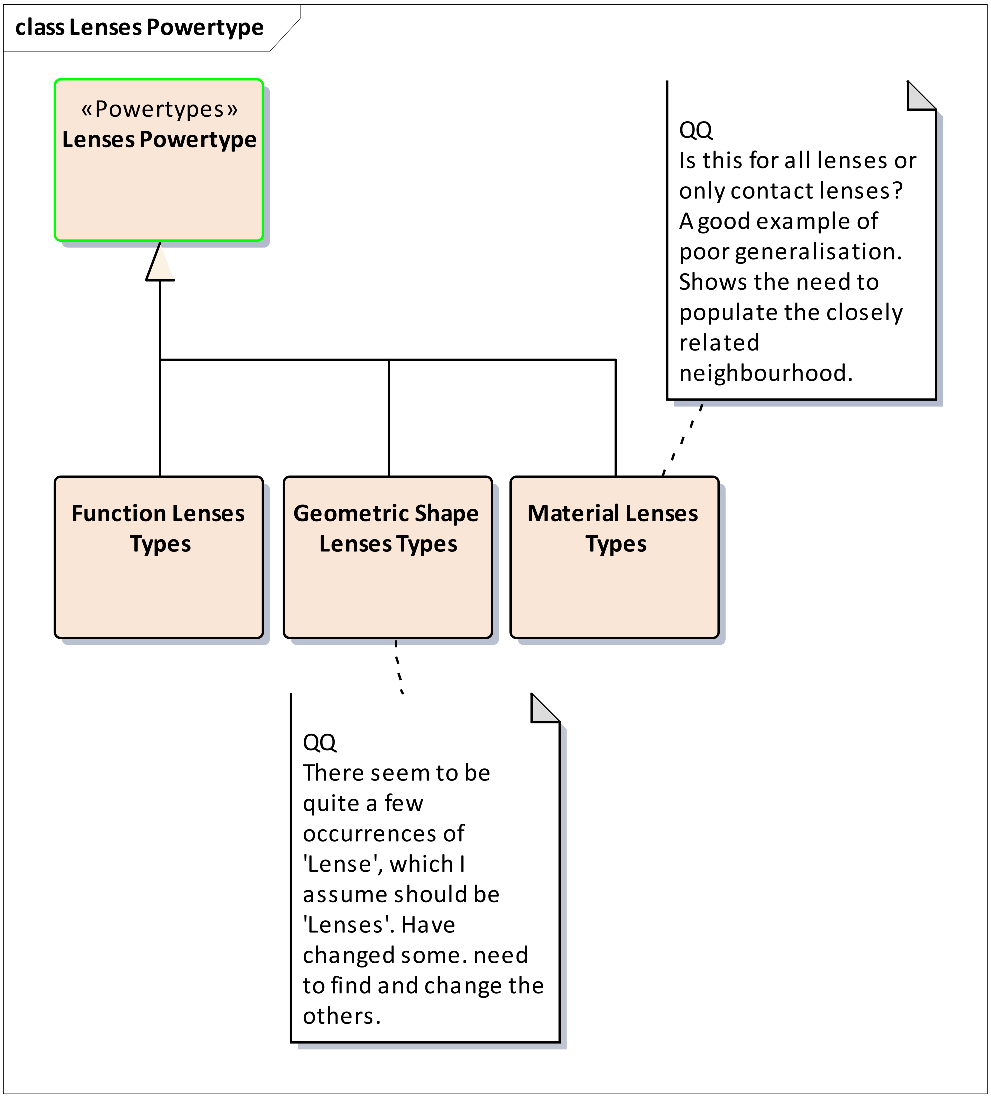

Figure 34 Lenses Powertype

The lens powertype has a number of subtypes, the functional characteristics of the lens, the shape aspheric or spherical and the material, for contact lenses they are either hard lenses or gas permeable soft contact lenses, each type has a classification,

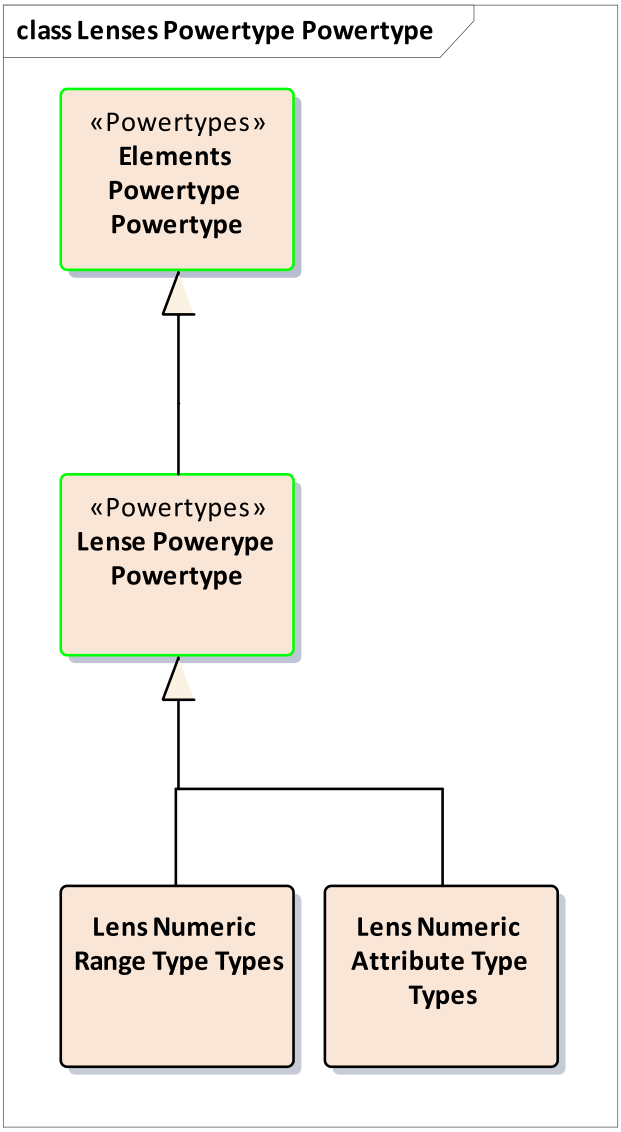

Figure 35 Lenses Powertype

the range of a contact lens is the number of individual powers that can be created from that type of lens. A typical lens range is from a plus power to minus power and a typical range set for popular lens brands is +20 to -20. This is often prone to errors in systems as from paper a range is a single line, but when entered into a database this needs to be an individual row for each power within the range. During the review of data numerous range errors where found across multiple products. The normal distribution of product range was deemed to be correct, but errors were found in ranges outside of the normal distribution.

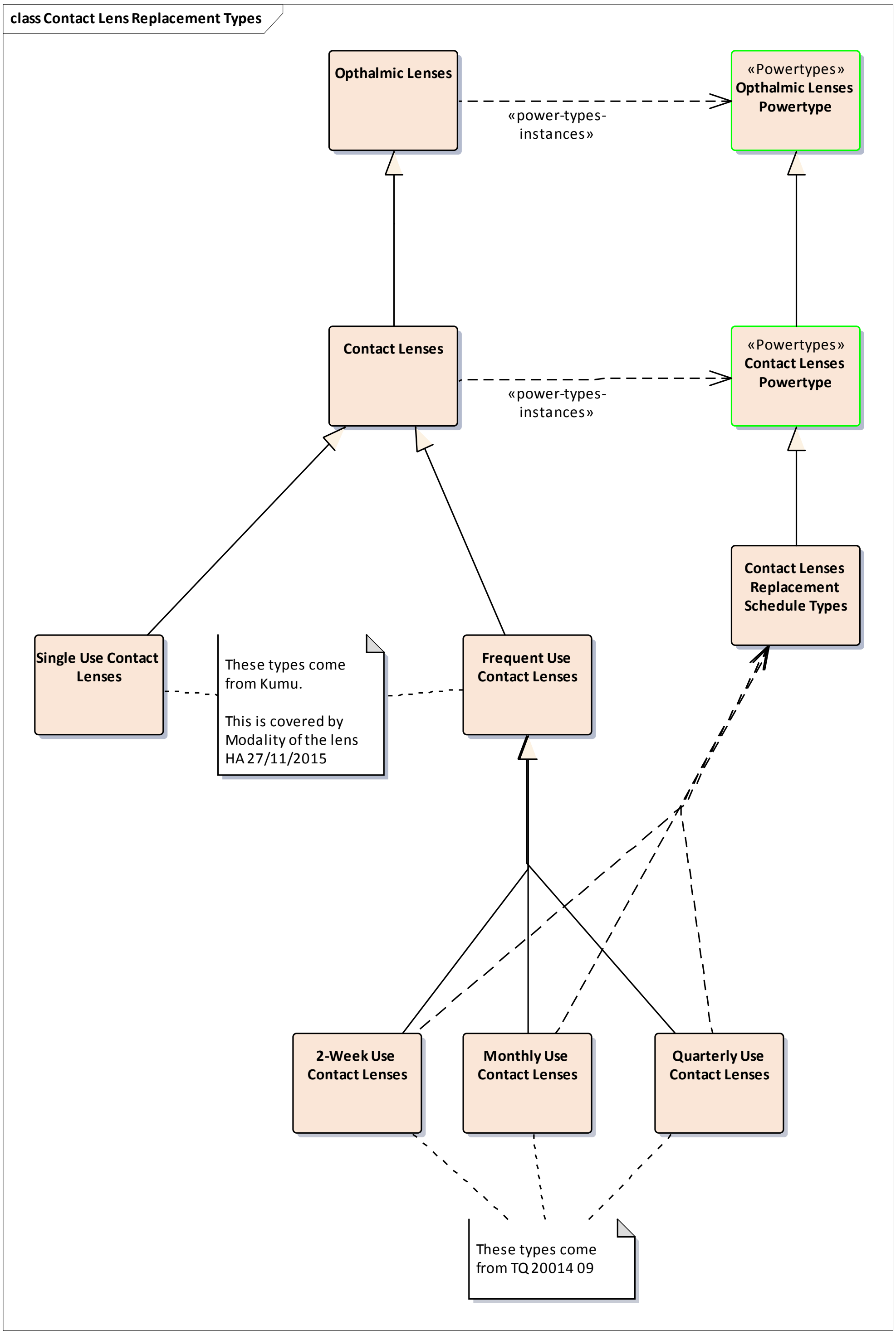

Figure 36 Contact Lens Replacement Types

Replacement types is a commonly known property of contact lenses, single use is as its name suggests used for one day only also known as a daily lens. These lenses have been registered with a regulatory body as fit for purpose for single use only, not to say they cannot be used for longer as often they are made of the same material as frequent use wear lenses. The classification is made based on the product type and the manufacturing process.

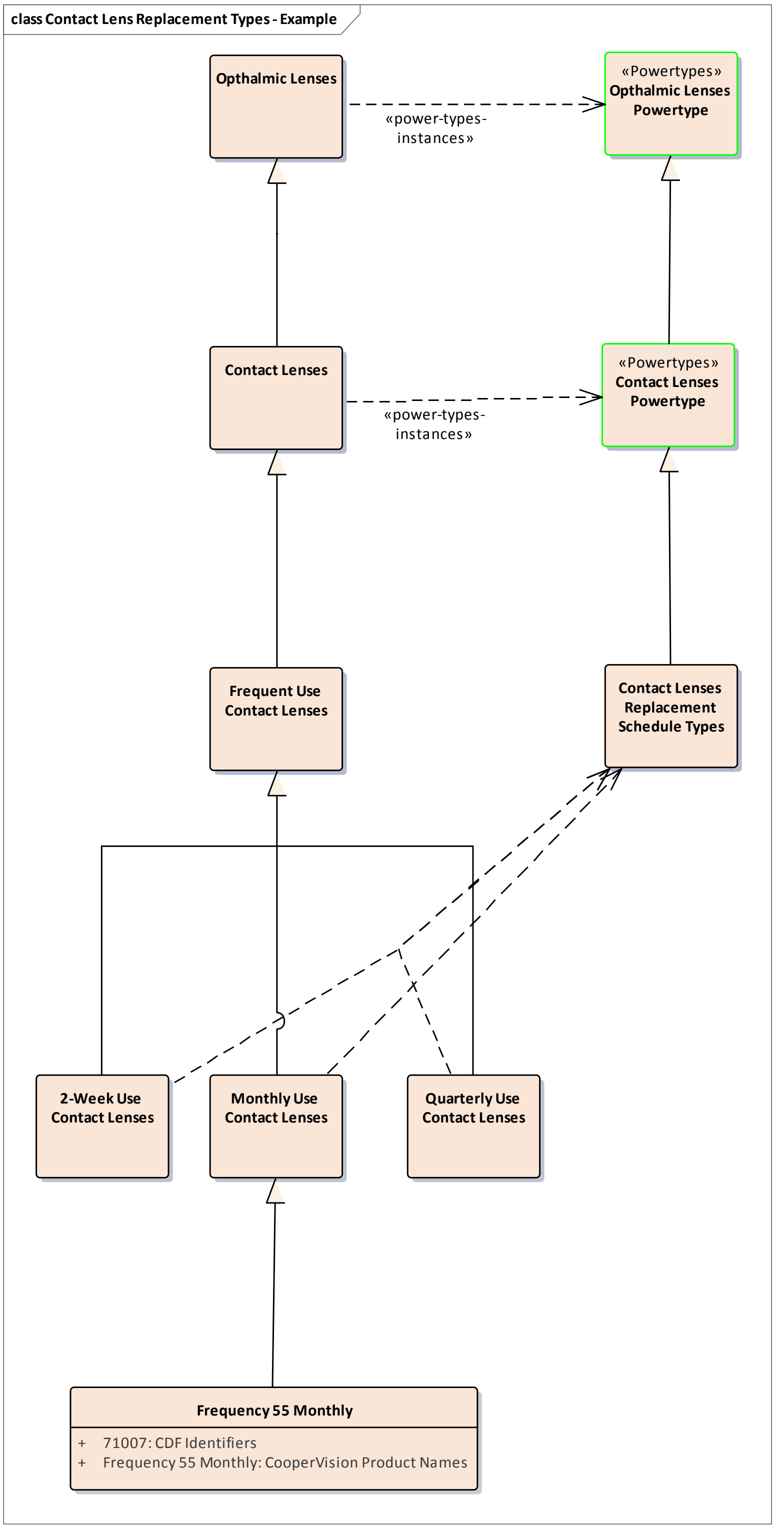

Figure 37 Contact Lens Replacement Types – Example

The sub classification within the frequent use classification adds two weekly, monthly and quarterly lenses, seen in Figure 36 and in Figure 37, this can be expanded to allow for any period cycle of contact lens wear, allowing for future state lenses that maybe allowed to be worn longer than the current defined periods of wear.

5.4. Build: Model & Space Time Maps

With the extracted product data, the products need to be mapped to the process and the process model built and evaluated by SMEs. The process steps that were gleaned and described in chapter 4, the next stage of the second iteration is to map the process steps using STMs in order to build a rich model of the process. This is the first time that this had been documented and a number of sessions were required to allow the SMEs to become familiar with the approach of STMs.

5.4.1. Graphic View: Space Time Maps

The secondary area of research for the domain model is the manufacturing process, defining and building all the process steps in terms of STMs and identify areas of interest including patterns of errors or where errors may occur. STMs are typically used as a first stage of analysis, where in the second stage these are translated into a BORO model. STMs provide an easy way to visualise 4D objects in a domain and as such are a useful way to start understanding them. For each domain a representative set of object types and associated objects are selected and then views over these objects – aiming to capture the main perspectives – are shown in STMs the object types are selected as those central to the domain. The object instances of the selected object types are examples that best illustrate the typical features of the object type. The STM visualisation aims to simplify the objects to their mereological essentials. In understanding how to read them, the 2D reference frame picks out the relevant fragment of the 4D domain. The domain's objects are shown as boxes, a box's boundary represents the object's real boundary boxes' containment, and overlap, etc. show the mereological relationships between objects. A box's name helps to further identify the object. Figure 38 Overview of general manufacturing in terms of STM, helps illustrate the base types for the manufacturing process.

5.4.2. Navigating the STMs and Core Object Model

- The Core Object model split into
    - General manufacturing – yellow boxes
    - Contact lens manufacturing – blue boxes consist of:
        - Contact Lens Factory
        - Contact Lens Product Manufacturing – Factory Perspective
        - Contact Lens Product Manufacturing – Product Perspective
        - Products

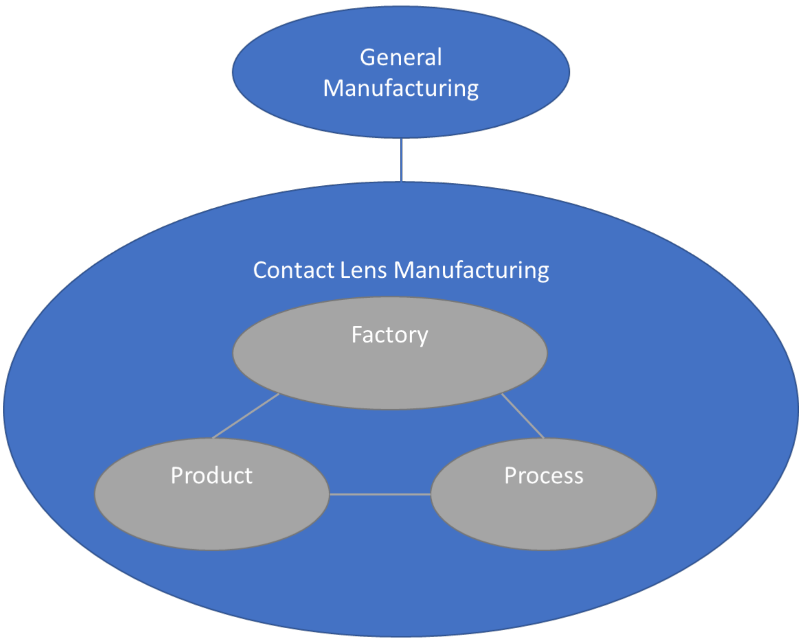

Figure 38 Overview of general manufacturing in terms of STM

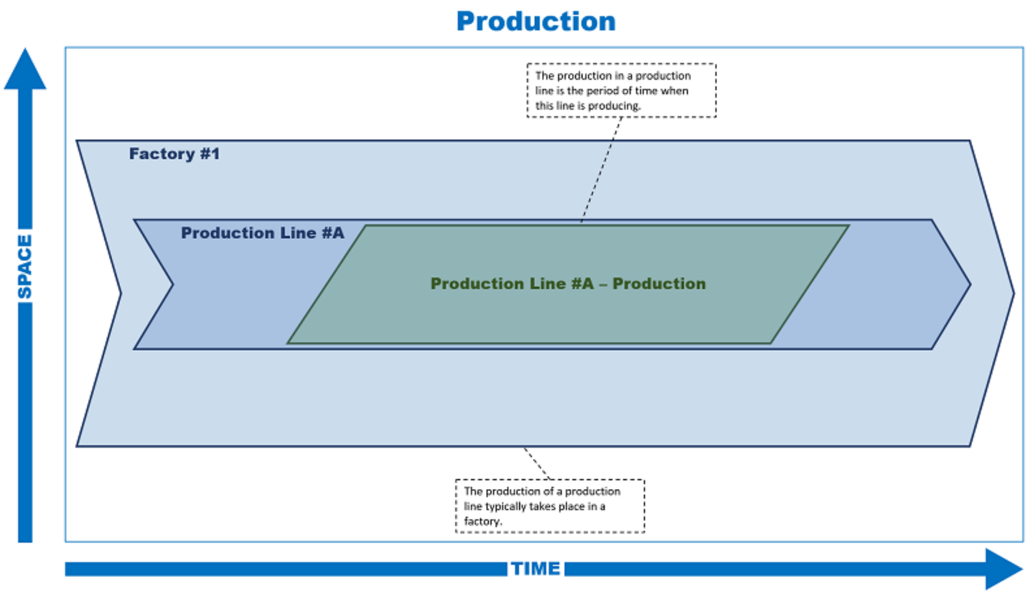

Figure 39 Factory representation STM

In its simplest form, production can be defined as in Figure 39, illustrating the factory with a production line and manufacturing production, in terms of space and time.

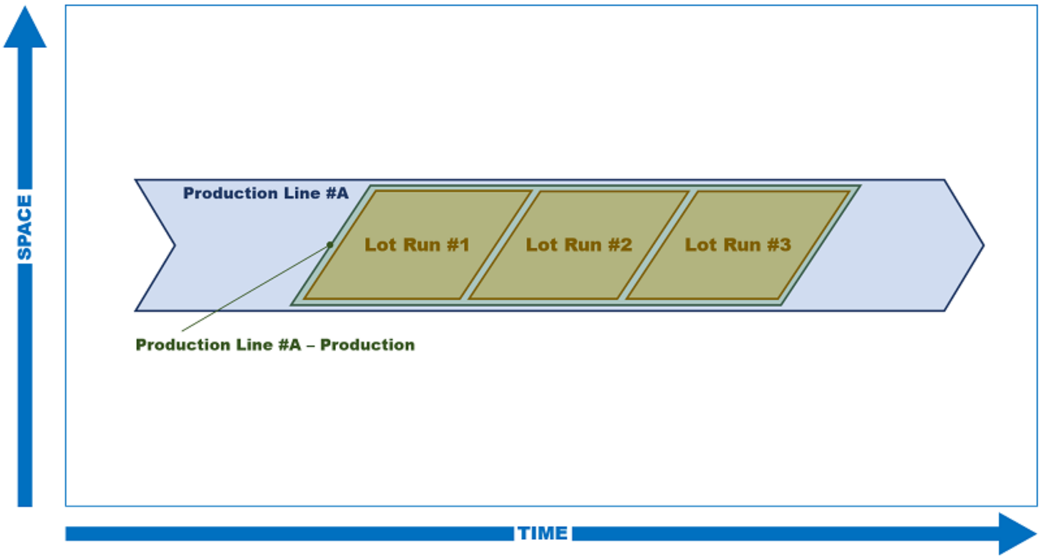

Figure 40 Production Representation STM

The production is mapped into run lots so from Figure 40 showing the production line A and multiple run lots being processed along the time line, it can be seen that this demarcation between the lots id not a sharp line vertical but a diagonal line as part of the previous lot is still being processed by that particular manufacturing production line.

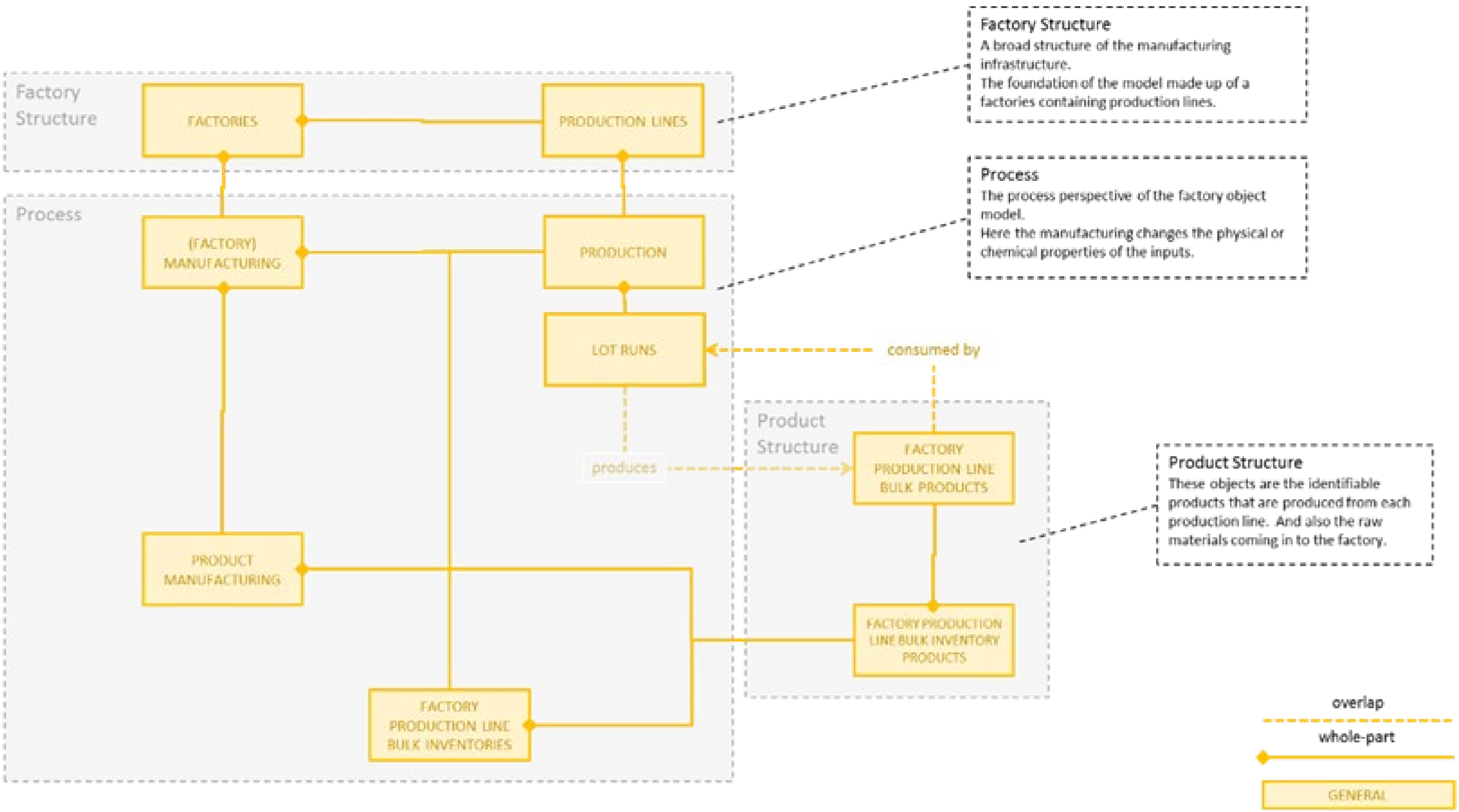

Figure 41 General Manufacturing (Generic MFG Model) STM

In general terms, factories manufacture items or produce something either in batches or as single discrete items, depicted in Figure 41 is a general factory layout, factories have production that has processes that make items, this element of the model illustrates the product structure and the concept of inventory as inventory grows through time. The process concludes with the concept of raw materials being processed into finished goods over time with part and whole part relationships between products being produced. SMEs found that in current CVI systems the concept of raw materials consumed was missing from the reconciliation process within the financial systems. This reconciliation of materials used and direct cost to manufacturing was manually reconciled and adjusted each month.

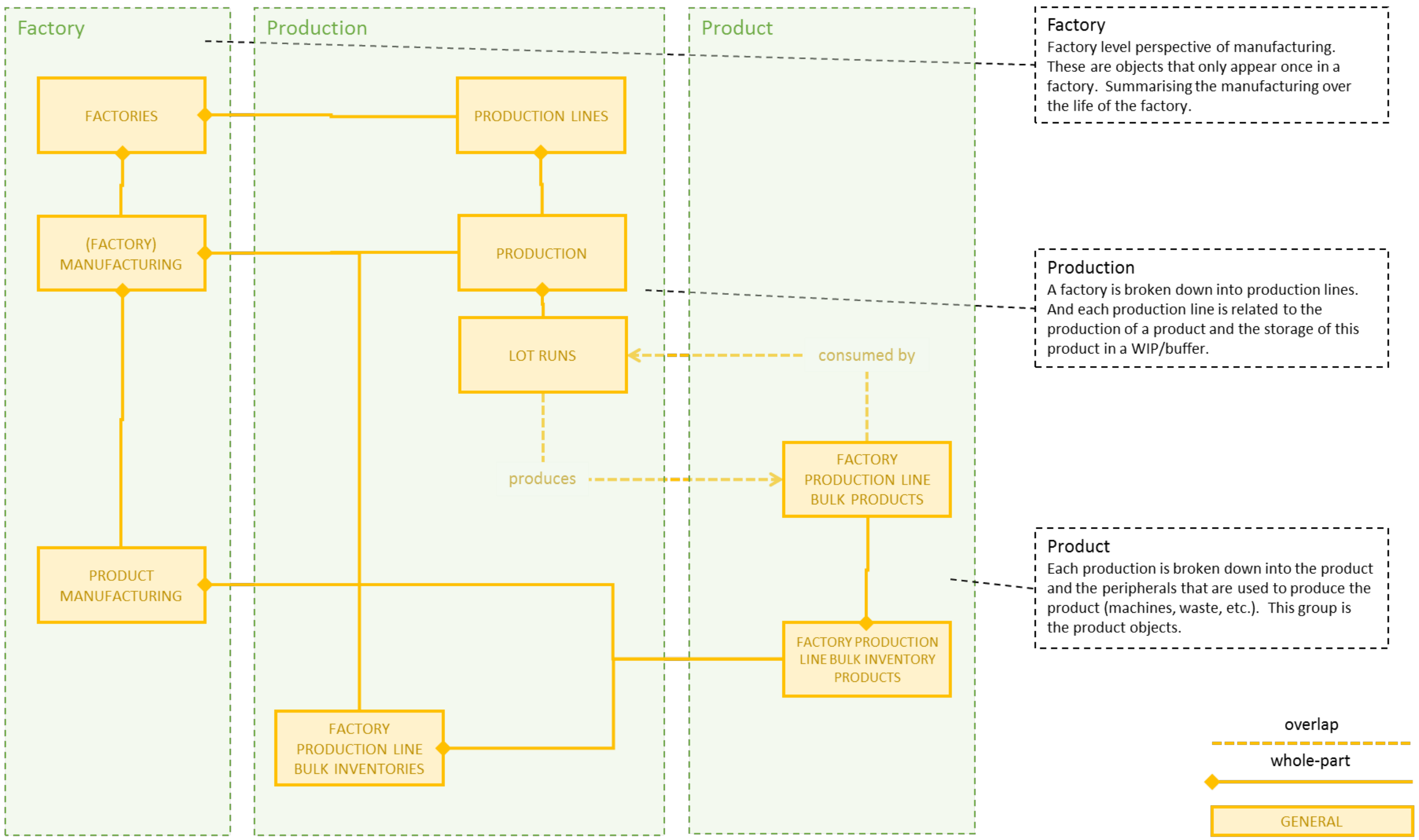

Figure 42 Factory, Production, Product relationship STM

The factory, production, product STM Figure 43 illustrates the concept of production lines within the factory and the idea of raw materials transformed into product.

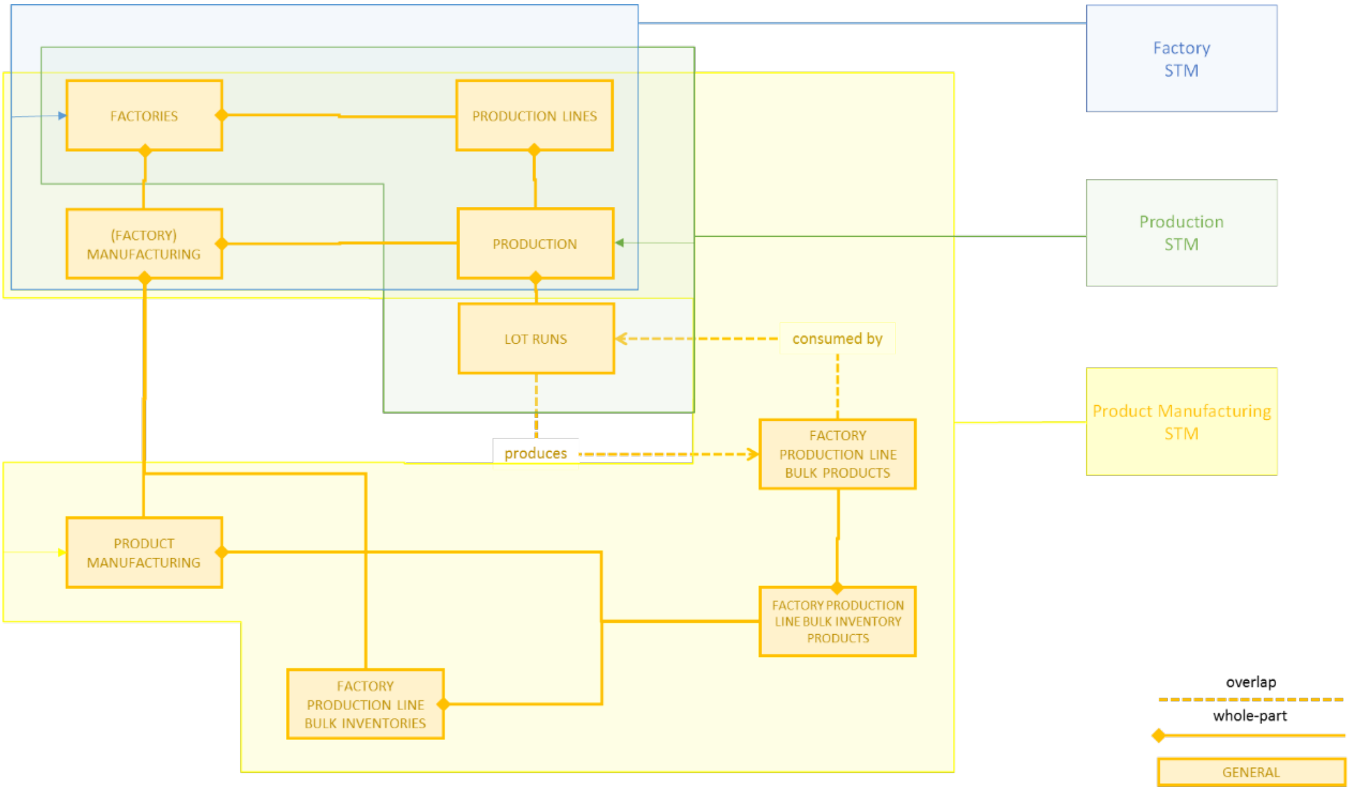

Figure 43 High Level Factory, Production, Product STM

The contact lens manufacturing process consists of factories, some consideration is given to a higher entity such as company or legal entities, but that is consider more for future work. Factories have a classification of manufacturing factories by their very nature of producing something. There is yet, I believe to be a factory that does not produce or manufacture any products.

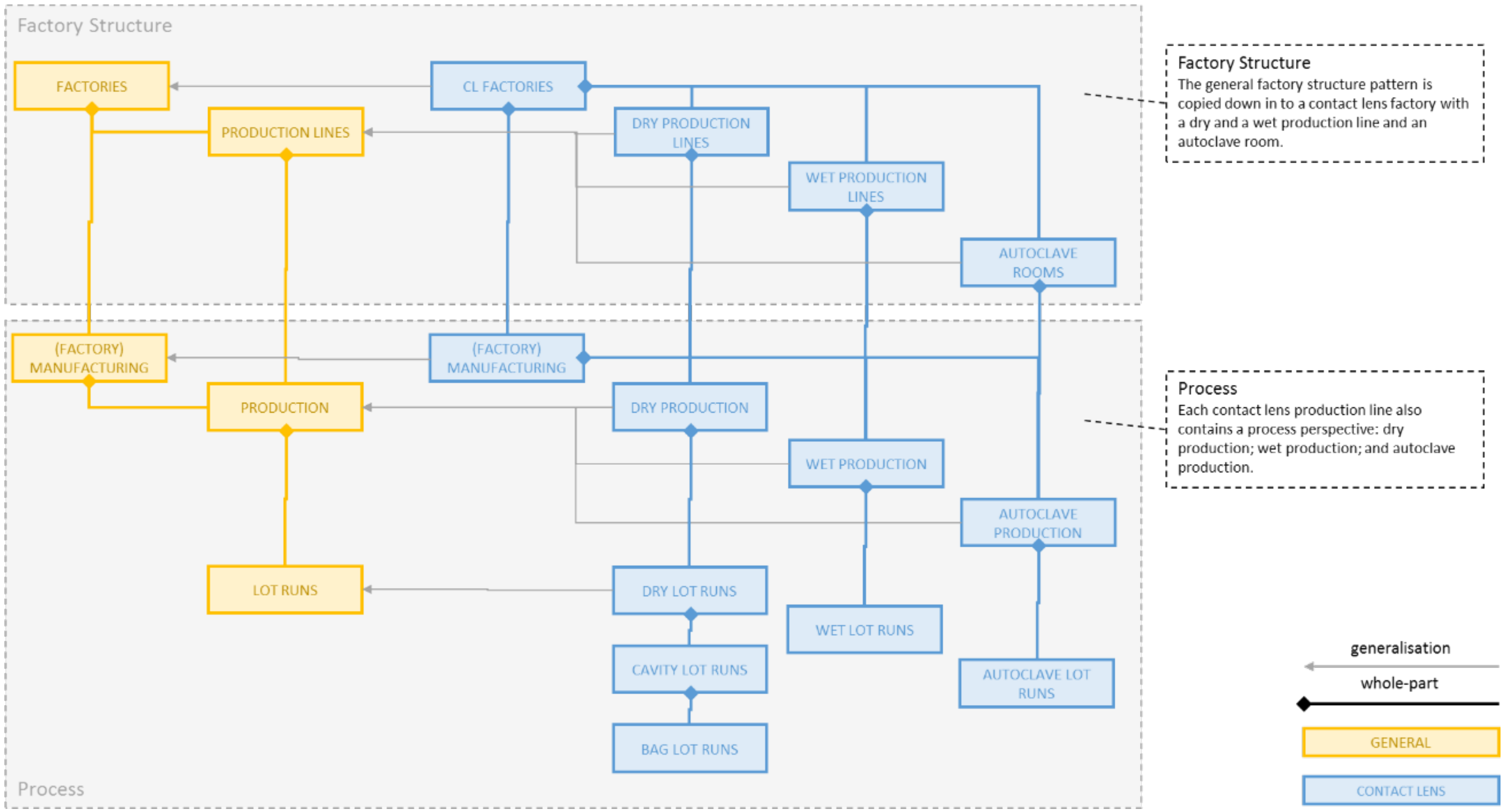

Figure 44 Factory to Contact Lens Factory STM

The factory and the contact lens factory relationship shown in Figure 44 depicts the production process steps specifically in terms of contact lens manufacturing, the association of dry lots, per cavity and the dry product held in dry lot bags, creating a batch process with the smallest batching being one bag. This part of the factory is only scoped for production, warehouse and secondary packing would be another process after autoclave.

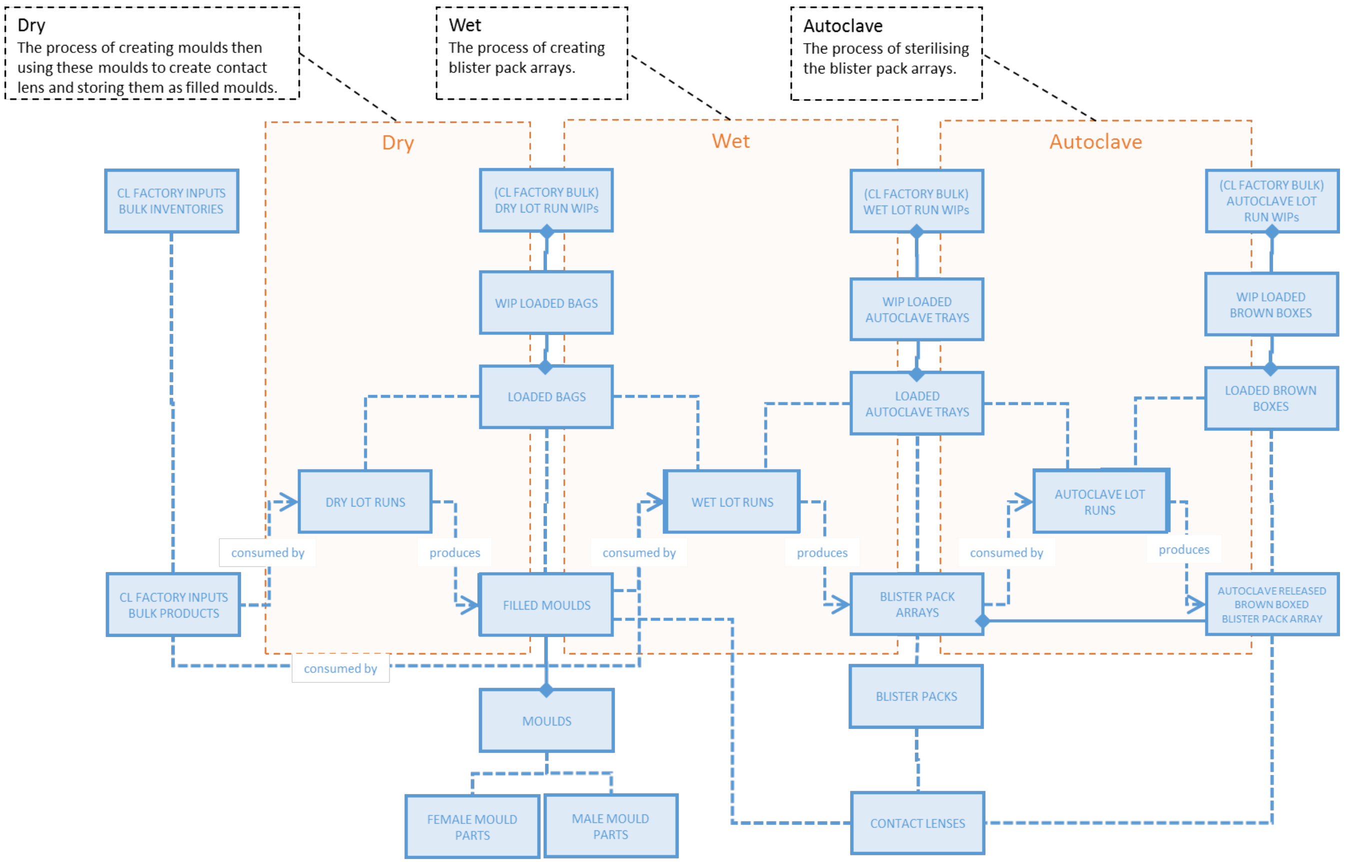

Figure 45 Contact Lens Factory Process STM

The manufacturing process STM in Figure 45 details the relationship between dry, wet and autoclave processing. This STM goes someway to answer the question on when does a lens become a lens? Although the lens is formed it needs to be packaged and have its labels added, thus the definition of a contact lens can be determined as, a lens is a lens when the brand is applied.

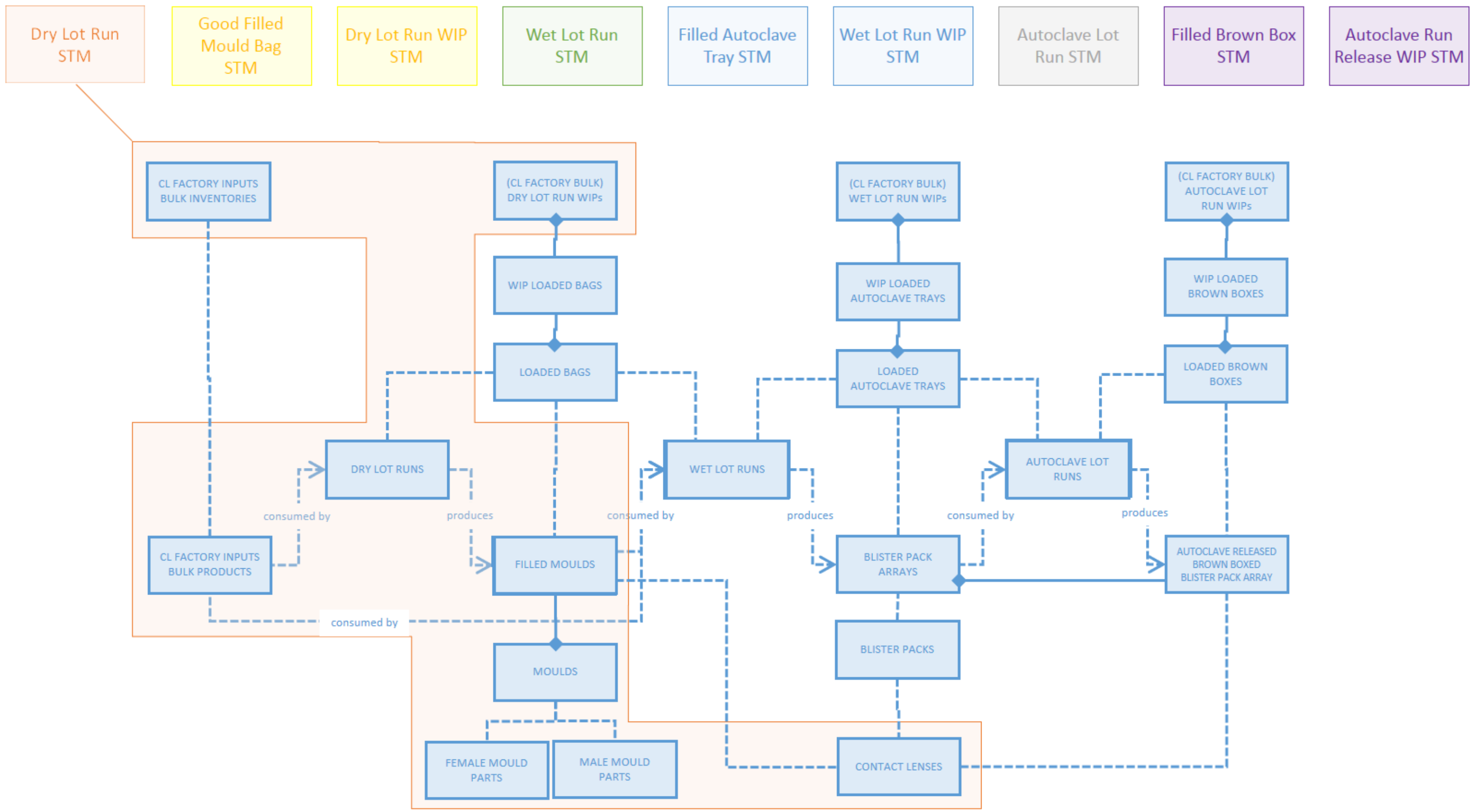

Figure 46 Dry Lot Run STM

The Dry process STM Figure 46 details the process steps undertaken in the initial stages on manufacturing the lens.

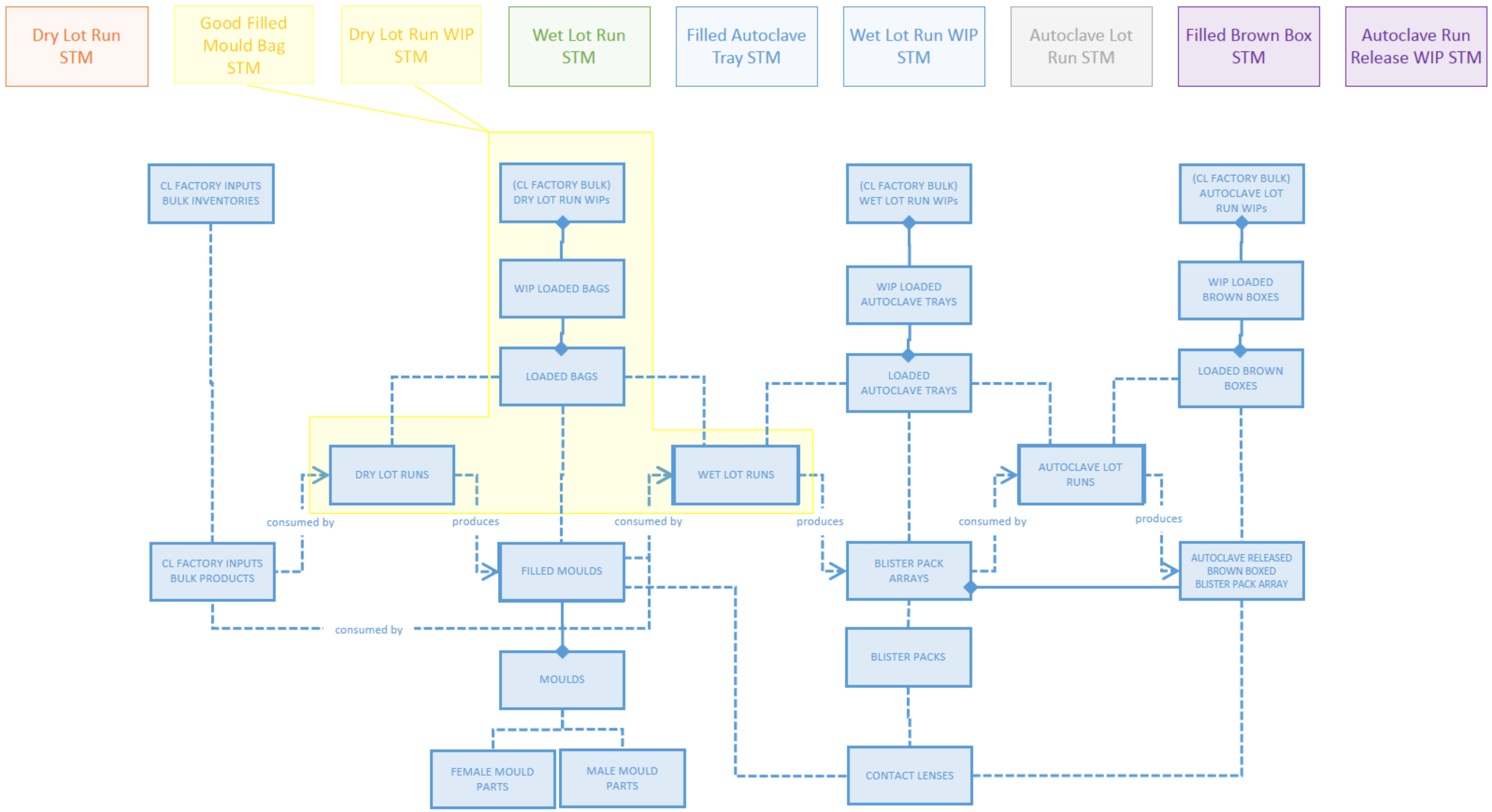

Figure 47 Dry Mould Bags STM

Moulds are processed and stored in bags on the dry line, bags are part filled, empty or full and contain male and female moulded parts (Mould) filled with the monomer as illustrated in Figure 47.

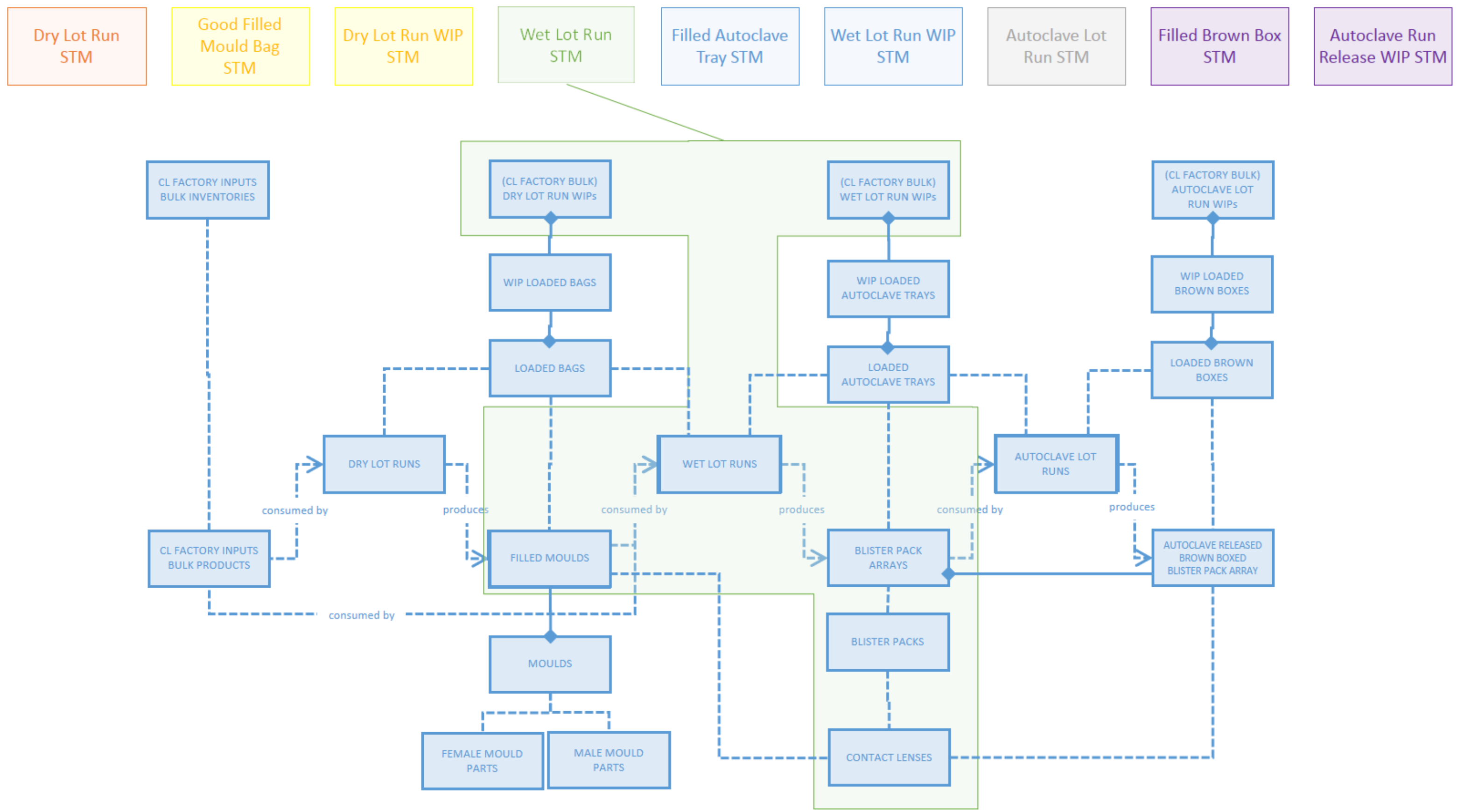

Figure 48 Wet Lot Run STM

The wet line processes the dry bags containing the moulds and introducing other raw materials to make a finished primary pack. Figure 48 and Figure 49 contain the STM for wet processing and wet WIP. This stage is where the raw materials are consumed to make a finished product.

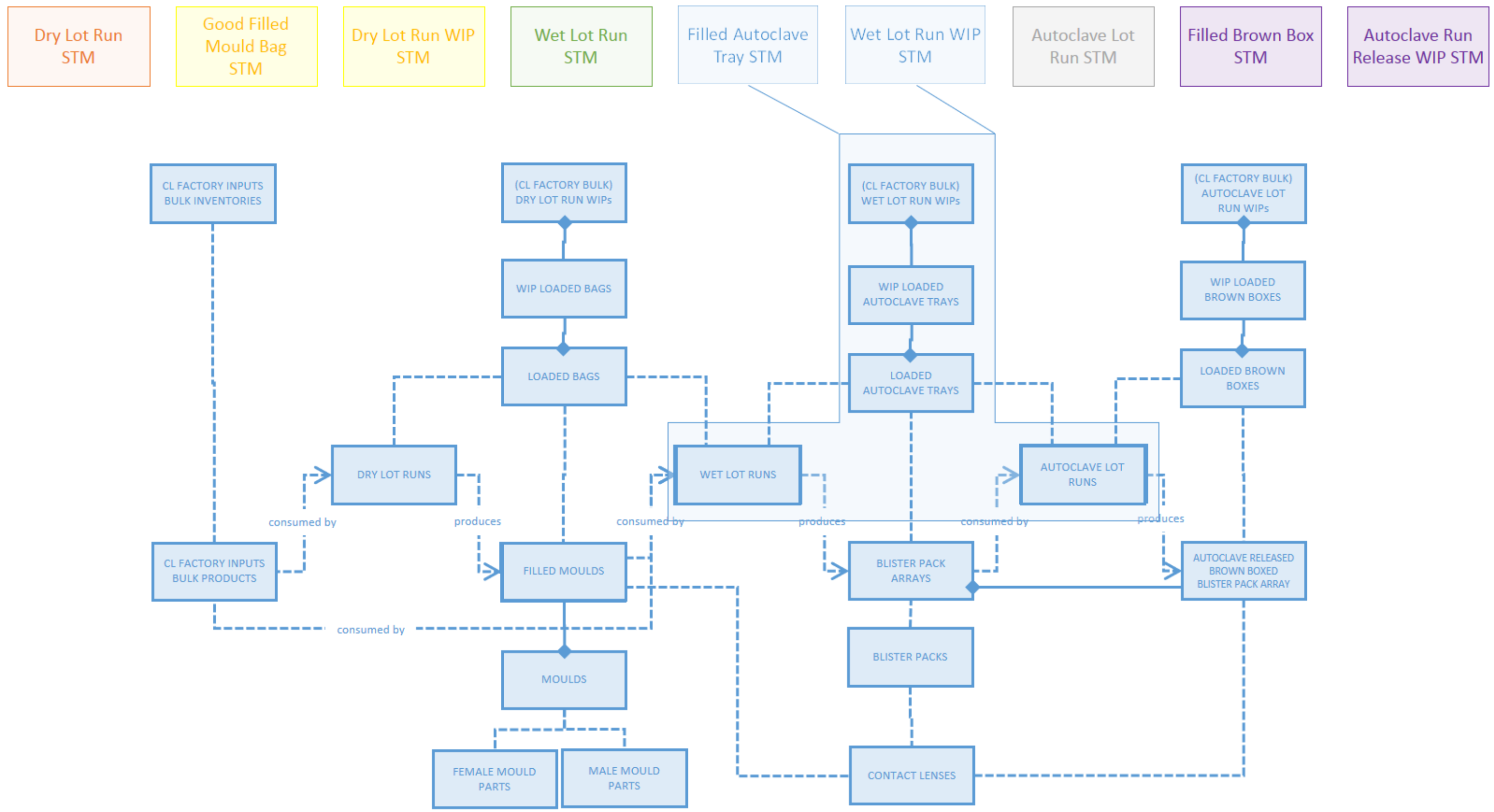

Figure 49 Wet Lot WIP STM

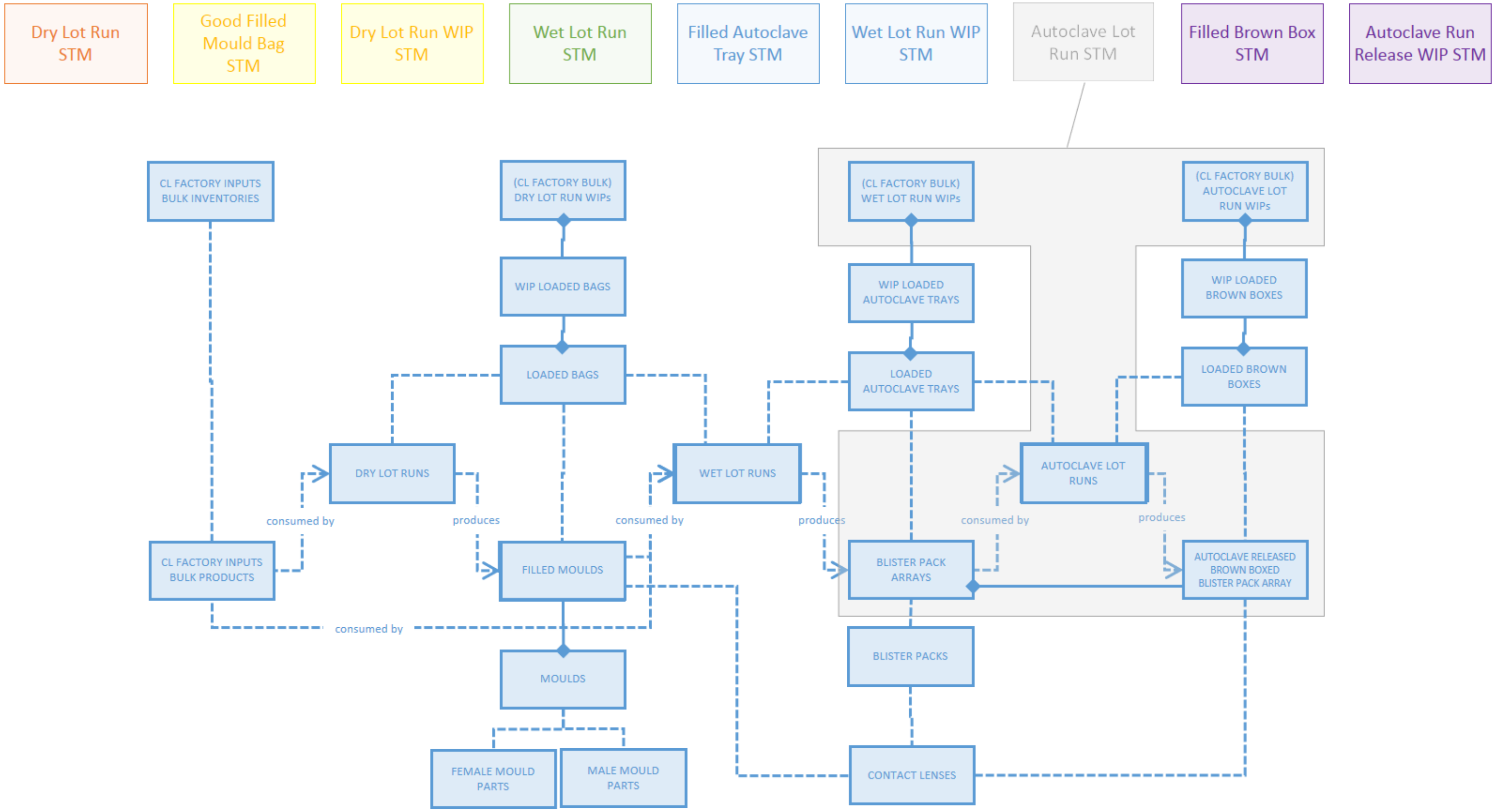

Figure 50 Autoclave STM

The Autoclave area is where the lens manufacturing process reverts from a linear process to a batch process. The autoclave cycle is for several trays to be process at a given temperature for an hour.

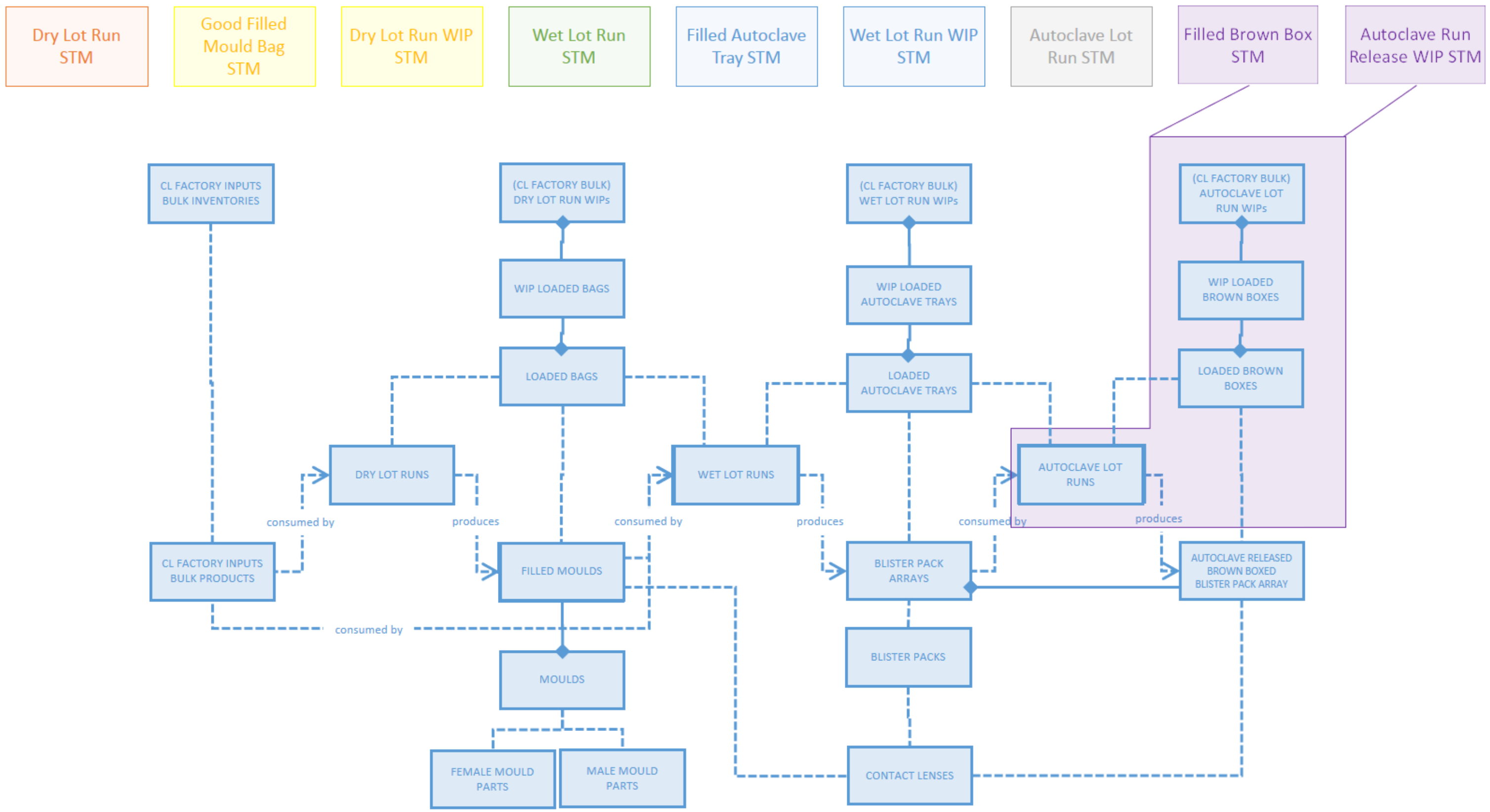

Figure 51 Autoclave QA release STM

The Autoclave release in Figure 51 concludes after a successful Autoclave run. There are some complexities to review in future work on how the expiry of the lens is added.

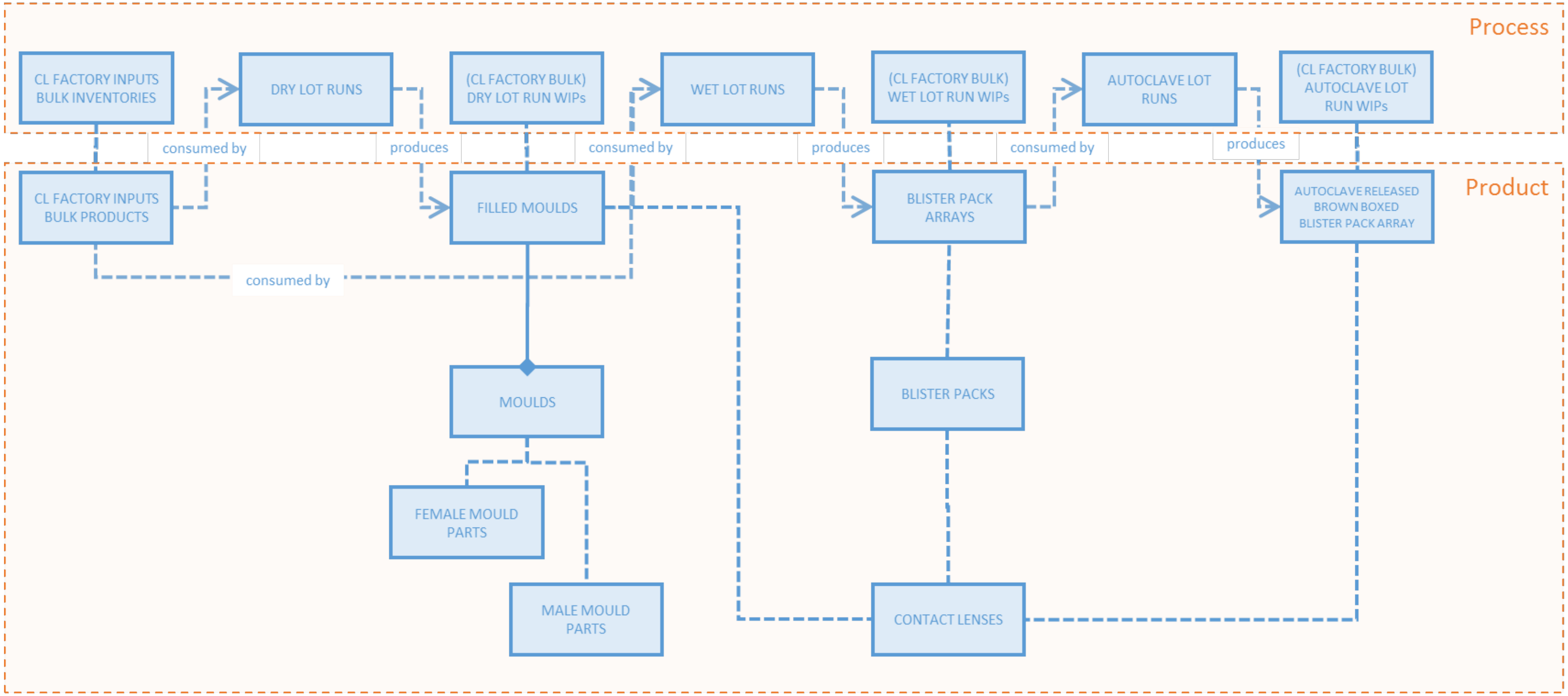

Figure 52 Contact Lens Process Steps to Product STM

In conclusion of the STM work for process steps, the process to product STM illustrates the raw materials being consumed by the manufacturing process detailed in Figure 52, in addition to this process would be to model how scrap and waste is handled over time.

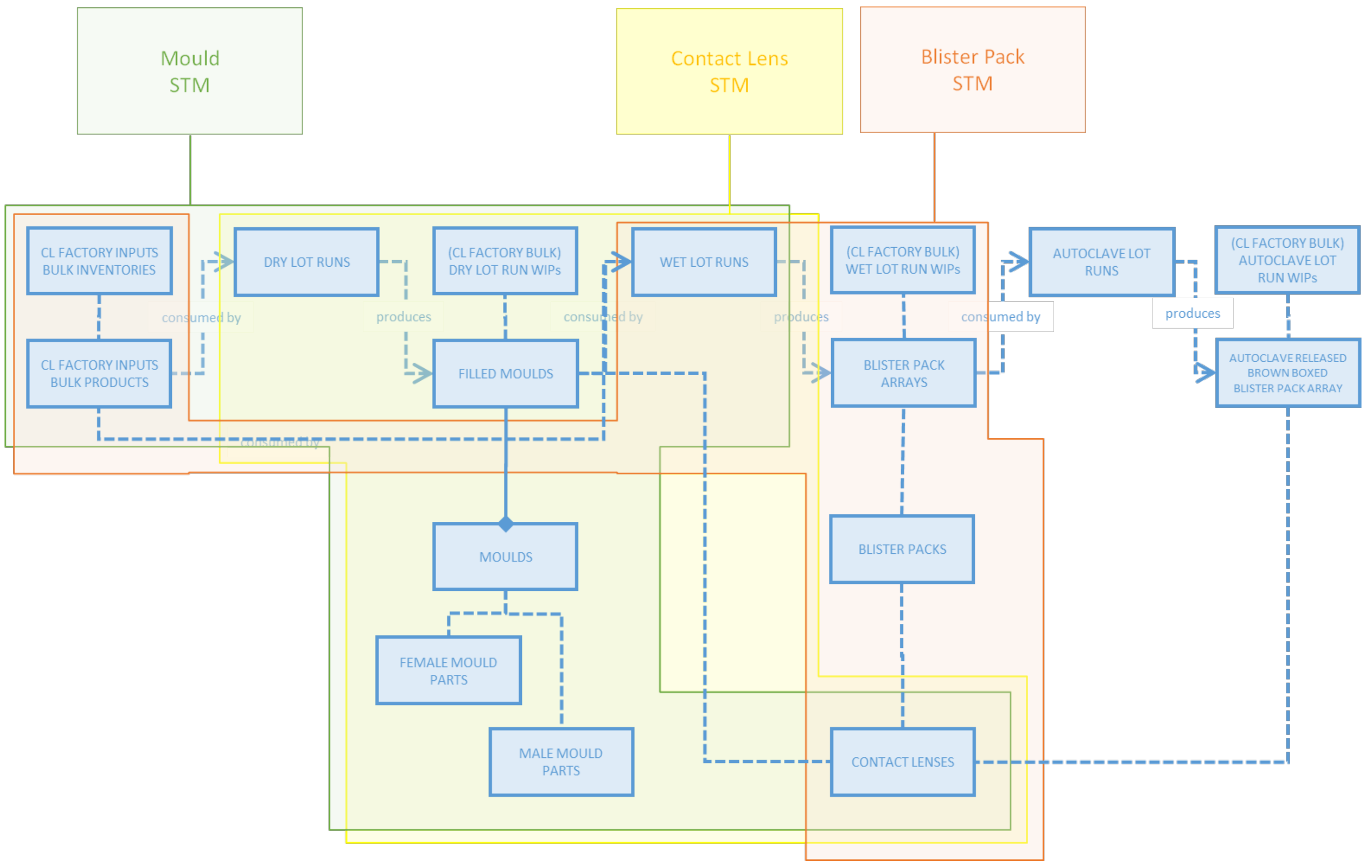

Figure 53 Dry Mould to Blister Pack STM

The manufacturing process leaves us with a good lens in the blister with saline and sealed foil. The foil has a label of lot number and expiry date. This constitutes silver stock (SS). Finished goods (FG) would require the branded over label and box with the instruction leaflet included.

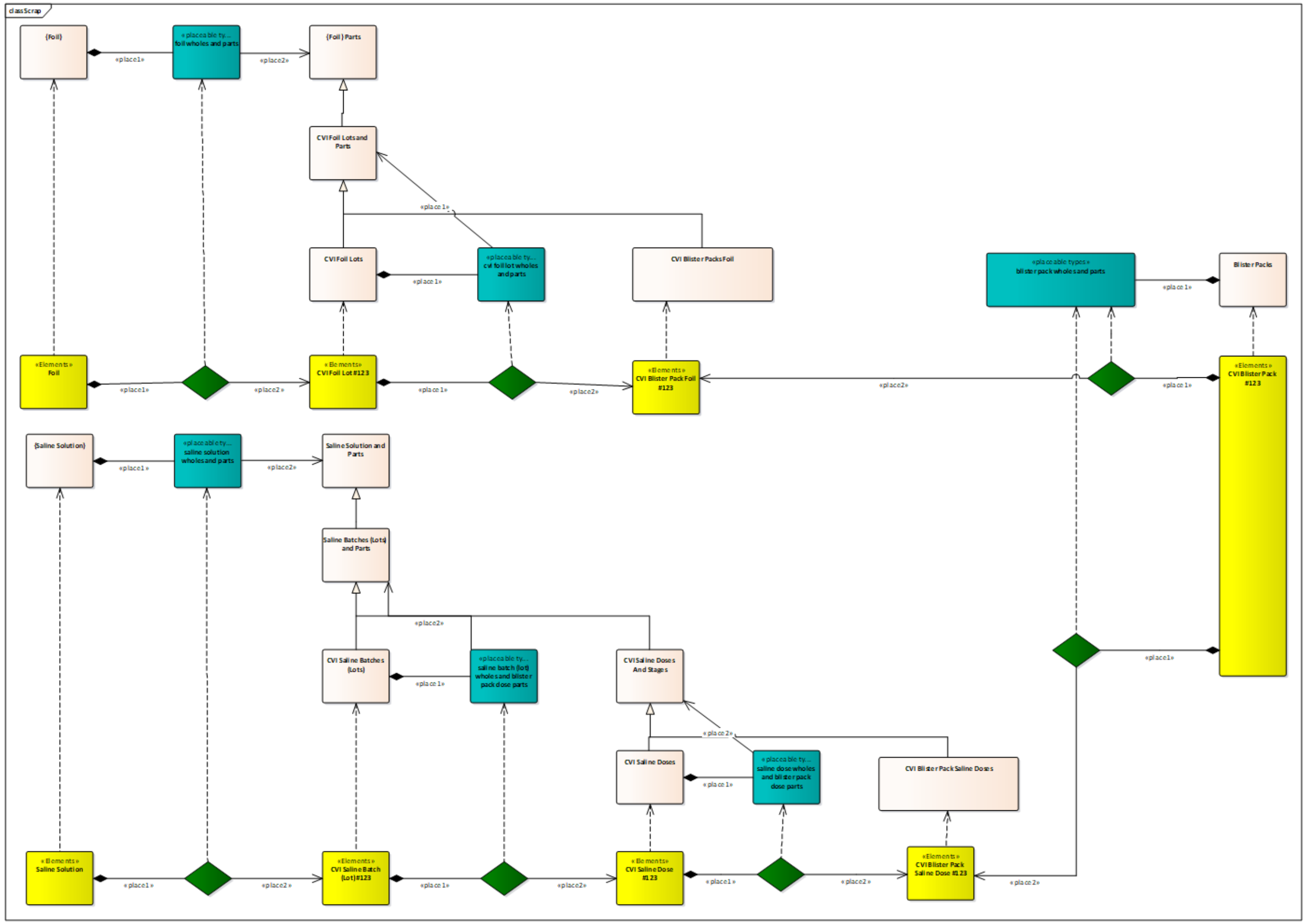

Figure 54 Process evolution from STMs to EA Model

From the STMs and SME review of the process steps involved during manufacturing, the EA model is created using the BORO foundation core. Illustrated in Figure 54 showing part of the detailed association of the foil, saline and blisters as they are attributed to the wet batch, the notion of parthood as the raw materials are consumed during the process. Further sections of the model are explained in chapter 6, with the introduction of more data from a legacy system and the conversion of this data into a new Oracle eBS ERP.

5.5. Evaluation

The evaluation of the model identified key points and decisions that where needed to be made. How the manufacturing process STMs were designed and developed with SME evaluation, bring different expertise to view one common picture of the process and understanding the multi-faceted face that manufacturing has. From the initial STMs and the base MVO, a simplistic view of contact manufacturing is born.

Issues with STM regarding factory and productions lines, a factory can exist but not be fully functional and contain a production line. The STM edges need to be well defined to illustrate this. SMEs can gain a better understanding of the complete manufacturing process and the STMs can provide a detailed evaluation of how a lens is produced in space time. In generating the STMs for contact lens replacement schedule and wear type, it is apparent that these amount to the same thing but found in different systems of record. The contribution artefacts in Chapter 5 are outlined in Table 8.

5.5.1. SME Evaluation

To gain a better understanding of what the model means and how this iteration of the model can help increase the understanding across the business. Mainly of the SMEs questioned in this research where unaware of the entire process from end to end and the information required at each process step. If for example there was one application that was the source of all things manufacturing or the process where more tightly coupled there would be a better crossover. Clear and accurate STMs provide a useful resource for SMEs to quickly review process steps, these are easily read by process orientated individuals and database programmers alike. The STMs became a simple, understandable and reusable tool to demonstrate to developers, database administrators and business orientated personnel alike.

New Contribution **Artefacts produced in chapter 5**	**Methods**	**Contributors**
• Lens Type Model • Lens Powertype • Lens wear schedule • Lens Single versus multifocal • Lens replacement type	• Use bCEARer to review errors • Review Visio drafts with SMEs	Built in Visio by researcher and BORO ratified by SMEs
• STMs • Factory STM • Production STM • Generic Manufacturing • Factory, Production, Product • Factory to Contact lens factory • Dry process	• Use bCLEARer to review • Review new Visio draft STMs with SMEs	Built in Visio by researcher and BORO ratified by SMEs

• Wet process • QA • Dry to Blister process		

Table 8 Contribution table for second iteration

5.5.2. Ontological evaluation

With the introduction of an ontological model, the reliance on the SME understanding is reduced, as stated by Partridge, et al (Partridge, 2005), the ontological demands on the structure are much clearer and the benefits of an ontology to interoperability and those arising from canonical representation rely on this; that the ontology is developed independently of the particular system's implementation requirements (Partridge, et al., 2013) meaning the ontology is system independent. As discussed in The Use of Foundational Ontologies in Ontology Development: An Empirical Assessment, the researcher Keet, assesses that using a foundation ontology, although a little time consuming in initial setup, provides quality of data and easier interoperability (Keet C.M, 2011).

5.5.3. Research Output Artefacts

In this chapter the MVO has been expanded to include more data on the CVI product range of families and introduce the process into the model, Dry, Wet and Autoclave process areas added and reviewed by SMEs. The product data has been cleaned and checked to make sure the power ranges are uniform -20 to +20 moving in a quarter dioptre to +- 6 then moving in half dioptre increments. Checking, to that other parameters are correct, base curve and diameters for each individual lens type.

The method of review and the framework from the bCLEARer method in chapter 4.11.3 was used extensively in SME reviews, firstly cleaning data errors or making decisions on what data is more important for example the modality or usage of a lens having a very similar meaning, one being a physical attribute and the other a marketing claim.

5.6. Summary and Conclusion from the Second Iteration

To summarise completing the second iteration of the DSRM, adding expansion to the MVO with the lens types building from elements in the BORO core foundation ontology. The manufacturing process was modelled using STMs after SME review to aid their introduction into the model for process steps. Items of note during the STM development, the sharpness of lines need understood by all SMEs as often the detail is where the biggest benefit resides. Leveraging from previous literature, STMs are a purposeful tool in demonstrating changes and interactions over time (Minkowski, 1908).

STMs help create a pictorial view of the mereological parts of the lens as it is processed through time, the notion of parts of a lens and parthood are illustrated. There is more detail to be uncovered and this has potential for further work, the chemical construct of the monomer becoming a polymer during the curing process or the physical changes that take place to make a contact lens, maybe this is more a philosophical argument and has a lesser impact on contribution to industry.

CHAPTER 6 THIRD ITERATION

6.1. Introduction

Using the MVO model and BORO techniques, to improve the data usability when transferring from a legacy system into a new empty data model. Shown in Chapter 5 the initial concept of the base contact lens, minimum viable ontology. The design science iteration now moves to the third iteration of the MVO for the domain ontology. Using real data from a legacy system to import into a new ERP system and review the data conversion using the MVO and BORO bCLEARer methodology.

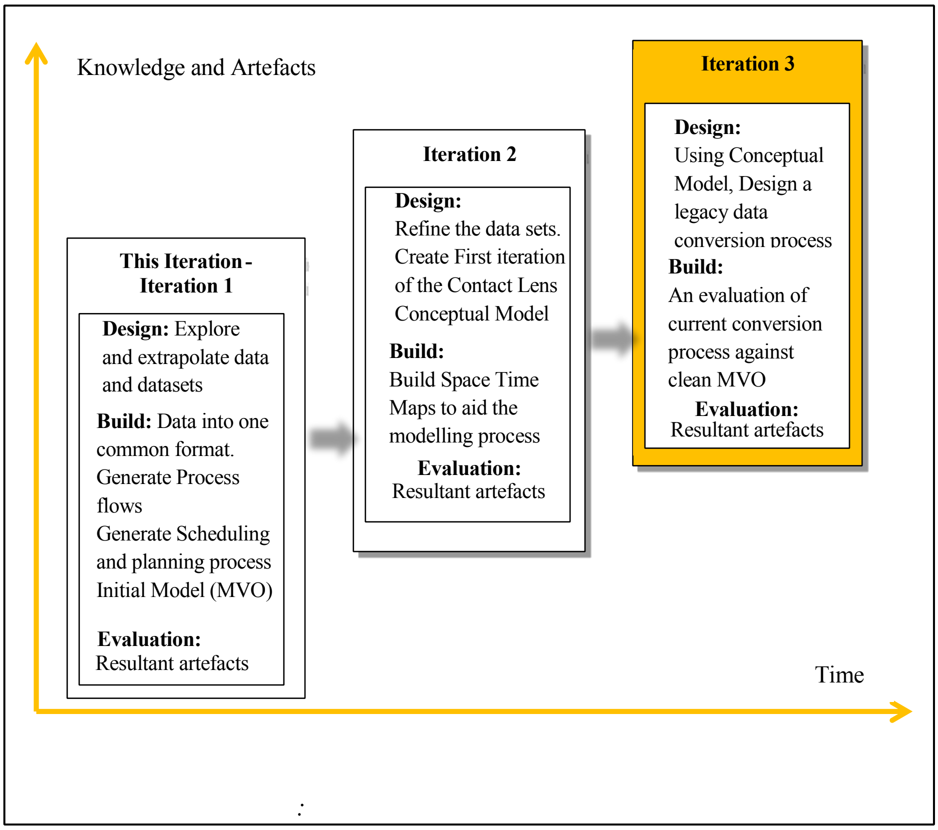

Figure 55 Third Iteration Design Sciences Research

6.2. Objectives of the Third Iteration

The overall objective of the third iteration is to show by empirical evidence the philosophical 4D ontology contact lens domain model, has over a legacy conversion process and improving the interoperability of systems. Utilising the bCLEARer BORO process to collect, load and evaluate data as part of the legacy conversion process. The final stages of the bCLEARer approach are not used to change the data in anyway as this is a live working application, so for evaluation the data is analysed in either Microsoft Excel or Access. The approach take is to create a manual conversion process, move the legacy data into a new Oracle eBS ERP system. Once the data load is complete and reviewed this data is passed through the BORO bCLEARer process. The elements from the MVO will be Products. The engineering spares and materials are not included in the current MVO but are planned for future work.

Stage	***Activity***	***Objective***	***Section Reference***
Design	1	A manual process for analysts to follow in extracting legacy data from systems, cleaning the data and preparing for load into a "new clean" build system	6.5.2
	2	Smart Template of Legacy data for Items and locators Items include Finished Goods, silver stock, engineering spares and raw materials	6.4.2
Build	3	Build Manual Conversion Process (Non-ontological)	6.5.4
	4	Load legacy data to Access Database, check for simple errors, naming conventions and data structure. Add unique identifiers	6.5.5
Evaluate	6	Analyse the clean data against the MVO and bCLEARer process	6.7

Table 9 Framework for Third Iteration

6.3. Legacy Data Conversions

Data conversions from legacy system into a new system such as an ERP or a warehouse management system, is a perfect test scenario to review dirty legacy data, extract, clean and import into a new empty base system.

For this iteration a multiple of legacy systems are used, System 21, an ERP system, Helix a maintenance management system used to manage assets and their history of performed maintenance as well as spare parts management and several, small spreadsheets used to hold data on inventory in the factory and warehouse.

6.4. Design

6.4.1. Legacy Data

The source system for this iteration is an extract from Systems 21, this is a legacy ERP system currently used by the manufacturing facility in Gyal Hungary. To facilitate the process of moving legacy data from one system to a new system involves a considerable number of people within the organisation. ERPs are predominantly split into tracks or silos, such as Finance, Supply Chain and Manufacturing modules. The current business SMEs within these tracks are the main source of resource in carrying out the conversion activity.

The entire conversion process for the Hungary facility was approximately 61 different datasets or conversion objects to convert. The data is split into static and dynamic, meaning if data is moved over on a Friday would that be classed as out of date by the Monday morning? If the answer to this question is yes than this would be classed as dynamic data and special provision would be required to sync this data prior to transacting in the new system. Static data such as suppliers or employees has a disposition of minimal change and therefore easier to convert into the new system. The lens attributes are common across all CVI Products so sample data from 4.9 Contact Lens brands and their transformation from Silver stock into Brands and 4.10 Design: Extracting the Model Data is used to format the existing data in System 21. The process model Figure 41 General Manufacturing (Generic

MFG Model) STM becomes the foundation for the locators and locations within the warehouse.

6.4.2. Items and Location, the data source

The conversion identified for this evaluation is the On-hand inventory conversion with the stock locators. The Oracle EBS target and specified fields will be identified with the required mandatory fields needed from the legacy system. The CVI on hand conversion program should handle conversions for items that are non-lot controlled as well as non-locator controlled, based on the smart template data. Following scenarios should be handled by the code:

1. Item is Lot controlled, but not locator controlled.

2. Item is Non-lot controlled, but locator controlled.

3. Item is Non-lot controlled and not locator controlled.

4. Item is both lot controlled, and locator controlled. The smart template data can have data on any of the above scenarios and the program should handle the data conversion.

Locators are the location stores, in a large warehouse environment there are tens or thousands of individual locations for items to be stored. CVI use either finished goods (FG), meaning the items have their finished brand label already on each individual blister or in silver Stock (SS), meaning the items have just a foil and a smaller label and missing the branding and final finished prescription of the lens on the pack.

The On-hand inventory conversion moves items (Product) from the legacy system (System 21) into Oracle along with its unique location. The purpose of this conversion is check for errors and avoid erroneous data in the new system. Simple errors like data types, are they the correct? Data lengths need to be assessed to make sure they are the correct or compatible size to be loaded into the smart template and then into the Oracle system.

6.5. Build: Legacy Data Conversion

6.5.1. The People Factor

Completing legacy conversions requires several SMEs, skilled in inventory control, finance, planning and manufacturing. The manual data conversion process gives them the guidelines to be able to all work in the same manor and give the correct level of rigor required to make sure the data is correct in the new system.

6.5.2. The Manual Data Conversion Process

To facilitate the process of legacy data conversion a manual process for converting data was derived, identifying the need to guarantee the data is correct at every stage of the process. The manual process that was built needed to be defined and for all active participants in the data conversion process to understand their role in the process.

From the actual legacy data conversion, the data is extracted and passed through the bCLEARer process before being assessed alongside the actual legacy data.

The manual conversion process was designed, built and evaluated outside of this research in order to facilitate legacy data conversions throughout all CVI. The process consists of four stages. The primary stage is to understand the legacy data that is required and extract, check and clean this data. As seen in previous chapters legacy data can be extremely dirty and therefore requires checking for duplicates and mistakes within the data, addresses, names, spaces with names can all be identified as data errors. Attention is required for financial data, for example inventory quantities and quantity types, are the quantities singes or a box of 10, this has a big bearing on the final monetary value when being loaded into the new system.

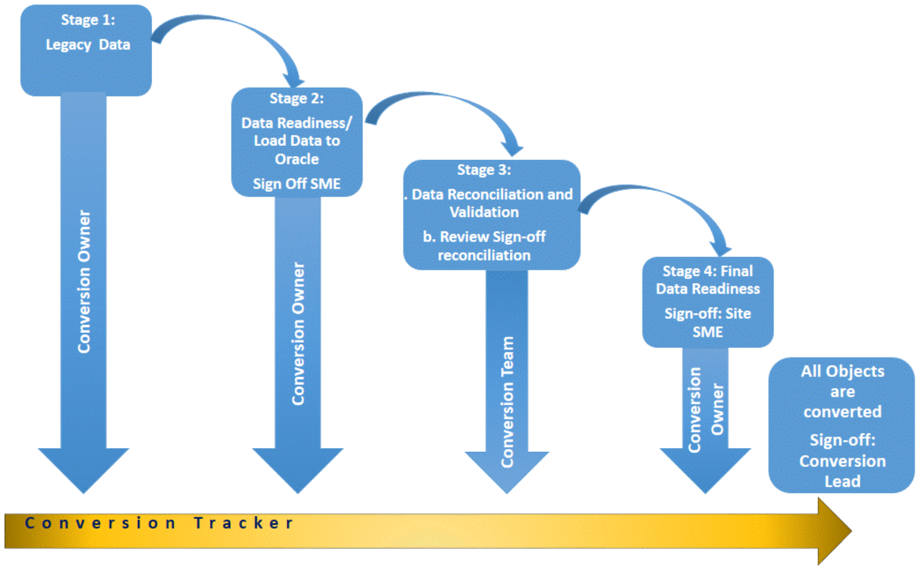

Figure 56 Manual conversion process

A brief overview of the high-level steps is illustrated in Figure 56, four simple steps: -

- Stage 1, where data is identified for extraction, reviewed for errors and extracted. Other errors such as address duplicates or name changes are identified and corrected at this stage.
- Stage 2, This data needs to be review by the data owner prior to any load into Oracle. It's an important part of the process as erroneous data is costly to fix at a later stage within the new Oracle system.
- Stage 3 is split into two activities, the reconciliation of what has been loaded into Oracle eBS verses the legacy extract. There must be 100 percent correlation between these two files to make a match. The second activity is the approval of this verification.
- Stage 4, the final stage is the approval of all the prior stages by a country manager or data owner of that workstream. This above manual process is required for all parties to understand the importance of the data conversion. As mentioned in Real-world Data is Dirty: Data Cleansing and The Merge/Purge Problem, Errors due to data entry mistakes, or more malicious activities, provide scores of erroneous data

sets that propagate errors in each successive generation of data (Hernandez & Stolfo, 1998).

6.5.3. Dataset Analysis and Editing

Legacy data set from source data loaded into smart template, this template is used as translation tool, to allow the new system to load the data into the appropriate locations within the database.

6.5.4. Software Design and Documentation

From a software point of view, the mapping from legacy to new oracle system needs to be defined and in Table 10 these translations are detailed, called a smart template. The smart template is the load document used to load the data into Oracle eBS using the data import tool within Oracle, attention, is required to make sure these mapping and the data within the columns fits with the data type of that column, any issues with this load will cause a rejection of the data load and an error reported back. The smart template column contains the headings in Oracle and the legacy mapping column is the data from the legacy system. This information is written in the software design specification for the conversion load for this conversion object. Table 10 Legacy data mappings defined in software design specification

Smart Template Column	Legacy Mapping	Comment
ORGANIZATION_CODE	manually added to Helix extract, always: HU1	Organization Name: HU1
LEGACY_CODE	Always HUH|	HUH| – Helix, HUS| – System 21, HUE| – Excel

LEGACY_ITEM_NUMBER	SELECT s.stockno, s.name, sp.quantity, sl.name FROM STOCKPILE sp LEFT OUTER JOIN STOCK s ON (sp.id_stock = s.id) LEFT OUTER JOIN STORE_LOCATION sl ON (sp.id_store_location = sl.id) where sl.ID_WAREHOUSE= 6 and sp.quantity <> 0	select s.stockno Item, sp.QUANTITY, st.name Legacylocator from stock s, stockpile sp, store_location st where sp.id_store_location=s.id_store_location_in and s.has_store_location = 1 and s.stockno not in ('00002', '00932', '00877', '01270', '02414', '01482', '02015', '02023', '02301', '04037', '04132') and st.id=sp.id_store_location
SUB_INVENTORY_CODE	Always ENGSPARES	Sub Inventory is not used in Helix, we need to default it to "ENGSPARES"
LEGACY_LOCATOR	SELECT s.stockno, s.name, sp.quantity, sl.name FROM STOCKPILE sp LEFT OUTER JOIN STOCK s ON (sp.id_stock = s.id) LEFT OUTER JOIN STORE_LOCATION sl ON (sp.id_store_location = sl.id) where sl.ID_WAREHOUSE= 6 and sp.quantity <> 0	select s.stockno Item, sp.QUANTITY, st.name Legacylocator from stock s, stockpile sp, store_location st where sp.id_store_location=s.id_store_location_in and s.has_store_location = 1 and s.stockno not in ('00002', '00932', '00877', '01270', '02414', '01482', '02015', '02023', '02301', '04037', '04132') and st.id=sp.id_store_location
LOT_NUMBER	Lot Number: for MOCK conversion: “MOCK DATA”	Optional

TRANSACTION_QUANTITY	SELECT s.stockno, s.name, sp.quantity, sl.name FROM STOCKPILE sp LEFT OUTER JOIN STOCK s ON (sp.id_stock = s.id) LEFT OUTER JOIN STORE_LOCATION sl ON (sp.id_store_location = sl.id) where sl.ID_WAREHOUSE= 6 and sp.quantity <> 0	Quantity per locator (and per lot for lot controlled). Decimal separator is Inventory Operator to provide Helix Select Statement
TRANSACTION_UOM	select ID_ME from stock -- Manual translation	Unit of Measure, need to be translated to Oracle Unit Of Measure Inventory Operator to provide Helix Select Statement
TRANSACTION_SOURCE_ID	manually added to Helix extract,	constant representing “CVI_HM_ONHAND_MIGRATION”
TRANSACTION_DATE	should be left NULL	If left null than SYSDATE (), Date format in Oracle is 'YYYY-MMM-DD'

Table 10 Legacy data mappings defined in software design specification

Any errors that occur during the loading process, either report a generic error and rollback the process or continue with the load, reporting an error on x number of records loaded with x number of errors and the need to review the logs for the description of the errors. In general, all financial conversions require a roll back and fix any errors for a 100% successful data load, other conversion such as inventory or suppliers can have errors requiring fixing.

6.5.5. Bulk Data Load

The On-hand Inventory consists of three unique warehouses, used for sliver stock, engineering spares and a fridge for materials. The data in the legacy system 21 has the following code to distinguish locators. These locators are split into Rack, Rack Rows and

Bins. The design of the legacy ERP System 21 and the new ERP Oracle eBS stipulates that the Racks, Rack levels and Bins cannot have '0' or '00' codes. The Locator format is arranged xABB.CCD.EE where: -

- x=Sub inventory (A-Z)
- A=Floor (0-9)
- BB=Row (01-99)
- CC=Rack (01-99)
- D=Rack level (1-9)
- EE=Bin (01-99)

The smart template is used to load directly into Oracle eBS, a template file in excel with the correct heading and legacy data, cleaned and check in accordance with the SME for the conversion as depicted in Figure 56.

Locator	Locator Description	Type	Status	Subinventory Code	Capacity weight uom
D001.001.01		Storage Locator	Active	DRYMOULD	KG
A000.000.00	Foldszinti padlo / On floor	Storage locator	Active	ENGSPARES	KG
A000.000.01	Foldszinti padlo / On floor	Storage locator	Active	ENGSPARES	KG
A000.000.02	Foldszinti padlo / On floor	Storage locator	Active	ENGSPARES	KG
A000.000.03	Karmento talca / spill tray	Storage locator	Active	ENGSPARES	KG
A000.000.04	Karmento talca / spill tray	Storage locator	Active	ENGSPARES	KG

Capacity weight maximum	Capacity dimensions: uom	Legacy Locator ID	Organization	Picking Order
	CM		HU1	10
	CM	210401	HU1	33300
	CM	500111	HU1	33300
	CM	510209	HU1	33300
	CM	510321	HU1	33300
	CM	210102	HU1	33300

Figure 57 Smart Template for Locators

The Smart Template Figure 57, a smaller set of locator for illustration purposes, holds the information on the locator, description, type, sub inventory codes, units of measure (UoM) and the information from the legacy system, this is to allow for full traceability back to the source data.

ORGANIZATION_CODE	ITEM_SOURCE	LEGACY_ITEM_NUMBER	ORACLE_ITEM_NUMBER	SUB INVENTORY CODE	LEGACY_LOCATOR	LOT_NUMBER	TRANSACTION_QUANTITY
HU1		B6AD01M0025+150		SSTOCK	C001.011.01	X0000001	408
HU1		B6AD01M0025+275		SSTOCK	C001.011.01	X0000002	3789
HU1		B6AD01M0075+150		SSTOCK	C001.011.01	X0000003	183
HU1		B6AD01M0075+275		SSTOCK	C001.011.01	X0000004	4104

Figure 58 Smart Template for Finished Goods and Silver Stock

The Finished Goods and Silver Stock conversion uses a similar smart template Figure 58 illustrates the headers for the import into Oracle eBS.

6.6. Evaluation

The evaluation of the MVO, products and brand families, which equates to Items and locations for the stock warehouse.

A Microsoft Access database is used to evaluate the data, as Oracle eBS is a live system transacting business for other CVI locations and no data interrogation can take place on a live system whist this is being used as an operational system. The BORO bCLEARer methodology is used to collect, load, evaluate, assimilate and reengineer the data.

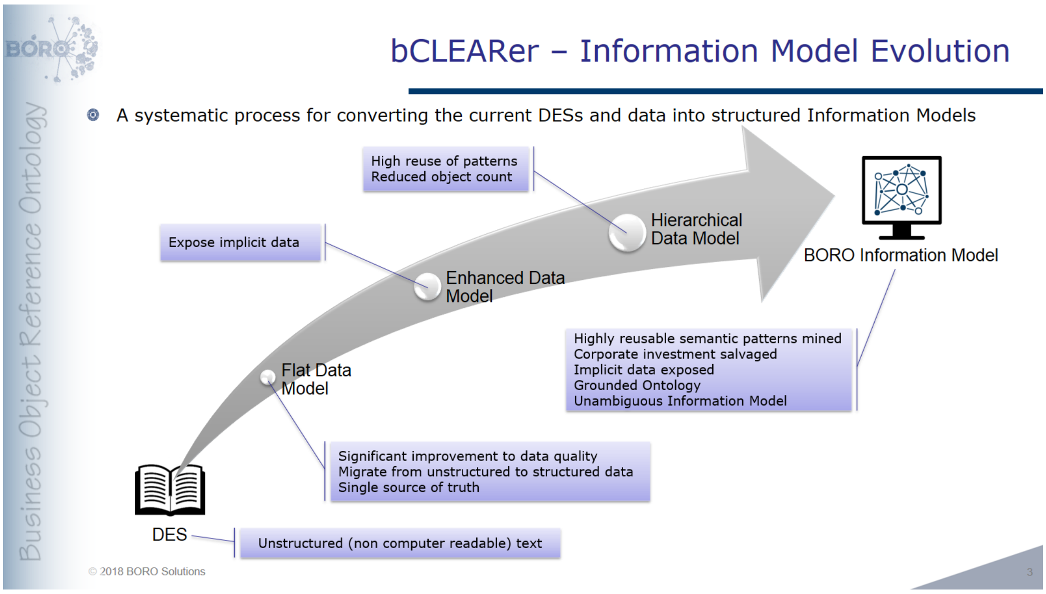

Figure 59 BORO DES Data Exchange Specification Model

Figure 59 shows the BORO Data Exchange Specification model (DES) qualifying from unstructured dirty data to a new information model, the process stages included the cleansing of dirty data, identifying and removing the gross errors in the important data.

Further cycles expose and improve the data quality over time. Implicit data is the data gathered from several data streams[11].

6.6.1. Query Response

To evaluate the data the Smart templates (Excel Data sheets) for the load into Oracle eBS were evaluated through the BORO bCLEARer process and loaded into Access and EA Model.

- Finished Goods (FG)
- Silver Stock (SS)
- Raw Materials (RM)
- Engineering Spares (ES)
- Locators (Loc)

Questions were asked of the SMEs on any ambiguous data found for clarification.

6.6.2. Ontological evaluation

The third iteration used legacy data from finished goods and locators. These flat spreadsheets were exported from System 21 and cleaned, loaded for evaluation using bCLEARer BORO process. A review of the legacy functional specifications was also conducted to understand the translations and mappings in to the new system. Several errors or confusion points were noted, documented in the functional specification for system extract were the following acronyms as shown in Figure 60

Appendix B: Added Legacy Source Code, Legacy Item Number & Legacy Locator to smart template

The new smart template file will contain the following elements in the specified order. The existing on hand conversion program should be updated to use the new fields as part of the conversion program.

Element	Field	Comment
1	Inventory Org Code	Organization Name Example(HU1, HU2)
2	Legacy Source Code	HUH| – Helix, HUS| – System 21, HUE| – Excel. In case of items mastered in IMDM the legacy source code will be null.

Figure 60 Conversion Functional specification errors

[11] https://whatis.techtarget.com/definition/implicit-data

This error when first discovered in the MVO led to there being two instances of System 21, HUH and HUS. However, on further investigation with SMEs exposes the poor level of detail in the documentation and what the author was trying to elaborate on was the following: -

HUH = Helix

HUS= System 21

HUE =Excel from any other system that does not have an export

An illustration where small errors in documentation have huge effect on large systems. Other incidents of note were the locations or building layouts, the Gyal facility is undergoing huge redevelopment and areas change over time. Planning and consideration has to be incorporated into the model to allow for change to location.

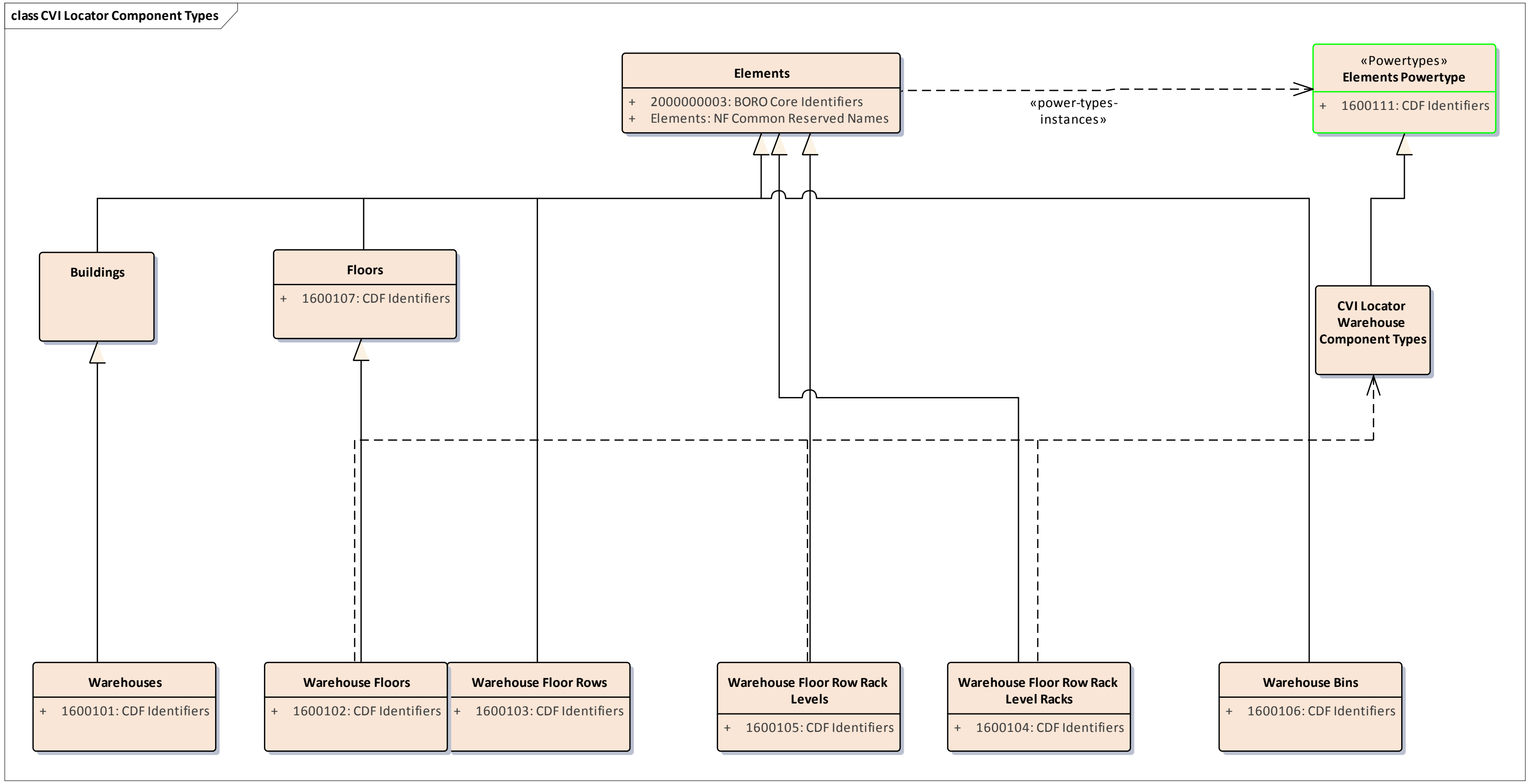

Figure 61 CVI Locator Component Types

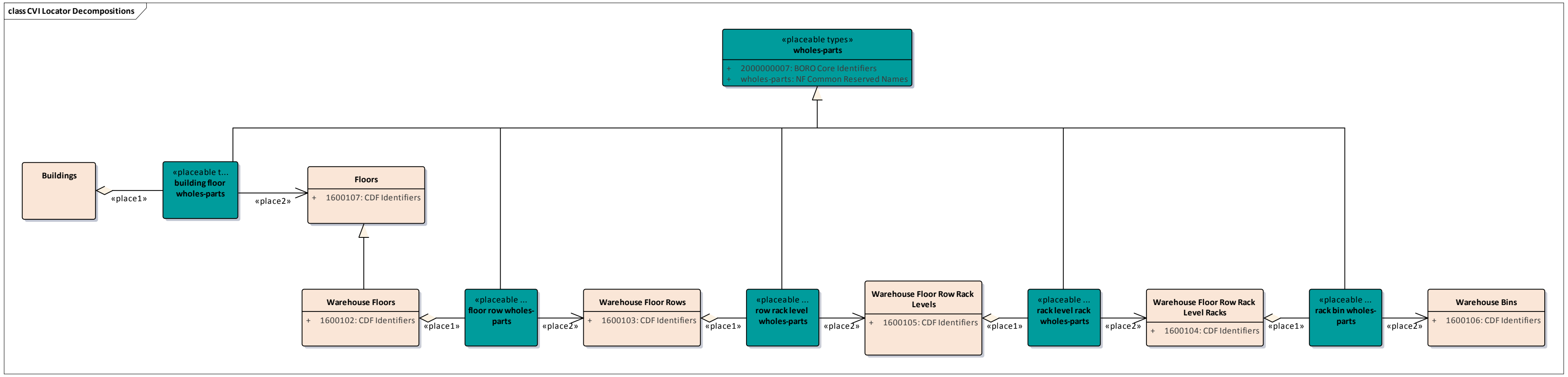

Figure 62 CVI Locators Modelled

In Figure 61 and Figure 62 is a detailed view of the locators in the CVI HU facility, the relationship between buildings, warehouses and floors could be expanded to include CVI entities. Useful for the financial consideration when shipping products across boarders or pending Brexit negotiations, which may inflict a higher degree of taxation upon numerous manufacturing companies across Europe to the UK.

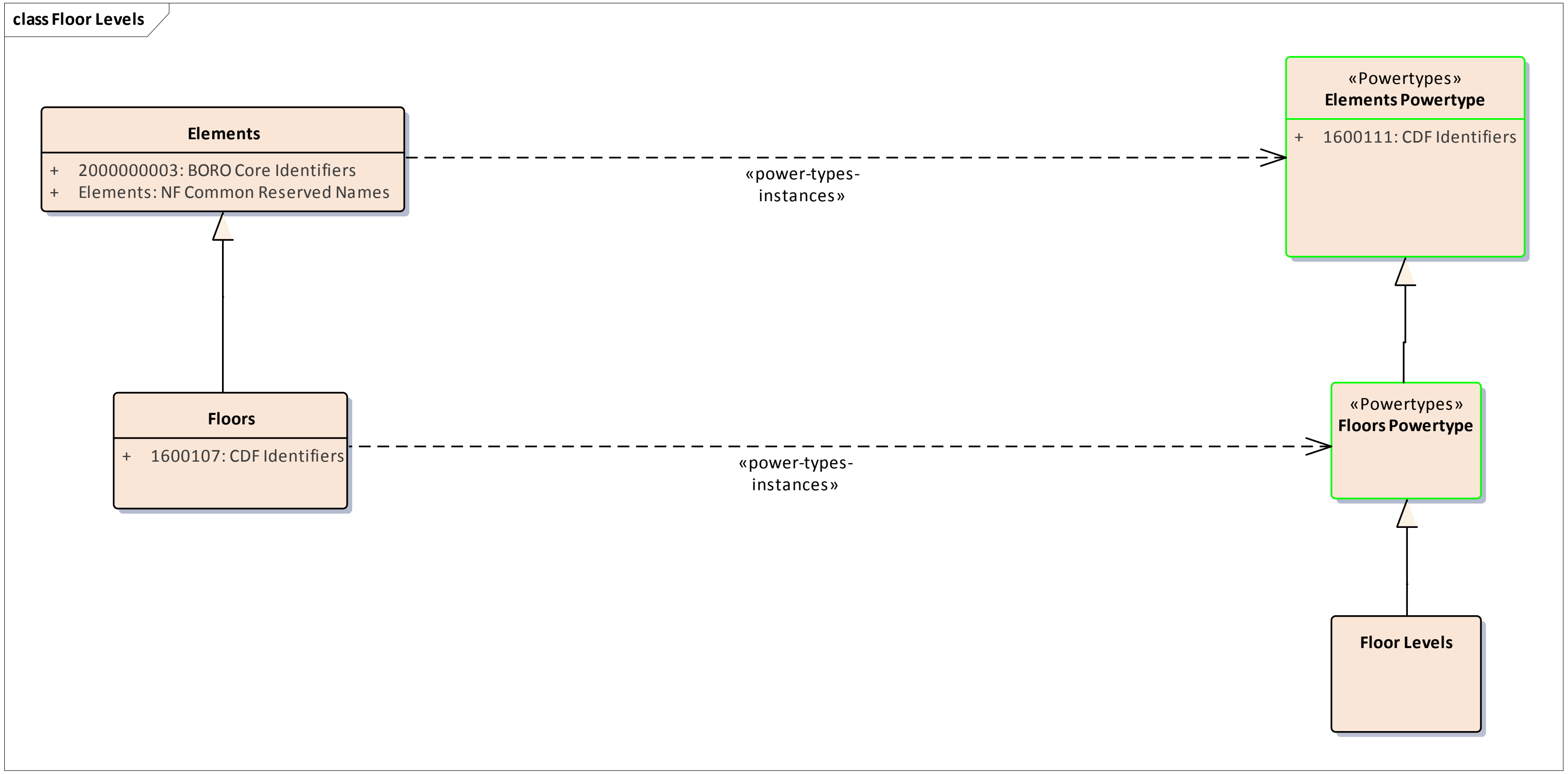

Figure 63 CVI Floor Levels

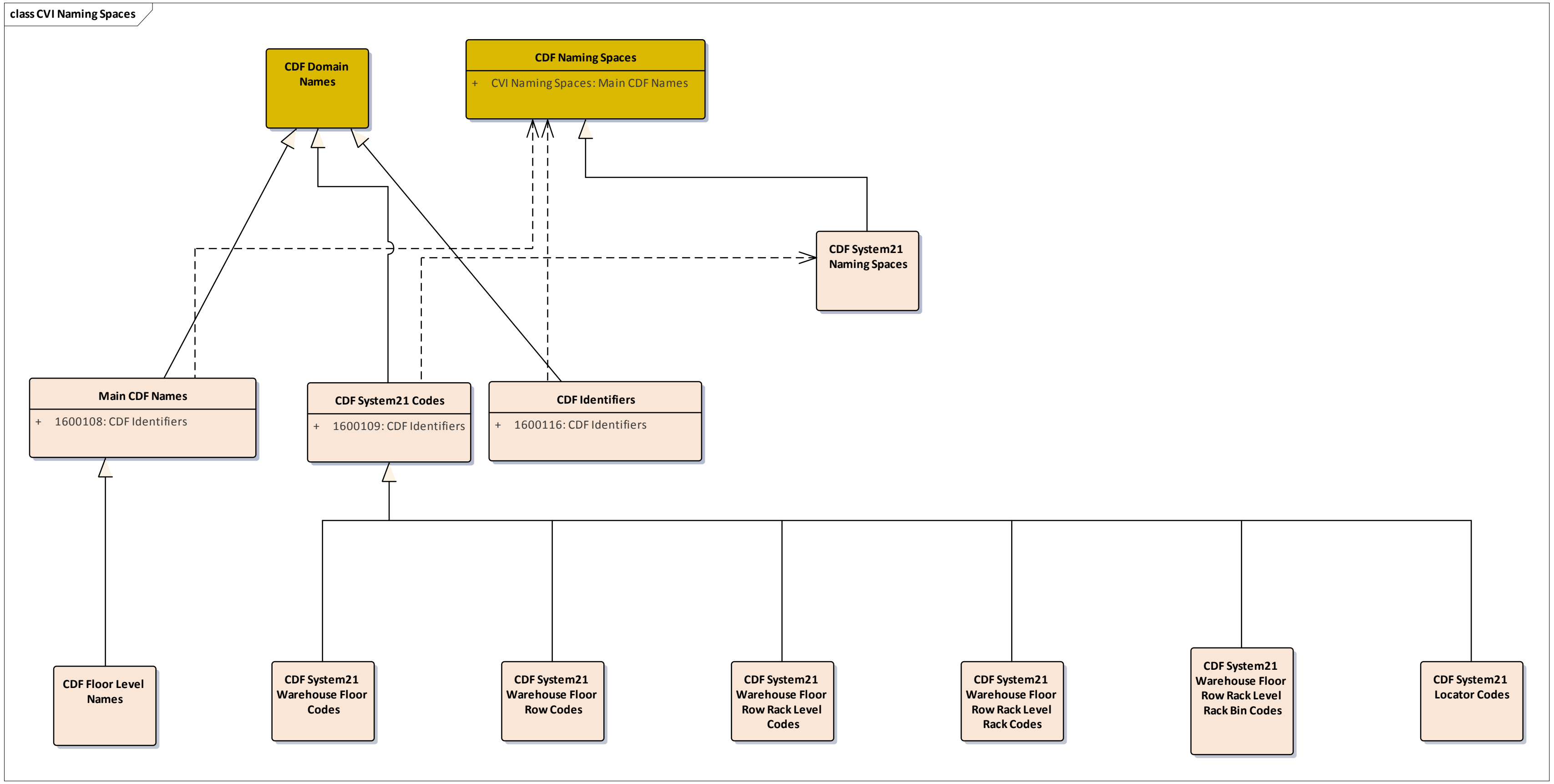

Figure 64 CVI Naming Spaces

The CVI naming spaces come from the legacy ERP system, System 21. The floor space is model from legacy data in Systems 21 and depicted in Figure 63. The system 21 layout for racks and row codes are shown in Figure 64 for illustration purposes. The physical labels matched the data in the legacy ERP system and new ERP system so no further changes were noted.

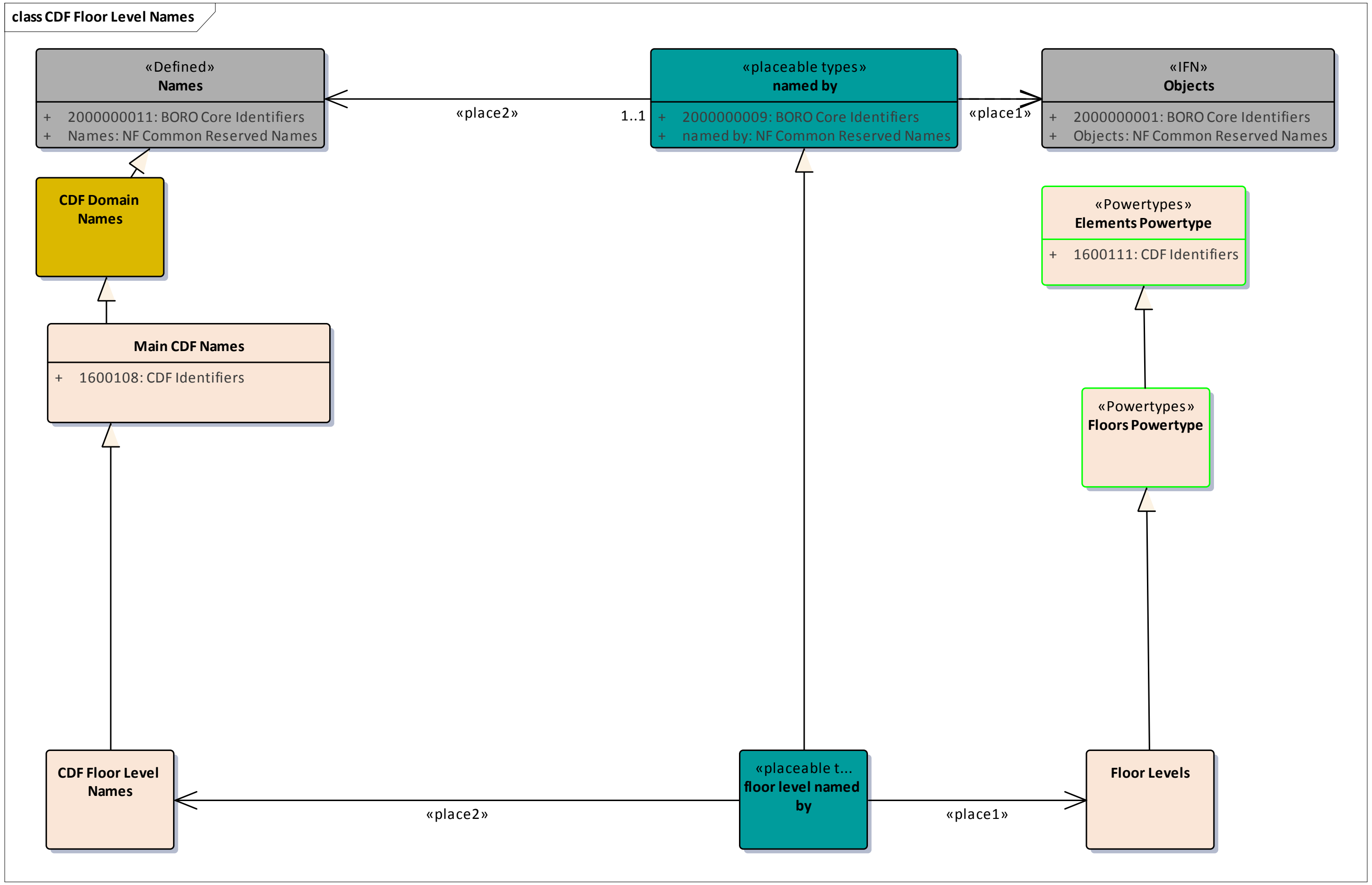

Figure 65 Floor Levels

The basic floor names are modelled in Figure 65 floor levels to floor level names. These are direct conversions from legacy System 21 into Oracle eBS.

6.7. Issue found during the evaluation: Bad Data

6.7.1. Location 00,00

Introduction

During the review of the locators, the uniqueness was assessed to ensure there were no duplicate locators in the dataset. The location 00, 00 or 0,0 was deemed to be an illegal location through the systems design and as such nothing could be located there. These are depicted in Table 11, the investigation surrounding the reason, was engineering spares being received into the organisation last thing at night and the operator not having time to source a suitable location for the inventory. The system both System 21 and Oracle eBS allowed this error to take place even though the specification did not allow such action.

Analysis

In p003-s002-c020-3e - Locator Analysis.accdb (Access Temporary evaluation) show that there are 28 locator codes used for Engineering Spare Part Inventory Bin Stages with illegitimate '0' or '00' parts.

warehouse_name	storey_code	row_code	rack_code	level_code	bin_code	sub_inventory_code
CV-HU	0	03	07	2	00	A003.072.00
CV-HU	0	00	00	0	11	A000.000.11
CV-HU	0	00	00	0	04	A000.000.04
CV-HU	0	00	00	0	01	A000.000.01

CV-HU	0	00	00	0	08	A000.000.08
CV-HU	0	00	00	0	06	A000.000.06
CV-HU	0	00	00	0	12	A000.000.12
CV-HU	0	00	00	0	10	A000.000.10
CV-HU	0	00	00	0	05	A000.000.05
CV-HU	0	00	00	0	13	A000.000.13
CV-HU	0	00	00	0	00	A000.000.00
CV-HU	0	00	00	0	16	A000.000.16
CV-HU	0	00	00	0	02	A000.000.02
CV-HU	0	00	00	0	09	A000.000.09
CV-HU	0	00	00	0	17	A000.000.17
CV-HU	0	02	02	4	00	A002.024.00
CV-HU	1	00	00	0	14	A100.000.14
CV-HU	1	00	00	0	11	A100.000.11
CV-HU	1	00	00	0	13	A100.000.13
CV-HU	1	00	00	0	06	A100.000.06
CV-HU	1	00	00	0	00	A100.000.00
CV-HU	1	00	00	0	02	A100.000.02

CV-HU	1	00	00	0	10	A100.000.10
CV-HU	1	00	00	0	05	A100.000.05
CV-HU	1	00	00	0	09	A100.000.09
CV-HU	1	00	00	0	08	A100.000.08
CV-HU	1	00	00	0	12	A100.000.12
CV-HU	1	00	00	0	03	A100.000.03

Table 11 Erroneous Locators

The pink highlighted items show a sub inventory code in location 00,00 the illegal location. From this research this was amended in the new Oracle eBS system, operators now must book in the items directly to a location so stock can be reconciled correctly by the finance team. If there are items in locator 00,00 at month end or yearend these would not be reconciled in the ledger and would create a discrepancy.

6.7.2. Many items in the same location

Introduction

A bin in locators, cannot have more than one (sub-inventory) stage in the data according to the design specifications for Oracle eBS.

Analysis in query p003-s002-c020-3e - Locator Analysis.accdb (Access Temporary evaluation) shows that there are 423 bins with multiple sub-inventory stages.

Analysis

database Custom Group: Analysis - Check - Bins with Multiple Sub Inventories

Database Query: check_bins_multipleSubInventories (Access Temporary evaluation).

The Query shows that there are 423 bins with multiple sub-inventory stages. The query also splits out the sub inventory type and shows that the overlap is between engineering spares, raw materials and silver stock. With further investigation, there is a warehouse for 3 separate elements, engineering spares, silver stock and raw materials, each physical warehouse is in different areas of the factory all using the same warehouse structure coding. In Table 12 the data view, highlighted shows the bin location 001.021.01 having a bin with raw material and a having silver stock located in the same location. Having 3 warehouses for differing items in the same factory may well cause issues with future expansion or a restructure of current warehouse layout. See Appendix C

bin_code	bin_locator_code	count_of_sub_inventory_stages	ENGSPARES	RAWMAT	RMFRIDGE	SSTOCK
01	001.011.01	2		1		1
01	001.012.01	2		1		1
01	001.021.01	2		1		1
01	001.023.01	2		1		1
01	001.024.01	2		1		1
01	001.031.01	2		1		1
01	001.032.01	2		1		1
01	001.033.01	2		1		1
01	001.034.01	2		1		1
01	001.041.01	3	1	1		1
02	001.041.02	2	1	1		
01	001.042.01	2	1			1
02	001.042.02	2	1	1		
03	001.042.03	2	1	1		
01	001.043.01	3	1	1		1

Table 12 Duplicate Locators

From this discovery the code in oracle has been updated to include either raw materials, silver stock or engineering spares as part of the primary key to create uniqueness.

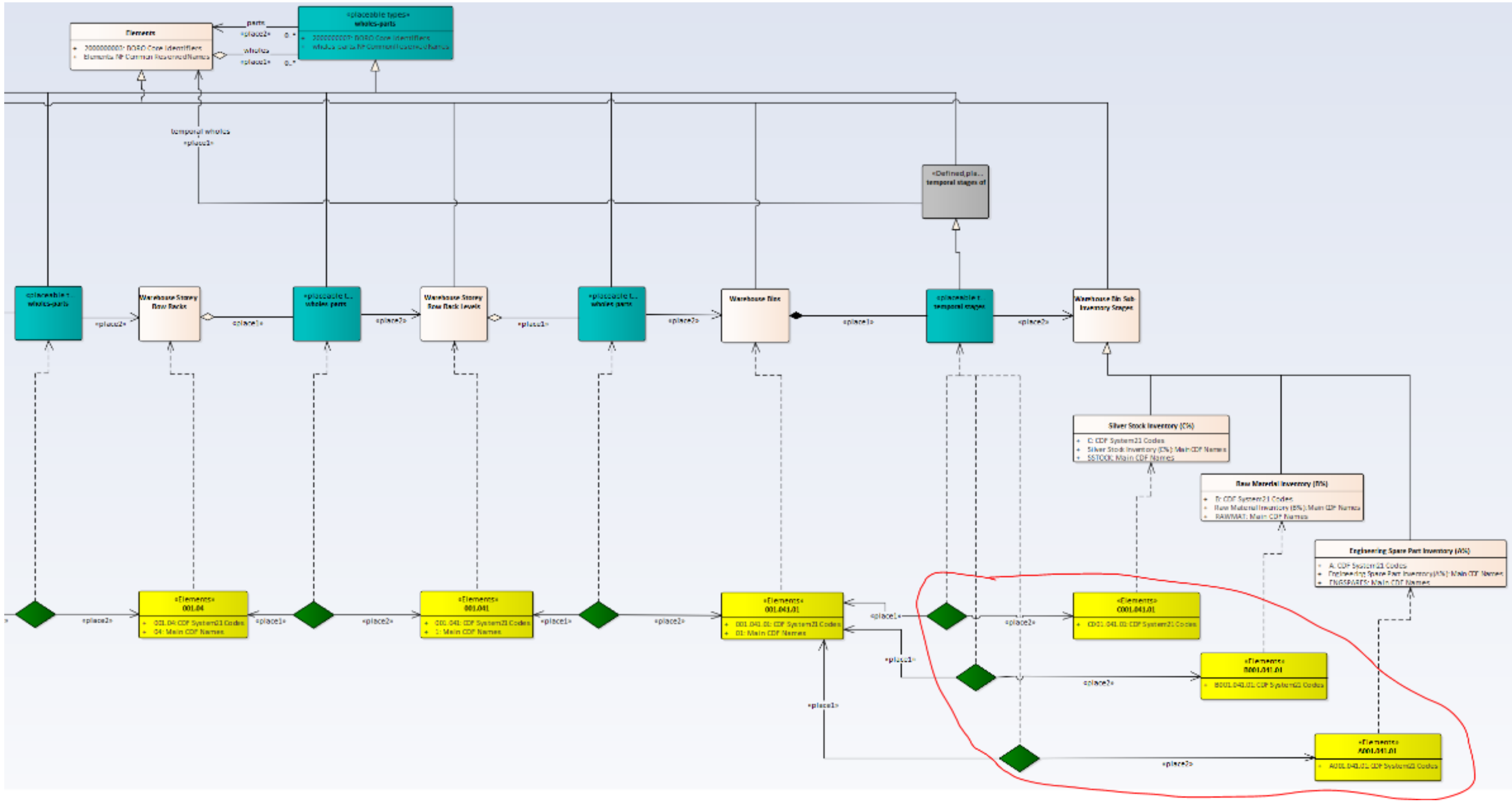

Figure 66 Multiple Warehouses with same name in the model

6.7.3. Multiple Units of Measure for a Bin Location

p003 - CV-HU Python Test - Query - Locators with Multiple UoMs (Access Temporary evaluation).

Introduction

It is assumed that a location (bin) in the warehouse will only have one type of content. The granularity of the type is yet to be determined. However, it is expected that they should at least have the same UoM.

18 locator codes have multiple UoMs.

Analysis

Source data: 'Export Worksheet' sheet from the 'INV_CNV_09_HM_FG - On Hand Qty – Silver Stock -SourceReconcReport.xlsx' Workbook (from CVH-S001-C001-C - Global Collect - Transaction Data)

The full list of locators with multiple UOMs:

18 locator codes have multiple UoMs. the first one: B001.051.01 has been highlighted below and it shows that it contains types measured in 'each' and 'kg'.

ⓘ 18 locator codes have multiple UoMs. the first one: B001.051.01 has been highlighted below and it shows that it contains types measured in 'each' and 'kg'.

Locator Index	sub_inventory_code	SUBINVENTORY_CODE	Sum Of OHQ	UOM	ITEM_TYPE	ORACLE_ITEM_NUMBER	ITEM_DESCRIPTION
484	B001.051.01	RAWMAT	21000	EA	Pkg Controlled Material	100004432	CARTON C51SD56JZZ
484	B001.051.01	RAWMAT	3000	EA	Pkg Controlled Material	100004433	CARTON C51SD56WZZ
484	B001.051.01	RAWMAT	6000	EA	Pkg Controlled Material	1029523022	CT4802 CARTON BINOVA ULTIMATE 1 DAY 5PK
484	B001.051.01	RAWMAT	1375	KG	Controlled Material	100003457	PCGH19 0090 Polypropilen
487	B001.051.02	RAWMAT	1375	KG	Controlled Material	100003457	PCGH19 0090 Polypropilen

18 locator codes have multiple UoMs, these are all of type RAWMAT (raw materials). Table 13 shows all the locators in the INV_CNV_09_HM_FG - On Hand Qty – Silver Stock conversion.

Index	sub_inventory_code	UOM
875	B001.011.01	EA
875	B001.011.01	KG
877	B001.011.02	EA
877	B001.011.02	KG
874	B001.012.03	EA
874	B001.012.03	KG
890	B001.021.01	EA
890	B001.021.01	KG
892	B001.021.02	EA
892	B001.021.02	KG
840	B001.041.02	EA
840	B001.041.02	KG
484	B001.051.01	EA
484	B001.051.01	KG
487	B001.051.02	EA
487	B001.051.02	KG
581	B001.061.01	EA
581	B001.061.01	KG
590	B001.061.02	EA
590	B001.061.02	KG
702	B001.071.01	EA
702	B001.071.01	KG
712	B001.071.02	EA
712	B001.071.02	KG
905	B001.083.01	EA
905	B001.083.01	PLT

904	B001.083.02	EA
904	B001.083.02	PLT
903	B001.083.03	EA
903	B001.083.03	PLT
913	B001.084.01	EA
913	B001.084.01	PLT
910	B001.084.02	EA
910	B001.084.02	PLT
911	B001.084.03	EA
911	B001.084.03	PLT

Table 13 List of Locators with multiple Units of Measure (UoM)

The 18 locators that have multiple units of measure was not deemed to be a design feature but does allow these locations to contain either or UoMs. Errors could occur with differing raw materials in the same location.

6.7.4. Visual View of the Warehouse Data

Introduction

Lens types have been decoded from the source data and 11 main types have identified. These have been overlaid onto a floor plan and the following shows the analysis.

Analysis

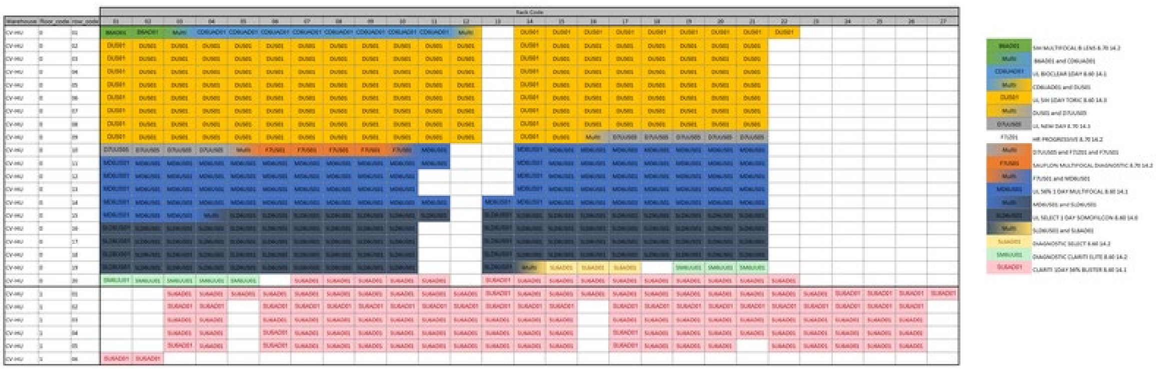

Figure 67 Lens Type Layout by Rack Query

The warehouse floors have been laid out by lens type. Racks have been left for expansion for the bottom three types. All the other types have overlapping types on the racks - and even in the bins.

Figure 67 shows a pictorial view of the data, even showing the walkway between the racks at column 13. Issues found were the 8 locators that contained different lens Type Codes, meaning that different products could be mixed in this location. These were the only lens type errors noted on all the finished goods and silver stock locations and shown in

Table 14.

LOCATOR	Lens Type Codes	Lens Type Descriptions
C001.032.01	B6AD01	SIH MULTIFOCAL B LENS 8.70 14.2
C001.032.01	CD6UAD01	UL BIOCLEAR 1DAY 8.60 14.1
C001.123.01	CD6UAD01	UL BIOCLEAR 1DAY 8.60 14.1
C001.123.01	DUS01	UL SIH 1DAY TORIC 8.60 14.3
C009.161.01	D7UUS05	UL NEW DAY 8.70 14.3
C009.161.01	DUS01	UL SIH 1DAY TORIC 8.60 14.3
C010.051.01	D7UUS05	UL NEW DAY 8.70 14.3
C010.051.01	F7JZ01	HR PROGRESSIVE 8.70 14.2
C010.053.01	F7JZ01	HR PROGRESSIVE 8.70 14.2
C010.053.01	F7US01	SAUFLON MULTIFOCAL DIAGNOSTIC 8.70 14.2
C010.104.01	F7US01	SAUFLON MULTIFOCAL DIAGNOSTIC 8.70 14.2
C010.104.01	MD6US01	UL 56% 1 DAY MULTIFOCAL 8.60 14.1
C015.042.01	MD6US01	UL 56% 1 DAY MULTIFOCAL 8.60 14.1
C015.042.01	SLD6US01	UL SELECT 1 DAY SOMOFILCON 8.60 14.0
C019.142.01	SL6AD01	DIAGNOSTIC SELECT 8.60 14.2
C019.142.01	SLD6US01	UL SELECT 1 DAY SOMOFILCON 8.60 14.0

Table 14 Bins with overlapping Lens Types

There are potential contamination issues with different lens types residing in the same locator, however these are mitigated by the pick process, the operator will scan product to and from different locators. However, caution is advised with any future migration or integration to a new system such as a warehouse management system (WMS) this could be a potential issue.

			rack_code																											
warehouse_name	**storey_code**	**row_code**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
CV-HU	**0**	**00**	14																											
CV-HU	**0**	**01**		0	0	0	108	88	101	89	0	0	0	0	0		0	0	0	0	0	0	0	0	0					
CV-HU	**0**	**02**		0	4	21	40	84	31	48	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**03**		0	1	1	41	11	6	13	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**04**		0	0	0	60	66	58	37	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**05**		0	0	0	25	72	28	62	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**06**		0	0	0	95	106	92	66	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**07**		12	17	24	45	72	53	48	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**08**		80	100	11	119	107	103	102	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**09**		0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0						
CV-HU	**0**	**10**		0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0						
CV-HU	**0**	**11**		17	16	22	43	41	21	54	0	0	0	0			0	0	0	0	0	0	0	0						
CV-HU	**0**	**12**		23	48	23	24	23	48	12	0	0	0				0	0	0	0	0	0	0	0						
CV-HU	**0**	**13**		0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0						
CV-HU	**0**	**14**		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0						
CV-HU	**0**	**15**		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0						
CV-HU	**0**	**16**		0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0						
CV-HU	**0**	**17**		0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0						
CV-HU	**0**	**18**		0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0						
CV-HU	**0**	**19**		0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0						
CV-HU	**0**	**20**		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0					
CV-HU	**1**	**00**	12																											
CV-HU	**1**	**01**		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
CV-HU	**1**	**02**		1	2	0	0		0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	
CV-HU	**1**	**03**				0	0		0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	
CV-HU	**1**	**04**			6	0	0		0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	
CV-HU	**1**	**05**			4	2	7	8	0	1	0	0	0	0	0	0	0	0		0	0	0	0		0	0	0	0	0	
CV-HU	**1**	**06**		1	3		2	5	1	2																				

Figure 68 Rack, Row and Bin Layout Review

In reviewing the data converted from System 21 in to Oracle eBS patterns began to be exposed in

Figure 68, popular locations, tend to be within arm's reach, the operators don't like to locate the fastmoving items in awkward locators on the rack. The low moving items are optimised without any real systematic approach and there is reliance on the scanning guns to scan the correct barcodes on the product and the locator to make a match for a successful pick.

6.8. Summary and Conclusion from the Third Iteration

Following the completion of this evaluation of the artefacts produced by this final iteration of the design science cycle, the quality and reliability of the artefacts is deemed to be sufficient to provide a final evaluation to fulfil the aim of the project.

The legacy data conversion, extracting, cleaning and reviewing through the BORO core foundation ontology EA model and using the bCLEARer tool set to identify and evaluate apparent data errors. Single source errors from legacy system, illegal attributes, uniqueness violation and referential integrity violation (Rahm & Do, 2000). Coupled with dirty data, such as clear typos in the original product type setup and manual human errors. These are never realised due to the scan guns utilising product labels and locator labels to move stock in and out of the warehouse. The contributions are listed in Table 15

New Contribution **Artefacts produced**	**Methods**	**Contributors**
• Manual conversion process (Section 6.2.5)	• Creating a new manual process to	Process designed, built and tested by researcher

	identify legacy data need in new systems, building in interoperability	
• Legacy mapping templates (Section 6.5.4 Table 10)	• Review with SMEs	Built in Excel by researcher ratified by SMEs
• Evaluation Access database (Section 6.6)	• Create a new database to demonstrate the interoperability benefits moving data from legacy to Access	Built in Access by BORO and Researcher
• Locators model, for bins, rows, racks and floors (Figure 62)	• Work with legacy data to create EA model with BORO	Built in EA by BORO and researcher and ratified by SMEs

• Warehouse visualisation (Section 6.7.4)	• Work with Imported data to create an Excel representation of the warehouse with BORO	Built in Access by BORO displayed in Excel by BORO & Researcher
• Ware house EA Model (Section 6.7.2 **Figure 66**)	• Model generated from Access database	Built from Access in EA by BORO and researcher and ratified by SMEs

Table 15 Contribution table for third iteration

There is of course further work and further improvement of the model in other conversions of products from legacy systems into new ERP or similar level systems. Other conversion data objects were processed through the bCLEARer process and errors and potential errors identified, but they were outside of the scope of the MVO and contained financial data with primary and secondary ledgers, suppliers, accounts receivable and accounts payable.

The method of collecting and manipulating the data within this chapter gave way to the development of the manual conversion process to capture and control the legacy data required in the new system. This new conversion method and framework is new contribution knowledge shown in Figure 56 along with the data mappings template illustrated in Table 10.

Opportunities for further work in the expansion of the MVO into the distribution warehouses would add more robustness to the contact lens domain before researching financial systems.

CHAPTER 7 CONCLUSION AND DISCUSSION

7.1. Introduction

This chapter is the conclusion of the design research methodology adopted from Peffers et al and the design methodology tools used by March and Smith the design, build and evaluate with elements of theorise and justify wrapped in an iterative process (Peffers, et al., 2007) (March & Smith, 1995). The iterations move forward with more refined and broader datasets being added to each iteration, culminating in a empirical review of the MVO for contact lenses. The migration of data from one legacy system into a new ERP system and subsequent evaluation of the data in a standalone database.

7.2. Key Findings

The process of unearthing all of the pertinent data on the products made by CVI made the discovery of tribal knowledge and systems born from paper. When CVI started it was a small cottage industry, through acquisition the company has grown its product portfolio. This entails transferring products into one organisation and the knowledge on how these products are manufactured. The information is often not held within a specific system but held as silos of knowledge within groups of individuals.

Until the data from any legacy systems has been check, cleaned and re-evaluated they are always going to be unknown issues with this data. There have been numerous methods of data cleansing discussed in literature but the BORO bCLEARer methodology creates uniqueness of data checks data integrity and identifies issues with collations between data sets. The bCLEARer methodology also detects foreign language constraints, these may have a different ASCII number between data collations or insert rogue blanks into data. Using the bCLEARer method and cycling through the data with SMEs has dramatically improved the final result of the data in the target system, increasing the interoperability between legacy and new.

7.3. Meeting the Research Aims and Objectives

The contact lens domain ontology was developed over three iterative cycles, scheduling and planning were thought to have been the most fruitful area of data, but as this was a single source with only one SME required to review the process the benefits over time were reduced. If CVI were a less profitable organisation and were required to hold stock for longer periods of time, then this process area would have held more interest. At present for the popular products demand out ways supply.

7.4. Original Contribution to Knowledge

The introduction of a domain ontology for contact lenses is the first foundation grounded ontology developed from contact lens production data. Improvements in automation over the last 20 years have been immense, the introduction of robots is ubiquitous in all high-volume manufacturing plants not just contact lens manufactures (Cox & Goldratt, 1986). The interoperability of legacy data into a new system has been a consistent issue within any domain, not least contact lens manufacturing.

The contribution to knowledge within this research is summarised in Table 16.

Artefact	Contribution	Chapter
Scheduling and planning	New scheduling and planning process map generated to illustrate an unknown process	4
Manufacturing Process maps	Manufacturing process maps developed to illustrate the dry and wet process to manufacture contact lenses	4
Conceptual Models	To design and build the first ontological conceptual model for contact lens products and brands.	5

	This is the first model built using the BORO foundational ontology for the contact lens domain.	
Space Time Maps	The use of Space Time Maps (STM) to help illustrate the process steps and transformation over time changes to the lenses as they travel through the manufacturing process.	5
Data Conversion method	To design and build a manual data conversion process that allows data to be: identified, extracted, cleaned and loaded in a control manor and allow a process of verification that the new staged data is correct.	6
Software design template	Design and evaluate a template to identify legacy data transposition into a new system and integral to a software design specification	6
Interoperability Demonstration	Empirical evidence for the transfer of products and locations (locators) from System 21, analysed and grounded in BORO bCLEARer process. A test for the BORO foundational ontology in identifying any data issues that may arise, the next challenge will be to assimilation and reload to the live data source without any physical downtime.	6

	MS Access was used for this analysis for its ease of use and simple SQL query engine.	

Table 16 Contribution to Knowledge

7.5. Contribution to Industry

The artefacts generated in this research provide generous contribution to the manufacturing domain for contact lenses. Products and process grow over time, new acquisitions require companies to merge vast sums of similar information into a manageable order, the regulatory bodies for medical device impose rigorous demand on device history records and product parameters. Failure to realise or control the lifecycle of product parameters recorded on any regulatory registrations are at a company's peril.

The manual conversion process, although not ontologically based is a purposeful tool to use in any legacy data conversion, where there are numerous SMEs working to convert large data sets from one system to another in a controlled manner. The identification and removal of erroneous data at the earliest stages of the data extract are important as errors are costlier to fix in the new system.

Space Time Maps, as mentioned in the contribution to knowledge these are also a valuable resource to use and share within the industrial domain.

7.6. Accomplishments of the research objective

The foundational ontological model for the manufacture of contact lenses, described and evaluated in this thesis will provide valuable guidance when adding or merging similar product types into one system. This classification of similar lens types needs to be adhered to in order to increase the interoperability results of merging like products. The methods of manually discovering, cleaning and converting legacy data through the manual conversion process has provided a clean proven method to de risk the possibility of erroneous data being transferred to the new system. This method provides the correct segregation of duties to not allow a single person to complete the process, providing a more robust solution for industry to adopt. The accomplishments of this research objectives are detailed in Table 17.

Research objectives	Research Accomplishments
Objective 1 Review the literature on domain modelling within the Manufacturing domain and look at where novel ideas to address interoperability have succeeded.	Chapter 2 reviews the literature, on domain modelling, prior research into dirty data, data cleaning examples and datasets coming from paper.
Objective 2 To collect and collate information on current manufacturing data within CVI, using an iterative process to design, order and reorder the data into a structured format for evaluation. Initially using the product and brands of contact lenses, understanding when a lens becomes a lens and when the brand is placed upon the lens making it a saleable product.	Chapter 4 introduces the initial sets of data from several disparate systems. Working with SMEs to understand the most valuable and important data to contact lens manufacturing. The concept of when a lens exists, is discussed in chapter 4 the first iteration of the DSRM applying the branding to a fully packaged lens in blister.
Objective 3 Collect data from the manufacturing business units to understand and design a model of the manufacturing process, to evaluate where products are made a how	Detailed in the first iteration chapter 4, bring together the first datasets from products and brands, understanding, first the simple data required for contact manufacturing is identified with SMEs.

the process could be simplified and optimised.	The BORO Minimal foundation core is used to reengineer the products from data sheets and Kumu visual data tool.
Objective 4 To re-engineer these data sets through an iterative process to design, develop and evaluate a Minimum Viable Ontology (MVO) of the product classification brands process. Build a set of process steps or stages to allow users or analysts to convert legacy data into new systems. Identify a subset of legacy data to clean and prepare for conversion using this new approach.	The base MVO is improved in chapter 5 more data is included regarding the contact lens manufacturing process, Dry, Wet and Autoclave. This data is modelled in space time maps and reviewed with SMEs. In chapter 6 an empirical example of legacy data, of products that fit into the MVO are converted into a new system (Oracle eBS). The data is reviewed, cleaned and errors / patterns noted and reviewed.

Table 17 Accomplishments of the research objects in this Thesis

7.7. Research Limitations and future Research topics

To build on this research and add further contribution, there are other areas within contact lens manufacturing that would benefit from expansion of the domain model. I have identified an expansion of the model to include a Toric lenses used in the correction of stigmatisms of the eye and the Made to Order process. The addition of both product types would create a full MVO as of the present time. The consideration for expiry dates of products being added to the model will help provide a more efficient management of products, either through shelve life or goods returned and how these are managed. Consideration must also be given to the next layer of automation for the manufacturing arena, faster, less downtime and overall more efficient. The manufacturing process changes will need to be reflected in the model, potentially running side by side with older processes described in this research.

Limitations of the current MVO reside in the need to transform from model to system, not just utilising a small MS Access application, but to implement in a fully functional production instances of ERP or WMS. This transformation, the final stage of the bCLEARer process needs to be staged and evaluated with substantially larger data sets. Understanding all the transformation points and identifying the risks in changing that part of a design needs to be evaluated.

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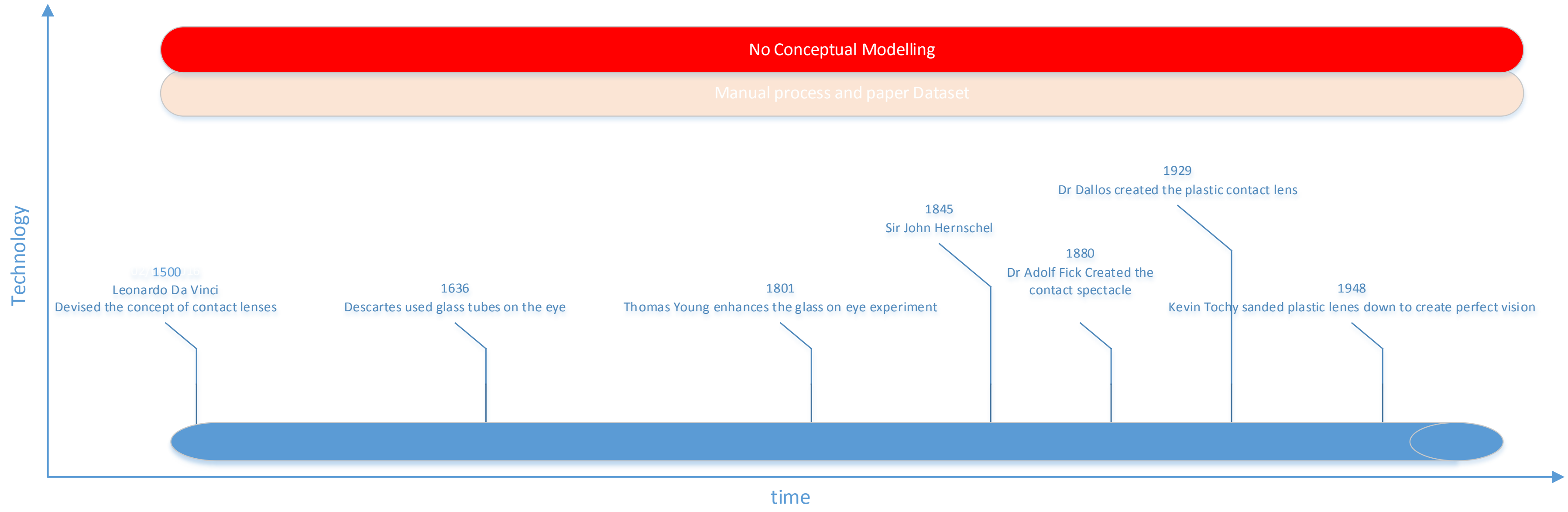
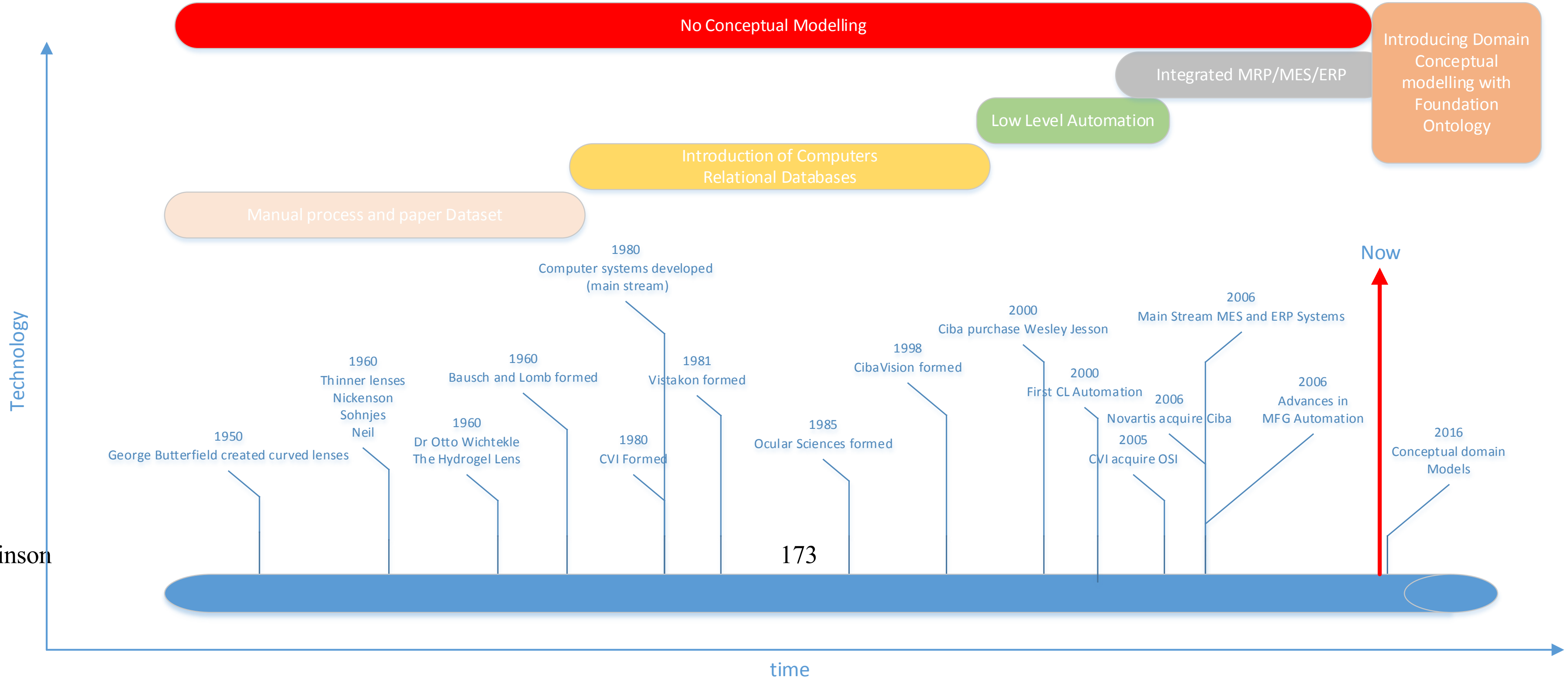
APPENDICIES

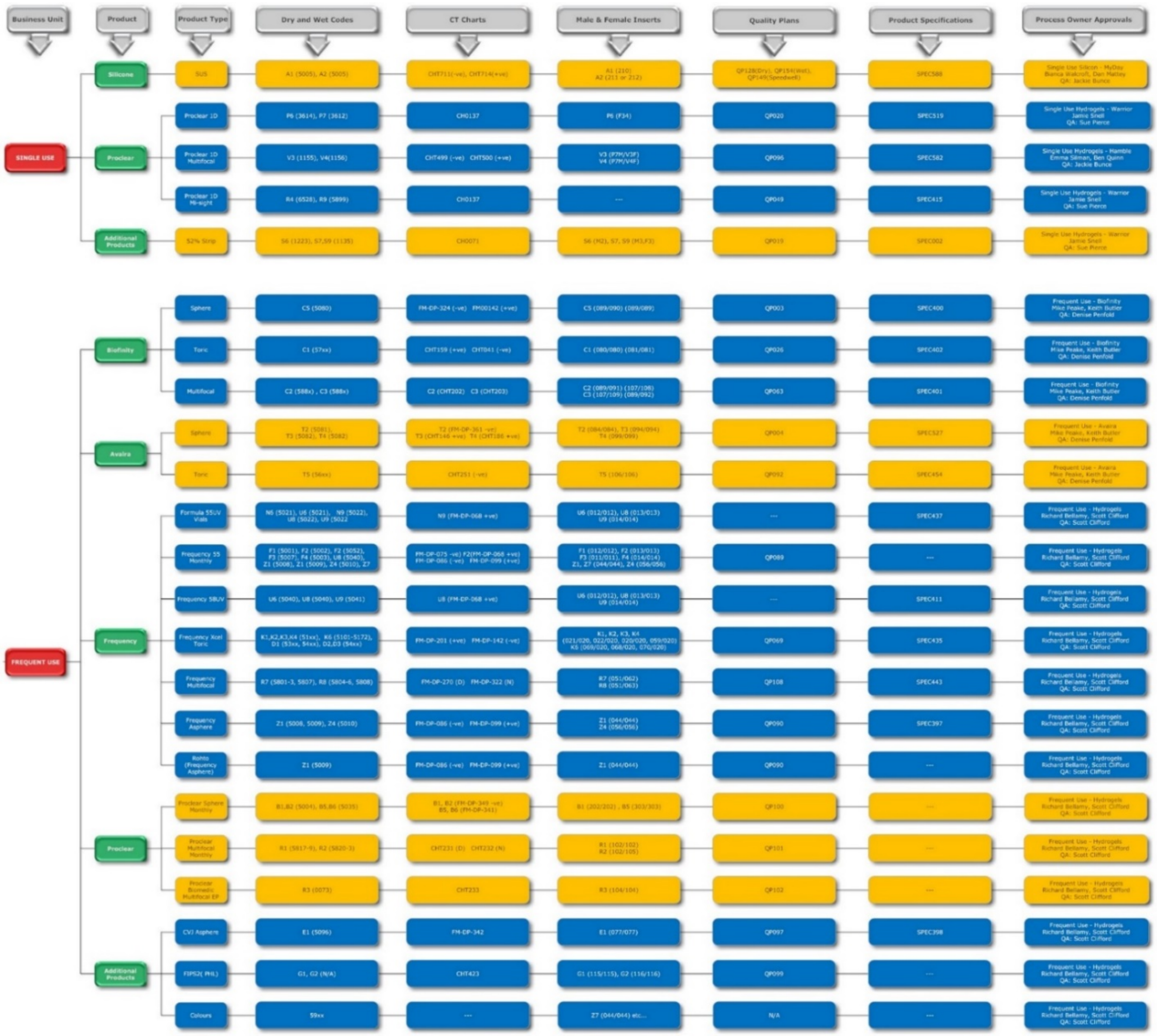
Appendix A Timeline of contact lenses, no conceptual model


No Conceptual Modelling
Manual process and paper Dataset
1929
Dr Dallos created the plastic contact lens
1845
Sir John Hernschel
1880
Dr Adolf Fick Created the contact spectacle
1500
Leonardo Da Vinci
Devised the concept of contact lenses
1636
Descartes used glass tubes on the eye
1801
Thomas Young enhances the glass on eye experiment
1948
Kevin Tochy sanded plastic lenes down to create perfect vision
Technology
time


No Conceptual Modelling
Integrated MRP/MES/ERP
Low Level Automation
Introduction of Computers
Relational Databases
Manual process and paper Dataset
Introducing Domain Conceptual modelling with Foundation Ontology
Now
1980
Computer systems developed (main stream)
2000
Ciba purchase Wesley Jesson
2006
Main Stream MES and ERP Systems
1998
CibaVision formed
2000
First CL Automation
2006
Novartis acquire Ciba
2006
Advances in MFG Automation
2005
CVI acquire OSI
1960
Thinner lenses
Nickenson
Sohnjes
Neil
1960
Bausch and Lomb formed
1981
Vistakon formed
1960
Dr Otto Wichtekle
The Hydrogel Lens
1950
George Butterfield created curved lenses
1980
CVI Formed
1985
Ocular Sciences formed
2016
Conceptual domain Models
Technology
time

Appendices
Appendix B Product and brand charts born from paper

Product charts Extracted from Systems both paper and computer system data from legacy systems.



Appendices

Appendix C Locators: Racks and Rows

Racks and Rows for Engineering Spares, Raw Materials and Silver Stock

	rack_code	01			02			03			04			05			06			07		
	SubInvertoryType	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK
Level	5				0	2	0	0	1	0	0	2	0	0	2	0	0	3	0			
	4	24	0	1	23	3	1	11	2	1	18	1	1	15	2	1	10	1	1	11	0	1
	3	24	3	1	22	3	1	0	3	1	22	3	1	18	3	1	17	3	1	23	1	1
	2	23	0	1	55	2	1	0	3	1	69	1	1	65	1	1	68	1	1	60	1	1
	1	9	2	1	0	2	1	0	2	1	10	2	1	9	2	1	8	2	1	8	2	1

	rack_code	08			09			10			11			12			13			14		
	SubInvertoryType	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK
Level	5	0	1	0	0	2	0	0	2	0	0	3	0	0	1	0						
	4	0	3	1	0	2	1	0	2	1	0	2	1	0	0	1				0	0	1
	3	0	3	1	0	3	1	0	3	1	0	3	1	0	3	1				0	0	1
	2	0	0	1	0	2	1	0	2	1	0	2	1	0	2	1				0	0	1
	1	0	0	1	0	2	1	0	2	1	0	3	1	0	3	1				0	0	1

	rack_code	15			16			17			18			19			20			21		
	SubInvertoryType	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK	ENGSPARES	RAWMAT	SSTOCK
Level	5																					
	4	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
	3	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
	2	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1

Racks and Rows in terms of data located in storage, with row 13 cleared as the walk way.

			Rack Code																											
warehouse_name	storey_code	row_code	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
CV-HU	0	00	2																											
CV-HU	0	01		5	5	5	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1	1					
CV-HU	0	02		5	7	7	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1						
CV-HU	0	03		5	7	7	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1						
CV-HU	0	04		5	5	5	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1						
CV-HU	0	05		5	5	5	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1						
CV-HU	0	06		5	5	5	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1						
CV-HU	0	07		7	7	7	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1						
CV-HU	0	08		7	7	7	7	7	7	7	5	5	5	5	5		1	1	1	1	1	1	1	1						
CV-HU	0	09		1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1						
CV-HU	0	10		1	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1						
CV-HU	0	11		3	3	3	3	3	3	3	1	1	1	1			1	1	1	1	1	1	1	1						
CV-HU	0	12		3	3	3	3	3	3	3	1	1	1				1	1	1	1	1	1	1	1						
CV-HU	0	13		1	1	1	1	1	1	1	1	1	1				1	1	1	1	1	1	1	1						
CV-HU	0	14		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1						
CV-HU	0	15		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1						
CV-HU	0	16		1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1						
CV-HU	0	17		1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1						
CV-HU	0	18		1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1						
CV-HU	0	19		1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1						
CV-HU	0	20		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1					
CV-HU	1	00	2																											
CV-HU	1	01		8	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CV-HU	1	02		2	2	1	1		1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	
CV-HU	1	03				1	1		1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	
CV-HU	1	04			2	1	1		1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	
CV-HU	1	05			2	3	3	2	1	3	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	
CV-HU	1	06		3	3		2	2	2	2																				
CV-HU	1	07		2	2	2	2	2	2	2																				
CV-HU	1	08		2	2	2	2	2	2	2																				
CV-HU	1	09		2	2	2	2	2	2	2																				
CV-HU	1	10			2	2	2	2	2	2																				
CV-HU	1	11		2				2	2																					
CV-HU	1	12		2		2	2																							
CV-HU	2	01		8																										
CV-HU	3	01		8																										
CV-HU	4	01		8																										
CV-HU	5	01		8																										