Developing the First Phase of Warehouse Storage Design in High-Mix, Low-Volume or Service-Centric Organizations

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Abstract

Conventional warehouse design techniques are tailored for mass production environments. Applying them to a warehouse in a high production mix, low production volume or service-centric operation does not yield expected space and part handling efficiencies. The first phase of design in a warehouse needs to address two key issues viz. the elimination of obsolete parts and storage management of required parts. This thesis develops methodologies to address each of these issues by creating a standardized obsolete part elimination guideline and a comprehensive Class Based Storage (CBS) policy respectively. The standard guideline uses a combination of survey data collection and swim lane mapping technique to create a part excessing Standard Operating Procedure (SOP). The storage policy uses a multi-variable CBS and a standardized bin selection method, both of which are incorporated in a Plan For Each Part (PFEP) database. The application of these two methodologies ensures the right part at the right place in a warehouse. Each methodology is implemented in a suitable warehouse in Tennessee.

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Chapter 1

Introduction

1.1 Motivation

The design/redesign phase of a warehousing system, now a critical part of the modern supply chain, is where organizations make most of their strategic decisions as per delivery goals. Hence, it is important for them to have a structured approach for designing the storage component of their warehouse. Warehouses that cater to mass production environments can be designed using conventional methods due to regular rotation of parts. The design of warehouses in such environments is a collaborative effort to optimize storage space, material handling equipment, labor, and infrastructure.

However, for companies with high production mix, low production volume, or service-centric operations, conventional methods do not work in achieving their delivery goals. These organizations place a lot on emphasis on their service-side goals and minimal focus on supporting operations such as warehousing or purchasing. For example, in mass production environments, spare part stock levels can be kept significantly low without affecting daily production goals. However, in the case of service-centric companies, reducing spare part inventories without jeopardizing their availability for supported products is a core requirement for the competitiveness of companies. However, higher inventory level negatively affects the warehouse by increasing space requirements. Another example is in high-mix and

low-volume environments where management of expensive and slow moving parts inventories is challenging due to the scarcity of historical data, fluctuations in demand rate, and risk of obsolescence (Pinçe and Dekker, 2011).

Warehouse storage management in these industries is restricted to the ad-hoc analysis of each warehouse and use of naive sorting techniques. There is a lack of standard methods to eliminate unwanted parts and organize storage requirements for necessary parts. This thesis attempts to address these research gaps by providing a guideline for eliminating obsolete parts and a user defined CBS (class-based storage) policy. The developed research will also be useful when applied to the design of warehouses in mass production environments.

1.2 Background

A well-managed warehouse is a key requirement of modern supply chains and plays a vital role in the success or failure of any business (Frazelle, 2002). The capital and operating cost of warehouses in USA is more than 20% of logistic costs (Baker and Canessa, 2009).

Warehouse planning and control have been studied extensively in literature (Van den Berg and Zijm, 1999). However, a universally accepted methodology for redesigning a warehouse is absent (Baker and Canessa, 2009). Warehouse design depends on the characteristics of the company and their needs, also on the type and variety of parts. In situations where a proposed design is used, the method of validating the quality of the design is not defined (Rouwenhorst et al., 2000). The priority tasks in a warehouse design are order picking, space and information management.

Order picking is one of the central tasks in warehouse planning. It is the process of retrieving products from warehouse storage as per customer requirements. Manual order picking from the warehouse can be very labor intensive (De Koster et al., 2007). In manufacturing environments where just-in-time philosophy was more popular, warehousing professionals considered order picking as the top priority area for productivity improvements (Goetschalckx and Ashayeri, 1989). One of the most important factors that directly impact order picking, and subsequently the performance of the warehouse is its design. A design

that minimizes the warehouse area, travel time, and travel distance by selecting the best route of order picking will lower the operational cost (Hsieh and Tsai, 2006).

Other high priority concerns in warehouse design are space and information management. A key point to note is that the three factors, i.e. order picking, space, and information management, may be correlated. For example, wrong order picking could be due to incorrect information of parts. Delays in order picking could be due to improper space management. Another example would be underutilized space due to inaccurate information of actuals parts needed and inaccurate storage locations. These issues have been addressed in literature individually. There is a need for a structured approach which ensures the right parts in the right places so that the warehouse delivers high space utilization and material handling efficiencies. The right parts are retained when all the obsolete inventory is removed. The right places for the necessary parts is ensured when a storage policy is implemented.

1.3 Objective and Research Questions

This research focuses on the storage phase of a part's lifecycle after it enters the warehouse. The goal of this thesis is to develop guidelines for addressing two of the critical issues faced by warehouse personnel with respect to parts storage viz. obsolete inventory and storage policy. The research is validated using a case study that uses both quantitative and qualitative methods for data collection and analysis. In order to fulfill the purpose of this thesis, the following questions will be answered:

- How to methodically identify unwanted inventory across different departments and different part metrics?
- How to correctly excess each unwanted part with company-wide consensus?
- How to categorize the remaining inventory as per the organization's storage priorities?
- How to ensure ideal bin assignment, racking and information consolidation that makes designing warehouse layouts an easier process?

1.4 Research Overview

The methodology to address research questions from section 1.3 is shown in figure 1.1 which shows the aim, approach, and framework of the thesis.

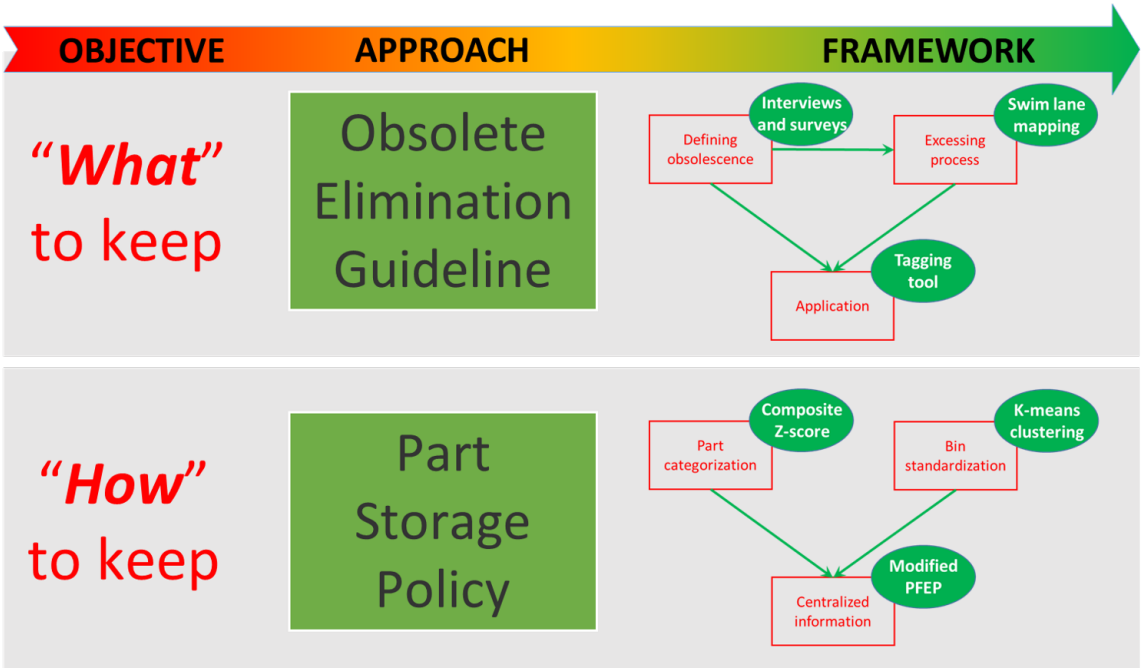


Figure 1.1: Thesis overview structure

The research framework is divided into two parts as follows:

1. Obsolescence elimination: In this component, an excessing guideline is outlined as shown in figure 1.1. In the first step, interviews are conducted to understand the current process outline. Based on the interviews, surveys are developed for the target audience. These surveys help identify obsolescence attributes, current excessing methods, responsibilities and organizational hierarchy related to excessing. They also help identify additional attributes that are unique to certain sections or groups in the organization. In the next step, the information obtained from surveys is used to design swim lane diagrams. These diagrams are used to create a better visualization of the excessing process and identify value added and non-value added activities. In the final step, a Standard Operating Procedure (SOP) is developed as a tool for

helping in the excessing activity. This tool comprises of tagging templates, charts, and work instructions developed using the survey information. The tool helps execute a systematic and accurate excessing of obsolete parts. The framework is validated by case study conducted at a service-centric research organization in the state of Tennessee.

2. Part storage policy: In this component, steps to categorize and store parts is outlined as shown in figure 1.1. The methodology begins with identifying relevant parameters for part consumption that can be used in class-based storage. These parameters are standardized using standard score (Z-score) technique. After obtaining the Z-score, a multi-parameter classification tool is created with user-editable weights for the parameters. Next, a statistical analysis is proposed to minimize the sizes of storage bins and pallets used. The number of size categories needed is assumed, and K-means clustering technique is applied to select the best bin in each category. The part classification and standardized bins are incorporated in a modified Plan For Every Part (PFEP) database that enables the user to change parameters such as standard deviation of orders, weight and volume limitations for each part classification, etc. The PFEP helps generate a layout plan based on total inventory, part classification, and ranking in the warehouse. The framework is validated by a case study conducted at a high-mix and low-volume manufacturing facility in the state of Tennessee.

The result of this thesis provide standard procedures for obsolescence elimination and part storage that can be used in developing similar systems for a high production mix, low production volume or service-centric organization.

1.5 Thesis Outline

- Chapter 1: This chapter provides a discussion on the motivation, background, research objective and approach for the thesis.

- Chapter 2: This chapter is the 'Literature Review' section. It presents an overview of the most relevant academic literature. It evaluates the research gap and provides the drivers to pursue this research.

- Chapter 3: This chapter is the 'Obsolescence Elimination' section. It addresses the first part of the inventory management objective, i.e., "What to keep" in a warehouse. It describes the approach in creating obsolescence elimination guideline and how the study was conducted. A case study with a research organization is embedded in the chapter as a part the explanation.

- Chapter 4: This chapter is the 'Storage Policy' section. It addresses the second part of the inventory management objective, i.e., "How to keep" in a warehouse. It describes the approach in creating storage policy and how the study was conducted. A case study with a regional special heavy equipment manufacturing organization is embedded in the chapter as a part the explanation.

- Chapter 5: This chapter is the 'Conclusion and Recommendations' section. It provides a summary of the most important elements and recommendations and suggests topics for further studies.

Chapter 2

Literature Review

2.1 Brief

This chapter covers current literature for issues in warehouse design and operation. An overview of this section is shown in figure 2.1. The framework for the thesis is based on the direction focus identified in the summarizing part of this chapter.

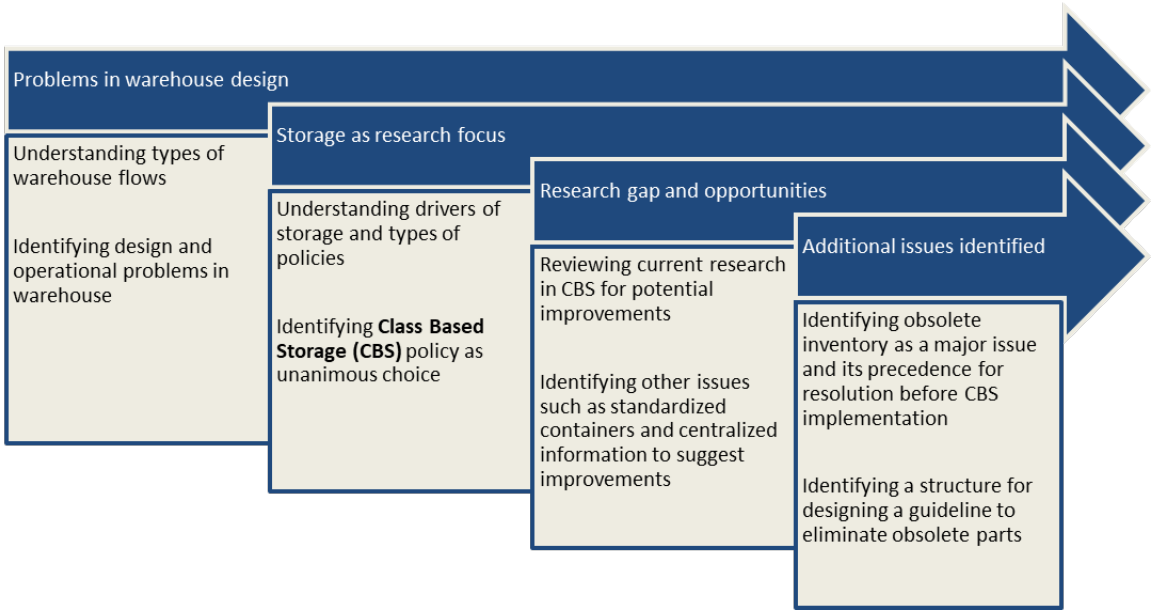


Figure 2.1: Literature review progression

A warehouse and its related terms are discussed to understand all functional components involved. Design and operation issues in a warehouse are cataloged. The storage component is selected as the research focus for this thesis. The three drivers for storage (physical characteristics of parts, material handling considerations, and storage policies) are evaluated to understand their impact on storage area design. The tools/methods available for these drivers are reviewed, and the storage policy driver is identified as one of the major contributors as per management considerations. Next, different storage policies are discussed to understand their uses, applications, and drawbacks. Class-based storage is identified as the preferred policy choice in most warehousing scenarios based on literature. The current gaps in class-based policy are identified and potential solutions to address their shortcomings are discussed. Other supplementary issues related to storage such as standardizing container/bin sizes and consolidating all part related information in a central database are also discussed. Obsolescence of parts is identified as another major problem related to part storage. The effects of obsolete parts on warehouse efficiency are discussed along with its precedence of being addressed before the storage policy. The lack of a standard guideline to eliminate obsolete parts is identified as a research gap.

2.2 Problems in Warehouse Design and Operation

A warehouse is a commercial building for storage of parts or Stock Keeping Units (SKUs) as per the traditional definition. Figure 2.2 shows an overview of warehouse activities such as receiving, transfer and put-away, order picking/selection, accumulation/sortation, cross-docking, and shipping.

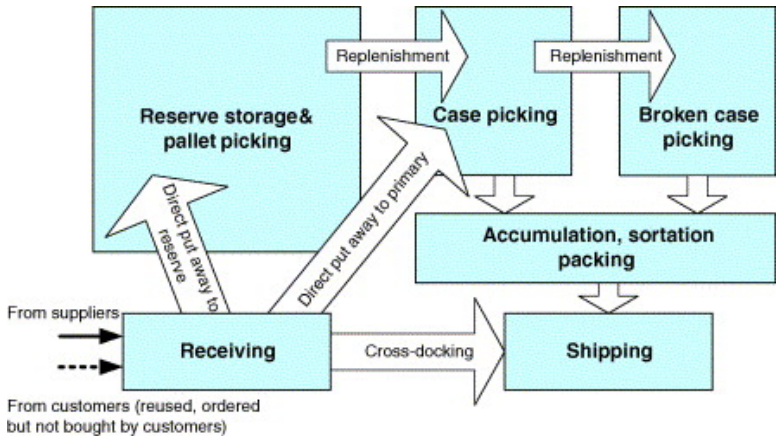


Figure 2.2: Warehouse flows by Tompkins et al. (2003)

The term 'warehouse' is commonly used if the main function is buffering and storage of parts for daily operations (raw materials, goods-in-process, finished products) and between points of origin and points of consumption. The terms such as 'distribution center', 'transshipment' or 'cross-docks' are used where additional distribution is the major role (De Koster et al., 2007). In this study, we focus on the former (storage of parts) and use the term warehouse throughout the paper. The scope of this thesis is restricted to the 'storage' component of warehouse design with a specific focus on identifying what parts to keep in the warehouse and how to organize them to get the best delivery efficiency. Readers may refer to Tompkins et al. (1996) for details on the other components.

The design and operation of a warehouse requires resources such as space, labor, and equipment to be allocated among the different warehouse functions. Each function needs to be implemented and coordinated to achieve system requirements regarding capacity, throughput, and service while keeping the resource cost at the minimum. Gu et al. (2007) have listed the design and operational problems in the warehouse as follows in table 2.1:

Table 2.1: Warehouse design and operation issues as listed by Gu et al. (2007)

Warehouse design/operation issues			**Decisions**
Warehouse operation	Receiving and shipping		Truck-dock assignment
			Order-truck assignment
			Truck dispatch schedule
	Storage	SKU-department assignment	Assignment of items to different warehouse departments
			Space allocation
		Zoning	Assignment of SKUs to zones
			Assignment of pickers to zones
		Storage location assignment	Storage location assignment
			Specification of storage classes (for class based storage)
	Order picking	Batching	Batch size
			Order-batch assignment
		Routing and sequencing	Routing and sequencing of order picking tours
			Dwell point selection (for AS/RS)
		Sorting	Order-lane assignment

2.3 Storage as Research Focus

The storage component of warehousing operation as shown in table 2.1 is concerned with the organization of parts in the warehouse to achieve optimum space utilization and efficient material handling. Parts in storage can be organized into different departments. The drivers of department organization may be material handling considerations (e.g., a forward area for fast picking vs. reserve area for retaining majority parts at one location); physical characteristics of part storage (e.g., pallet storage vs. case storage); or management considerations such as storage policies (a dedicated storage policy for specific parts/customer vs. random storage policy that leaves the decision to the operator) (Rouwenhorst et al., 2000)(Gu et al., 2007).

The material handling driver is more dependent on the resources of an organization such as labor, equipment, MRP systems and infrastructure. Strategies for the material handling driver on the forward-reserve problem have been discussed by Frazelle et al. (1994), Hackman et al. (1990) and Bozer (1985). Next, the physical characteristic driver is one that dictates the recommended storage container for a part and is relatively a simpler decision. However, the minimum number of container sizes needed to fit all storage needs has not been studied in warehousing literature. The third and final driver i.e., management considerations (or storage policies to be broader) is a major contributor to space utilization and efficient material handling goals. It acts as a mediator for the material that flows into the warehouse and when it gets picked, sorted or zoned. The commonly used types of storage policies as per De Koster et al. (2007), Hausman et al. (1976), Gu et al. (2007) and Rouwenhorst et al. (2000) are:

- Random storage; where parts are assigned a location in the warehouse that is selected randomly from all eligible empty locations.
- Dedicated storage; where parts have a fixed location.
- Family grouping; where parts are at nearby positions if they are often required simultaneously.

- Class-based storage (CBS); where parts are grouped into classes based on some form of demand frequency.

Although these policies are frequently used in warehouse design, they have some disadvantages. For example, random assignment method results in higher space utilization. However, travel distance gets increased to offset the space advantage (Sharp et al., 1991). This policy only works well in a computerized environment and is more suited to be used in high-performance distribution centers such as Amazon. Dedicated storage, on the other hand is simple to implement but may end up consuming lot more space. Additional space will also be lost in case there are part stock outs.

CBS policies, however, combine the benefits of other methods and are more efficient in the majority of warehousing scenarios (Kulturel et al., 1999; Gu et al., 2007). The main idea of class-based storage is to divide products into classes. Each class is then allocated a dedicated area of the warehouse. CBS policies differentiate each part based on a base parameter such as average consumption, popularity, cube-per-order index (COI), or pick volume. The part list is then divided into subclasses based on parameter cutoffs. The advantage of this policy is that fast moving products can be stored close to the depot while the flexibility and high storage space utilization of random storage are still applicable.

2.4 Research Gap and Opportunities

CBS is one of the more popular storage policies due to its consistent results when applied in most warehousing applications. However, there are some drawbacks that it shares with other policies. For example, most research in class-based storage has been performed in the context of automated storage and retrieval system (AS/RS) (Hausman et al., 1976). Any policy based on demand frequency require a strong data intensive approach than random storage since ordering and stocking information must be analyzed to rank parts (Caron et al., 1998). In some cases, this kind of information may not be available. For example, if the product assortment changes too fast, it is hard to get accurate statistics (De Koster et al., 1999). Another example is if the material requirement planning (MRP) system does not

capture consumption data per order and merely relies on Kanban systems to check stock levels, there is only purchasing or Kanban replenishment numbers available for any CBS analysis. An interesting observation is that the CBS is traditionally developed on a single base parameter such as turnover, or a ratio of parameters such as cube-per-order index (COI). The research gap to be addressed is the absence of CBS that is not data sensitive and can handle multiple parameters.

The advantage of having multiple parameters in CBS is that some parameters apart from the demand/consumption can also be used with regular parameters. If a subsection of the warehouse design does not need a certain parameter or is less influenced by one, it would be a simple alteration of the policy where that parameter could be dropped or adjusted in weight. This weight adjustment of parameters gives a broad class-based storage policy at the management level with enough flexibility as needed in each sub section or department.

While there is research available for standardized storage policies, there is very little or no research that discusses standardized containers/bins/carts used to store parts. Using standardized carts is always a recommendation in a warehouse (FINCH and Cox, 1986). The closest strategy to standardize is generally to pick three to four containers namely small, big and large (the fourth one being an oversize pallet/box) with distinct carrying capacities or visually different (Arbulu et al., 2003). An estimated guess in the selection of bins may result in bins with similar carrying capacities being selected instead of unique size bins. Such estimations lead to an extensive inventory of non-standard bins in the warehouse over a period. Space utilization (vertical and horizontal) on the racks is lower with such inconsistent bin sizes. From the layout perspective, estimating the number of racks and the bin arrangement on the rack becomes cumbersome with such large bin pool. A suggested way to approach this issue would be to analyze bin sizes using some form of clustering techniques.

Although assignment of CBS and standardized bins to warehouse inventory is good practice, it needs to be periodically reviewed. This assignment may change due to a variety of factors. Seasonality of part consumption is one such example (Petersen et al., 2004). Another example is where the part is no longer needed and replaced with a newer version. Apart from the storage policy of a part, additional information related to that part such

as safety stock calculations, bin/container location, etc. may also need to be updated. It would be convenient to manage these changes using a database that allows recalculation of parameters to reflect the part change.

2.5 Additional Issues Identified

While storage is the main problem being addressed here, other major issues need to be resolved before storage. Excess inventory and obsolete parts are the two key problems faced by most warehouses (Thummalapalli, 2010). Excess items have value, but they can incur space and other holding costs in the meantime. However, these items could perish or become completely obsolete. While excess stock may have to be adjusted in the production and account books, obsolete parts, unfortunately, have to be completely removed from the system and the warehouse. If this issue is not fixed before implementing the storage policy, it will affect the storage space utilization and related handling efficiencies despite the best policy used.

There are guidelines and models available to avoid excess inventory in the warehouse (Rand and Peterson, 1999; Raafat, 1991). However, there is no standard procedure on how to dispose excess or obsolete inventory (Rosenfield, 1989). Current research in the area of obsolescence elimination is restricted to introduction to generic techniques like red tags or inventory cycles (Agrahari et al., 2015). Literature regarding a framework for systematically conducting excessing activity is brief and in most cases, specific to the type of business environment. For example chemical manufacturing, defense equipment, and hazardous material industries study obsolescence to develop strategies (Redmond et al., 2014). Obsolescence for such industries may arise due to different reasons. For example, obsolescence issues in organizations that deal with hazardous material may primarily be due to the criticality of the material disposal regarding safety or sensitivity while excessing them. In the case of defense systems, however, most material used are mission critical components that need to be periodically upgraded. Their obsolescence excessing would need verification

from multiple stakeholders. So all excessing procedures, if available are industry/application specific.

A key point is that, while the flow of parts in a warehouse is very organized, i.e., through purchasing, logistics, receiving, and finally storage, there is minimal structure created for removal of obsolete parts. A warehouse may have parts from multiple users, each one having unique constraints or rules for handling obsolete parts. The key questions that need to be addressed in an obsolescence elimination guideline are categorized as follows:

1. *Defining Obsolescence*: How to define obsolescence for the system (organization/ department/ work groups)? Are there any critical or focus obsolescence attributes that should be prioritized in excessing? Do the attributes need to be the same for each work area? Who are the stakeholders related to obsolete parts?

2. *Excessing Process*: Who is responsible for the excessing process? Is excessing an inter-department or intra-department activity in the organization? Who has the authority to take decisions on handling obsolete parts? How does the communication need to flow while a part is being excessed?

3. *Excessing Application*: Is there a guideline of how to handle parts for excessing? Is yes, is the guideline comprehensive where it applies to all parts in the organization or just specific ones? Is the structure of the guideline inconsistent?

For defining obsolescence throughout the organization, it is necessary to get all the confirmation regarding process and part attributes from all stakeholders. There are six different sources for gathering data according to Yin (2003). These are documentations, archival records, interviews, direct observation, participant observation, and physical artifact. Each of these sources have their own pros and cons. An interview is the preferred choice amongst them as it will provide useful preliminary information about the process. Two aspects need to be considered during an interview: first is to follow the line of inquiry and second is to ask actual questions which come up during the interview (Yin, 2009). There are three ways of conducting these interviews. The first method is conducting a focused

interview where the interviewee answers specific questions for a short period and it can be open ended. The second one is a semi-structured interview where the arrangement stays the same. However, the topic and key points are determined, but no specific questions are selected. The interview will start with a general question and the interviewee's answers are used to formulate the subsequent questions. The last method is a formal survey and it follows procedures and instruments used in regular survey (Yin, 2003). The surveys can help quantify the critical attributes identified during focused interviews and identify all the stakeholders in the excessing process along with their roles in excessing.

For understanding the excessing process, using mapping techniques enables clear representation of the sequence of steps and can be used to redesign them to improve the performance of the system (Klotz et al., 2008). A graphical representation can show the differences between value added and non-value added activities which means everyone can visually understand all relevant aspects and the status of an operation at any time. Most organizations document processes using techniques such as process flow diagrams. In scenarios that involve a lot of interactions and information/product changes between people or departments, these diagrams are difficult to create and interpret. Swim lane diagrams, unlike generic process maps, represent the flow outline of a system in a manner that visually distinguishes job sharing and responsibilities for tasks in the process (Van Dyke Parunak and Odell, 2001; Jeyaraj and Sauter, 2014). It can be used to show cross-functional relationships between organizational units, to see how activities interlink while excessing, and who has what responsibility at each step of excessing a part.

The surveys identify stakeholders, task times, resources and part attributes. The swim lane diagram provides a detailed understanding of the excessing process for better planning. An ideal way to use this information for actual excessing activity is to create a standard operating procedure (SOP) using the information obtained in the previous two components. A comprehensive SOP can be utilized by personnel during excessing activity. The survey and swim lane diagram provide information about "who," "what," and "when" that can be used to create the SOP. For excessing activity, record-keeping forms can be designed along with related work instructions that will help excessing personnel.

2.6 Summary

Table 2.2 provides a summary of key issues in literature and an overview of the solutions identified for resolving the research questions. The approach taken to address the research gaps is described in chapter 3 'Obsolescence elimination' and chapter 4 'Storage Policy.'

Table 2.2: Literature review summary and approach

Research Questions	Research Gap	Approach
How to methodically identify inventory across different departments and part metrics?	Lack of standard excessing guideline that organizes part and user information related to excessing activity	Explore interview techniques as a means to obtain part attributes and stakeholder information
How to accurately excess each unwanted part with company wide consensus?	Lack of standard excessing guideline that maps the excessing process for clarity and instructions to execute tasks	Explore process mapping techniques that depict tasks and stakeholder roles clearly. Also explore SOP design methods
How to categorize the remaining inventory as per the organizations storage priorities?	Storage policies that are based on only single parameter, rigid and are highly data driven	Explore class based categorization and check possibility of using multiple parameters
How to ensure ideal binning and information consolidation that makes warehouse layout an easier process?	Lack of research in standardizing bins and consolidating part information	Explore techniques such as clustering to narrow bin choices. Also explore user friendly database designs

Chapter 3

Obsolescence Elimination

3.1 Research Objective

This chapter addresses the first part of the research objective, i.e., "What to keep" in a warehouse. The subsequent sections of this chapter develop a standard guideline for obsolescence elimination that can be used for any warehouse. A standard guideline will reduce the overall execution time. It helps the participants of the obsolescence elimination activity to visualize the entire process and guides them during each phase of the excessing activity.

Definitions

System: An organization or its components, viz. department, area or group.

Obsolescence: A state where a part should no longer stay in the system due to change that renders it inappropriate for its defined use.

Excessing: The process of identifying and eliminating obsolete parts from the system.

Task: An assigned piece of work to be completed within a certain time by the authorized personnel (not to be confused with "process," which is a combination of tasks to achieve a substantial output).

3.2 Purpose of Research

Research in obsolescence elimination is limited and specific to the type of business environment. For example, chemical manufacturing, defense equipment or hazardous material manufacturers study obsolescence to develop strategies that suit only specific areas or material in the warehouse (Redmond et al., 2014). A universally applicable obsolescence elimination guideline may be developed by addressing the following questions:

1. *Defining Obsolescence*: How to define obsolescence for the system (organization/ department/ work groups)? Are there any critical or focus obsolescence attributes that should be prioritized in excessing? Do the attributes need to be the same for each work area? Who are the stakeholders related to obsolete parts?

2. *Excessing Process*: Who is responsible for the excessing process? Is it an inter-department or intra-department activity in the organization? Who has the authority to take decisions on handling obsolete parts? How does the communication need to flow while a part is being excessed?

3. *Excessing Application*: Is there a guideline of how to handle parts for excessing? Is yes, is the guideline comprehensive where it applies to all parts in the organization or just specific ones? Is the structure of the guideline inconsistent? Is the instructional content too long and difficult to use due to excessive verbiage?

3.3 Research Framework

The framework of the obsolescence elimination guideline is shown in figure 3.1. Each component of the guideline is addressed by a solution proposed in this chapter (highlighted in green). In the first step, interviews are conducted to understand the current process outline. Based on the interviews, surveys are developed for the target audience. These surveys help identify obsolescence attributes, current excessing methods, responsibilities and organizational hierarchy related to excessing. They also help identify additional attributes

that are unique to certain sections or groups in the organization. In the next step, the information obtained from surveys is used to design swim lane diagrams. These diagrams are used to create a better visualization of the excessing process and identify value added and non-value added activities. In the final step, a Standard Operating Procedure (SOP) is developed as a tool for helping in the excessing activity. This tool comprises of tagging templates, charts, and work instructions developed using the survey information. The tool helps execute a systematic and accurate excessing of obsolete parts.

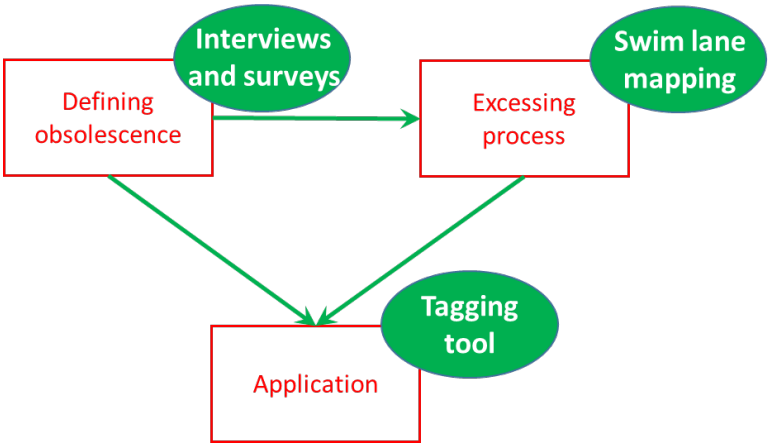


Figure 3.1: Obsolescence elimination framework

The framework is validated by case study conducted at a service-centric research organization in the state of Tennessee.

3.4 Interviews and Surveys

3.4.1 Purpose

The purpose of a preliminary investigation in a warehouse is to understand current excessing methods, part attributes (criteria for part obsolescence), organizational hierarchy and personnel roles in the excessing process. Standard methods for data collection need to be used to obtain the information systematically.

3.4.2 Background

Interviews are a good form of gathering information which may be subjective in nature or which may not be regularly documented. There are three ways of conducting interviews. The first method is conducting a focused interview where the interviewee answers specific questions for a short period and it can be open ended. The second one is a semi-structured interview where the arrangement stays the same. However, the topic and key points are determined, but no specific questions are selected. The interview starts with a general question and the interviewee's answers are used to formulate the subsequent questions. The last method is a formal survey and it follows procedures and instruments used in a regular survey (Yin, 2003). All the three types of interviews are useful to obtain a complete understanding of the warehouse system.

3.4.3 Method

The preliminary investigation of the current excessing process in an organization is designed in two phases. The first phase begins in the form of interviews (both focused and semi-structured) with designated warehouse personnel. These interviews helps establish a flow outline of the current excessing process. It includes details about types/categories of material stored, different groups or divisions of the organization accessing specific warehouse material, and the stakeholders involved in material management decisions. Other significant questions for identifying attributes of parts, task timelines, and the communication process amongst the stakeholders during part excessing are also included.

In the next step, the information obtained from the interviews is used to develop a survey for the target audience. The survey questions overlap most questions asked in the interviews. However, in the survey, the repetition of the questions is intended to obtain a quantitative verification from the target audience. Questions are designed to understand obsolescence attributes, non-obsolescence attributes, and to identify attributes used across the organization versus those that are used specifically in each user/group/department. Questions are also developed to capture types of information flow between stakeholders

and the organizational hierarchy for excessing authority. The structure of this section is shown in figure 3.2.

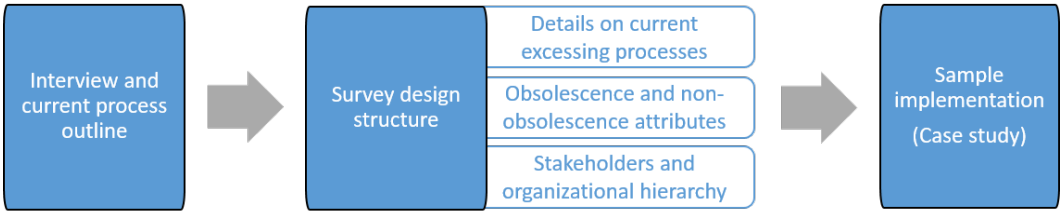


Figure 3.2: Survey methodology

3.4.3.1 Interviews

The interview process takes place in two steps. In the first step, a semi-structured interview is conducted with the warehouse manager to understand the current excessing process. Questions in this step are restricted to identify the objective of the warehouse operation, types of parts stored, and the stakeholders in the warehouse. In the next step, focused interviews are conducted with the identified stakeholders, warehouse personnel, and other groups. The questions asked in these interviews identify factors such as task time, entry/exit of stakeholders and resources used in the excessing activity. This step is an iterative process where the outcome of one interview leads to the preparation of another. The goal of these iterations is to have an exhaustive list of obsolescence attributes, excessing hierarchy information, and any details that help in constructing the survey. The detailed questions are discussed in the next section as most of them are covered again in the survey design.

3.4.3.2 Survey

After reviewing the results of the interviews, the first step is to identify a target audience for the survey. This audience may again include a combination of warehouse personnel and stakeholders. Next, the questions are designed to help quantify the attribute criticality in each group/department and to understand organizational hierarchy related to part excessing. The survey needs to address questions regarding the following key points.

- Obsolete Part Excessing policies: To identify current policies and trends for obsolete part excessing within a department/group of the organization. For example, the percentage of parts excessed per year and periodicity of obsolete part identification.

- Obsolescence vs. non-obsolescence attributes: To identify the attributes taken into consideration before a part is labeled obsolete versus others. These attributes may be universal or could be specific to the organization/department/user.

- Stakeholder roles: To identify the roles of all stakeholders (people/groups/departments). To understand types of information flow between stakeholders and the organizational hierarchy for excessing authority.

Understanding Current Excessing Policies

The questions related to current excessing policies are to confirm the overview information obtained from interviews. Some of the key points while developing these questions are as follows:

- The percentage of parts excessed each year.

- Tentative start and end time of current excessing activity.

- Number of inventory counts done per year to check obsolete parts.

- Relationship between obsolescence and monetary value of part.

Understanding Obsolescence and Non-Obsolescence Attributes

An obsolescence attribute is a condition where a part is no longer appropriate for its defined use and should no longer stay in the organization. The survey questions need to obtain information about the following key points:

1. Generic attributes which are common to all the departments or groups in the organization. The definitions of these attributes are provided by management and interpreted the same by all stakeholders.

2. Department or user specific attributes which are defined by each department or user for supporting their material management activities.

In addition to the obsolescence attributes, the survey is also used to identify attributes that may deem a part to be non-obsolescent, i.e., the part could be used/reused in the organization. These attributes can be categorized as follows:

1. Safety related attributes that are used for the safe functioning of the assets of a company such as personnel and equipment.

2. Process critical attributes that deem the part non-obsolete even in the absence of a clear indication of projected usage in future.

Understanding Stakeholder Roles and Hierarchy

Each task in an organization's excessing process may have a direct or indirect involvement of many personnel with varying responsibilities. The hierarchy of the organization also affects the time taken for excessing, depending on the personnel's role in each task of the excessing process. A clear representation of the stakeholder's role is illustrated using a responsibility assignment matrix or a 'RACI' matrix. RACI is an acronym derived from the four key roles most typically used; Responsible, Accountable, Consulted, and Informed (Kofman et al., 2009). Table 3.1 shows a RACI matrix with the acronyms and their descriptions. Two additional notations viz. Verifier and Support are added for clarity of certain roles in the excessing activity.

Table 3.1: Responsibility notations based on Kofman et al. (2009)

Acronym	Detail	Description	Key Notes
R	Responsible	Individual(s) who actually does the work to complete a task or action.	At least one role with R for each task
A	Accountable	Individual who is ultimately answerable for the correct completion of the task or for the decision outcome.	Only one A can be assigned to an action
C	Consulted	Individual(s), typically subject matter experts, who need to be consulted to complete the task or prior to final action or decision.	Two-way communication (with R)
I	Informed	Individual(s) to be informed upon the completion of the task/action or outcome of the decision.	One-way communication (from R)
V	Verifier	Individual(s) that check if the process is completed per regulations	E.g. Safety personnel to check safety issues
S	Support	Individual(s) who may assist in completing a task	E.g. Truck/lift operators

The RACI method helps the reader understand the roles more simply compared to descriptive verbiage used for the same. Table 3.2 shows a sample process of some warehouse tasks using the RACI technique. This information can be obtained either from the survey or the focused interviews.

Table 3.2: RACI example for warehouse tasks

	Stakeholders			
Action/Task	Director	Warehouse Manager	Team Leader	Safety Personnel
Initiate sorting of parts	I	RA		
Identify obsolete parts		I	R	
Remove obsolete parts	I	A	R	V

In the table 3.2, 'Initiate sorting of parts' is a task where the director of the organization is just informed about the process. The warehouse manager has dual roles, both for starting the task and is also accountable for its completion.

3.4.4 Sample Implementation

The interviews and survey were conducted for the organization's personnel. Eight stakeholders participated in this process. These stakeholders were selected based on their roles in warehouse operations or ownership of the inventory stored. Some of the sample questions used were as follows:

- How important are safety, hazardous or critical spare attributes while deciding whether a part is obsolete?
- How important is a generic listed attribute in deciding whether a part is obsolete?
- What are the specific attributes that help decide if a part is necessary (not obsolete)
- What is the duration of disuse before a part is considered obsolete?
- What are additional attributes that may be specific to the user's department/group?

Results of the survey were analyzed to consolidate the attribute types, process details and additional information related to excessing. Some of the analysis is compiled as follows:

Policies and Excessing Trends

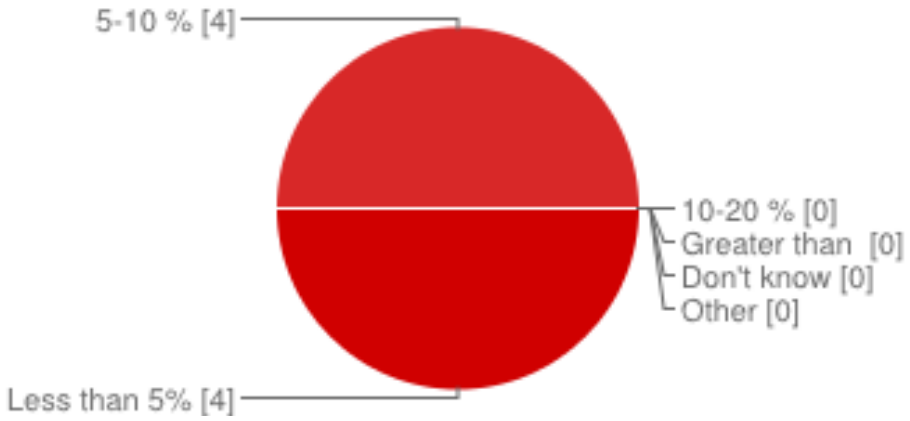


Figure 3.3: Parts excessed per year

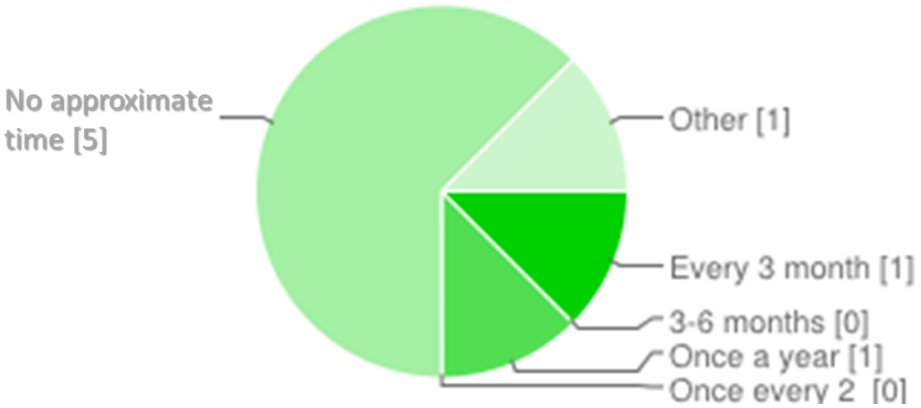


Figure 3.4: Periodicity of excessing

Figure 3.3 indicated that all groups excessed less than 10 percent of parts in their inventory each year. However, as seen in figure 3.4, many departments did not have a policy of periodic identification and excessing of obsolete parts.

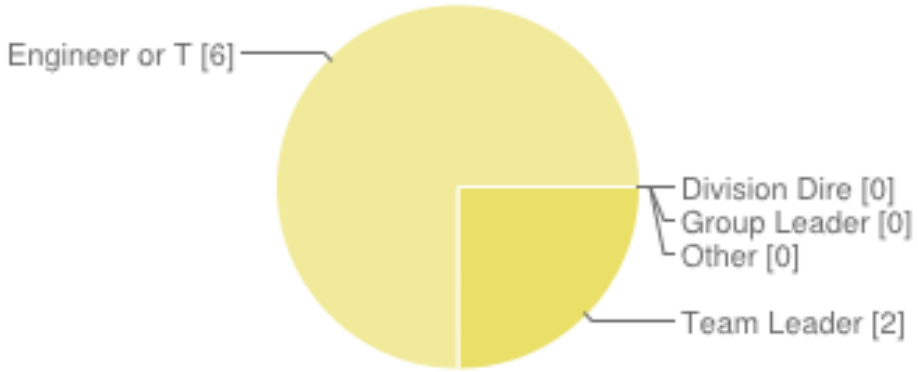


Figure 3.5: Responsibility for excessing initiation

Figure 3.5 indicated that obsolete part identification was initiated at a level no higher than a Team Leader across groups.

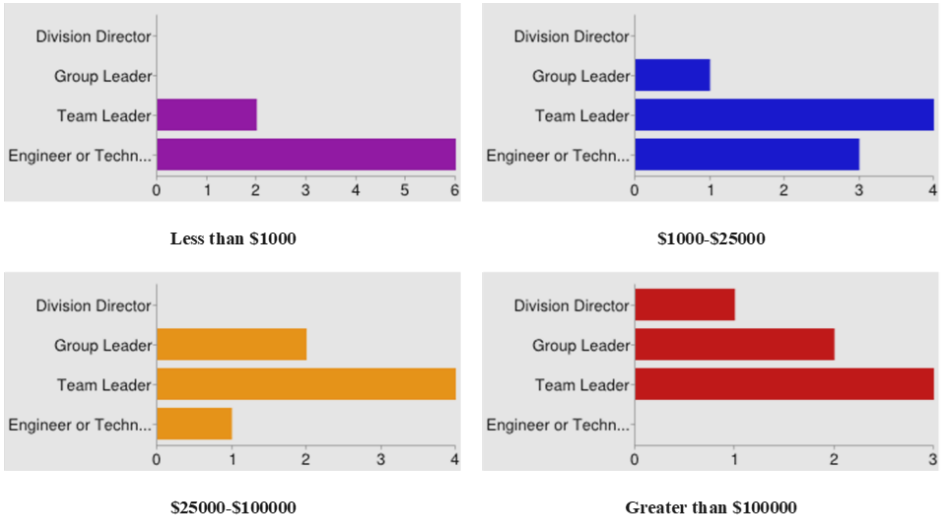


Figure 3.6: Responsibility for excessing action

Figure 3.6 indicated that the decision to excess a part was taken at higher levels of management depending upon the value of the part.

Obsolescence Attributes:

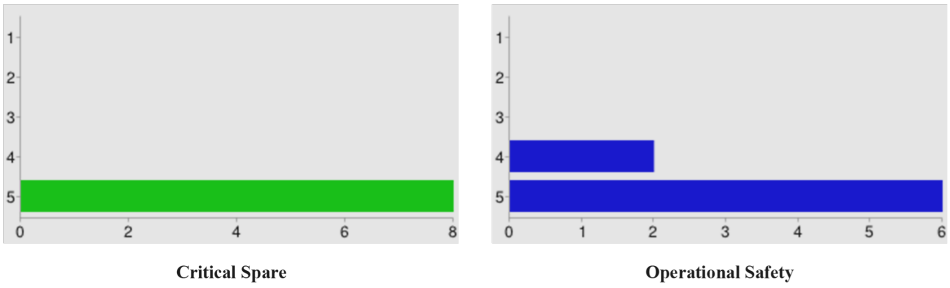


Figure 3.7: Critical and safety

Figure 3.7 showed the level of importance of an attribute on the Y axis (5 being most important) and the number of groups who rated at that level on the X axis. These graphs indicated that the criteria important to the groups were that part was a critical spare and part was important to operational safety.

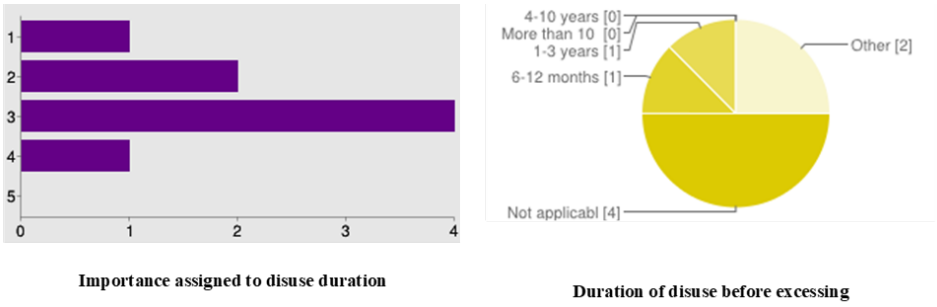


Figure 3.8: Disuse attribute

Figure 3.8 showed that most groups did not assign importance to the duration of disuse of a part. However, for those groups that assigned the duration, the obsolescence period had a high variation between 6 months to 3 years.

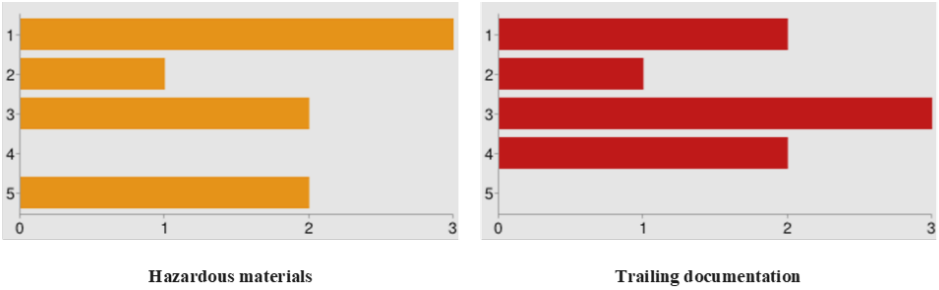


Figure 3.9: Hazardous attribute

Figure 3.9 indicated that hazard considerations (for example, radiological, chemical, etc.) and trailing documentation have varying importance across groups as obsolescence attributes.

The case study results give a summary of important attributes to the organization, the stakeholder's responsibilities and excessing authorities, part categorization information for excessing activities, and additional details about the organization.

The part attributes obtained from this section are used in the tagging tool section to help in part excessing. The responsibility matrix and process flow information obtained from the survey are used in the swim lane mapping section. This section addresses the defining obsolescence part of the obsolescence elimination framework.

3.5 Modified Swim Lane Mapping

3.5.1 Purpose

The information regarding stake holders and process flow is obtained from the interviews and surveys. However, this information needs to evaluated to check non-value added activities. The desired process flow and interactions of all the stakeholders also need to be depicted on a timeline, so that warehouse personnel can plan support activities (for example, resource allocation). Hence, an efficient mapping technique is required visualize the excessing process.

3.5.2 Background

In the case of executing obsolescence activity in a warehouse, a lot of time is spent in visualizing the desired process flow if it is purely documented in verbiage. Mapping techniques address this issue by providing a pictorial representation of the process (Klotz et al., 2008). Most organizations document processes using techniques such as process maps. In scenarios that involve a lot of interactions (information or product changes) between people or departments, these diagrams are difficult to create and interpret.

A swim lane diagram, unlike generic process maps, visually distinguishes job sharing for tasks (Van Dyke Parunak and Odell, 2001). However, visualizing roles of the stakeholders is still limited due to lack of suitable notations for the same. Additionally, the issue of differentiating between type of flow (value and non-value) still exists.

3.5.3 Method

The proposed mapping technique uses most of the basic concepts of traditional swim lane mapping. Limitations of swim lane mapping such as the absence of flow type indicators and identifying stakeholder's roles are addressed using color coded flow elements and the RACI matrix obtained in section 3.4.3.2 respectively.

3.5.3.1 Swim Lane Mapping

Swim lane diagram organizes activities into groups based on who is responsible for the different steps within a process flow. A sample swim lane diagram for removing obsolete parts from is shown in figure 3.10.

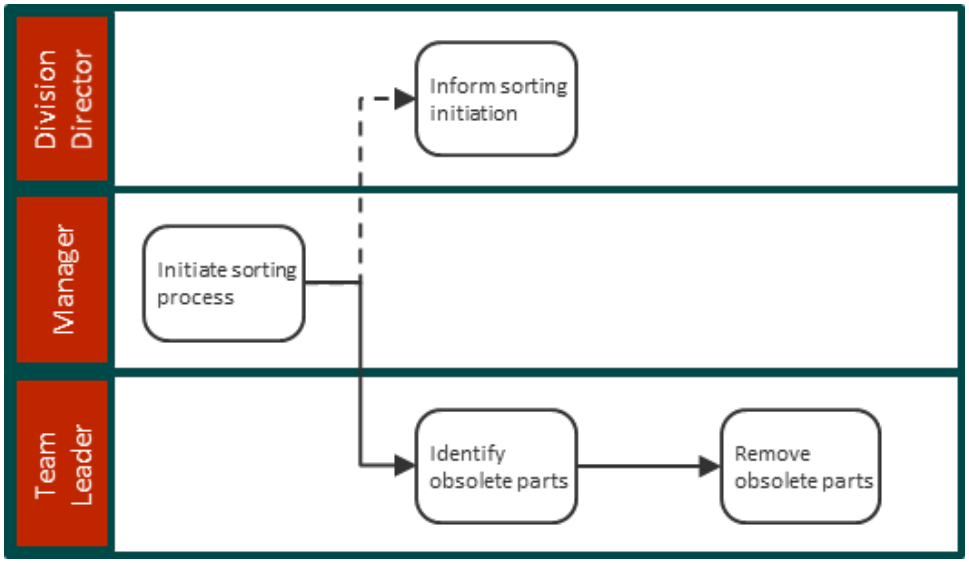


Figure 3.10: Swim lane example for removing obsolete parts

The swim lane diagram differs from other flowcharts because the processes and decisions are grouped visually by placing them in lanes that represent stakeholders (person/group/department). Parallel lines divide the chart into lanes, with one lane for each person, group or subprocess. Lanes can be either horizontal or vertical. A lane represents a stakeholder and a block inside a lane represents the subtask being executed. Thus, it is easy to map out the complete process and the inter-dependencies of the stakeholders.

The standard notations used for process mapping are also used in swim lane mapping (Damelio, 2011). Although an exhaustive list of these notations is available in literature, there are a few issues that need to be resolved before using it for designing the desired excessing process.

1. Flow elements that connect each process (physical movement or information communicated) do not have any notations to distinguish them based on the value added to the process.

2. Hierarchies in standard BPMI is not clearly defined, i.e., no standard notation to denote roles/responsibilities of stakeholders in a task.

Notations need to be developed to indicate stakeholder roles, and to differentiate between value added and non-value added flow for process improvement.

3.5.3.2 Flow Elements

Figure 3.11 shows the notations proposed to distinguish between the types of flows. The flow elements are categorized as value added, under performer, necessary, and non-value added. The description, value, and cost columns help categorize the flows. The color-coding suggested in the figure helps in easier visualization of these flows.

Flow Elements	Value	Cost	Description	Action	Physical flow notation	Information flow notation
Value added	++	+	Adds value to process	Refine		
Under performer	+	++	Potential to be value added flow	Convert to value added flow		
Necessary	0	+	No value added, but needed	Reduce costs		
Non-value added	-	++	Bad practice	Eliminate ASAP		

Figure 3.11: New flow elements for swim lane diagrams

3.5.3.3 Adding RACI Matrix

The RACI matrix developed in section 3.4.3.2 helps in identifying the roles of each stakeholder. This is incorporated into the swim lane diagram to identify the all roles in a task. The RACI notation and its usage in a task box is shown in figure 3.12.

Figure 3.12: RACI Notation and example

The rectangular task box shows a sample usage of the RACI notation for a warehouse manager. Although the removal process of excess parts is done by other designated personnel, the manager is still accountable for any issues and discrepancies in the task completion. The 'accountable' role of the manager is indicated by the highlighted portion "A" of the RACI notation.

3.5.4 Sample Implementation

The information obtained from the interviews and survey conducted at the organization is used to make the swim lane diagram shown in figure 3.13 for the case study. A partial image is presented here for brevity.

The modified swim lane diagram is used in the SOP developed in the next section. This section addresses the outlining excessing part of the obsolescence elimination framework.

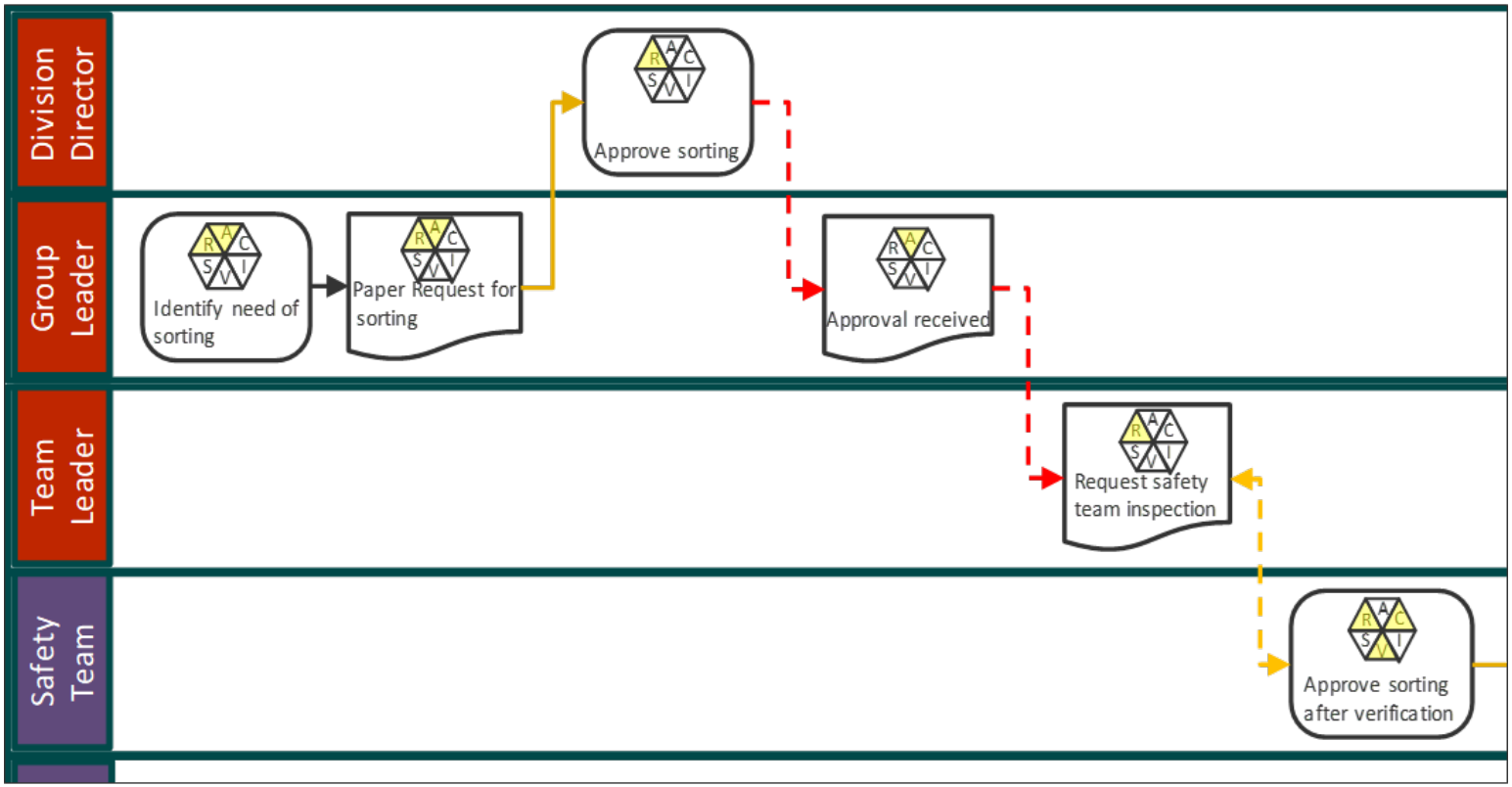


Figure 3.13: Swim lane diagram for excessing

3.6 Tagging SOP

3.6.1 Purpose

The survey section identifies stakeholders, task times, resources, and part attributes. The swim lane section provides a detailed understanding of the excessing process for better planning. The final step is to create a standard operating procedure (SOP) using information obtained in these two components. A comprehensive SOP can be used by personnel during the actual excessing task.

3.6.2 Background

The process of identifying and disposing material is done by personnel who are familiar warehouse protocols. These personnel can draft simple instructions (work instructions) on how to tag and remove material. However, decisions such as identifying part criticality, permissions/communication needed for obsolescence activities, and accounting obsolete parts to the correct stakeholder overheads and are not known to everyone. New models/revisions of a part may add new attributes. These attributes may require a change in the current way of excessing the part. All this information needs to be consolidated by management as a part of a SOP. The lack of proper work instructions and SOP, and an ambiguity between these two documents creates problems for the excessing activity.

3.6.3 Method

A comprehensive SOP helps excess parts with ease. The swim lane diagram obtained in section 3.5 provides information about "who", "what" and "when" of a process. This diagram along with survey results is used to create a method of procedure (MOP) that is a part of the overarching SOP and could also act as a stand-alone document. For excessing activity, record-keeping forms are designed. Written instructions for their usage are developed. Details identified in the survey such as part attributes, cost information, etc.

are used in a coded/tabular form to make the document compact for easier use. All the forms and MOP are a subset of the SOP.

3.6.3.1 Excessing Forms

The primary purpose of creating a standardized form is to help the personnel to excess material with ease on field. It is important to incorporate all the part attributes that help identify obsolete ands non-obsolete parts. It is also important to keep the document concise. Hence, the excessing form needs to be condensed by dividing the attributes. The critical/primary attributes that constitute most of the obsolescence cases are assigned individual columns. The secondary attributes are assigned a single column and denoted with short forms or acronyms using tables. The excessing form should have the following subsections;

1. **Part name**

   The part name for material in a primary identifier provided by the organization. In case of absence of any the part name, a user defined name may be provided by the personnel using a combination of shape, function, or raw material of the part.

2. **Location and other part characteristics**

   The location details are needed by personnel to identify the position of the part placement. The location details for the parts are also provided by the organization. However, if not provided, user defined positions can be used as a reference. An example of such a user defined location is shown in figure A.4. This location marker is created using an alpha-numeric description. The descriptions can be made using personnel name, organization id, serial number of item, and other part characteristics.

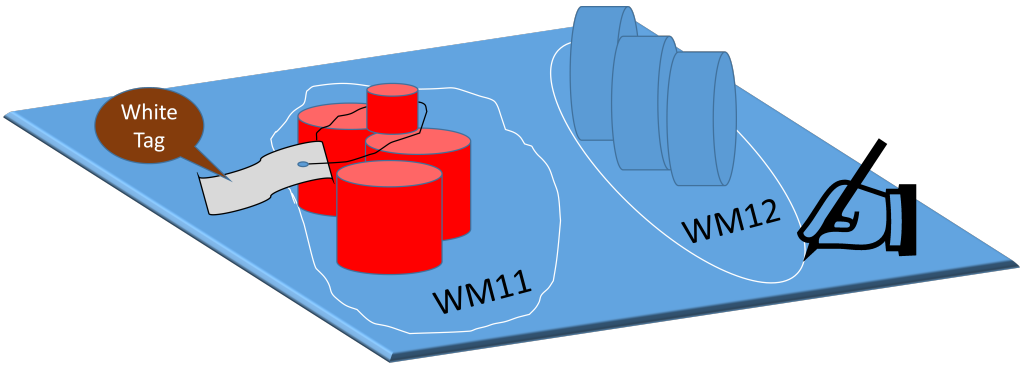


Figure 3.14: Location marking example

Other details that need to be recorded are company records such as dollar value of the parts (for categorization purposes) and control number/ part number to act as additional part identifiers.

3. **Part attributes identified in surveys**

   The forms should contain all the attributes identified in the survey. These attributes must be divided into primary and secondary attributes for ease of usage and form conciseness.

4. **Excessing tag details and personnel remarks**

   Obsolescence tag is used as a physical marker on the parts that have been deemed obsolete and need to excessed. This tag (usually red colored) includes details that are included in the location tag. It also contains the reason of removal and information regarding the authority of excessing and date of disposal. The serial number on the tag is needed on the excessing sheet to match records. A remarks section in the form is important to receive feedback from the personnel regarding the excessing process. It can be also used to indicate some additional characteristics of parts which may improve the categorization of the attributes.

3.6.3.2 SOP-Method of procedure (MOP)

The objectives of a MOP are as follows:

1. To instruct participants about their roles in excessing at different time points.
2. To instruct the participants on prepping for excessing and filling up the excessing sheet.
3. To provide information on assignment of leadership and hierarchy.
4. To provide information on resources or external support needed at different time points.

The stakeholders refer to the swim lane diagram in the instruction sheet to identify their alloted tasks. When a stakeholder is informed of the next task, it helps address two questions:

1. What is the current status of excessing?
2. What is the stakeholder expected to do now?

Refer to the example shown in figure 3.15 that depicts task outline for four stakeholders from P1 to P4. The task alloted to a current active participant is highlighted. Let the task be 'N' and the time point when it occurs is 'm'. Note that the time points may not occur at fixed equal intervals.

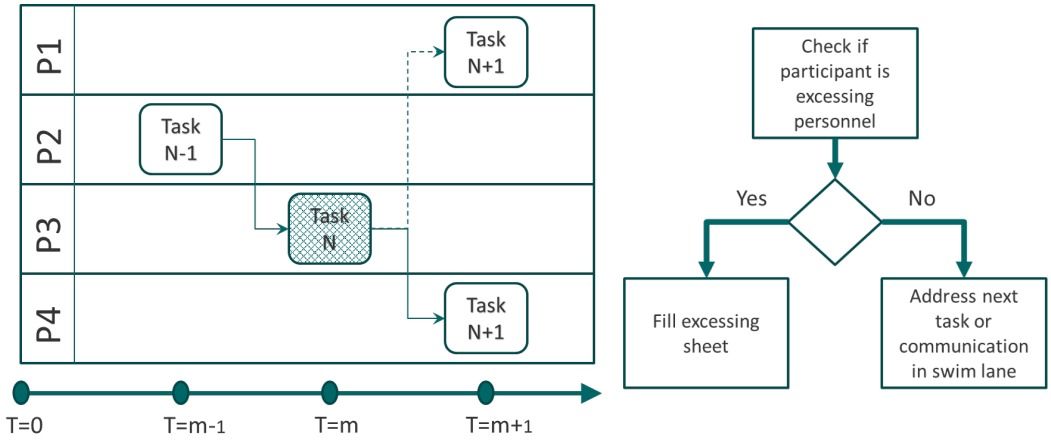


Figure 3.15: Excessing role decision flow

By referring to the instructions or observing the swim lane map, the stakeholder is able to understand the task time line. The stakeholder executes the next set of tasks as outlined, which in this case, is task N+1 forwarded to stakeholder P4 and a parallel communication to participant P1.

Next, work instructions need to be drafted to execute excessing using the forms and swim lane diagrams. The components of the work instructions are as follows:

1. Preparation: Listing material such as handling equipment, stationary, etc. needed for excessing.

2. Work Briefing: Assigning work areas, supplies to personnel, and reviewing the swim lane map.

3. Obsolete identification: Actual tagging exercise, filling all the details in the forms, and collecting feedback by verbal or written communication.

3.6.4 Sample Implementation

In this section, an SOP is developed using the swim lane and survey results of the organization. The objectives of the SOP are as follows:

- To standardize an obsolete unit identification and excessing paradigm for the research organization.

- To generate feedback from all participating members. Feedback will be used to improve the obsolete tagging procedures

- To help personnel groups customize the obsolete unit identification procedure to suit their needs.

The complete SOP from the case study is added in Appendix A of the thesis for reference. This addresses the final component of obsolescence elimination framework.

Chapter 4

Storage Policy

4.1 Research Objective

After successfully eliminating obsolete parts from the system and identifying "What to keep", the next phase is to address the second part of the objective, viz. "How to keep" the remaining parts. This chapters develops a storage policy for methodically organizing the parts in a warehouse. A storage policy will help organizations to plan the warehouse layout and achieve delivery efficiencies.

4.2 Purpose of Research

The parts in a warehouse may have different inventory behavior (minimum stock requirements, consumption patterns, etc.) based on their attributes. The choice of storage equipment (bins, pallets or crates) and the warehouse layout needs to be selected based on these attributes. For example, fasteners may be needed periodically in fixed quantities while certain spare parts may be needed very occasionally, but with no prior notice. In such a case, faster-moving parts need to be stored closer to point of use compared to others. Another example is where certain parts may be process critical and hence command a specific inventory level for maintaining service level. In contrast, some other smaller parts may just have a single unit that needs to be stored as standby. Thus, more space needs to be

permanently assigned for some parts versus others. Absence of any defined storage policy results in issues such as random storage of parts, incorrect choice of storage equipment, etc. These issues affect the overall space utilization and increases part handling time (viz. storage, retrieval and re-stocking time) (Gu et al., 2007; Rouwenhorst et al., 2000).

Hence a storage policy that drives assignment of part priorities, determines optimum sized containers and centralizes part information is vital.

4.3 Research Framework

The framework of the proposed storage policy is shown in figure 4.1. Each component of the storage policy is addressed by a solution proposed in this chapter (highlighted in green). This sections begins with identifying relevant parameters for part consumption that can be used in class-based storage. These parameters are standardized using standard score (Z-score) technique. After obtaining the Z-score, a multi-parameter classification tool is created with user-editable weights for the parameters. Next, a statistical analysis is proposed to minimize the sizes of storage bins and pallets used. The number of size categories needed is assumed, and K-means clustering technique is applied to select the best bin in each category. The part classification and standardized bins are incorporated in a modified Plan For Every Part (PFEP) database that enables the user to change parameters such as standard deviation of orders, weight and volume limitations for each part classification, etc. The PFEP helps generate a layout plan based on total inventory, part classification, and ranking in the warehouse.

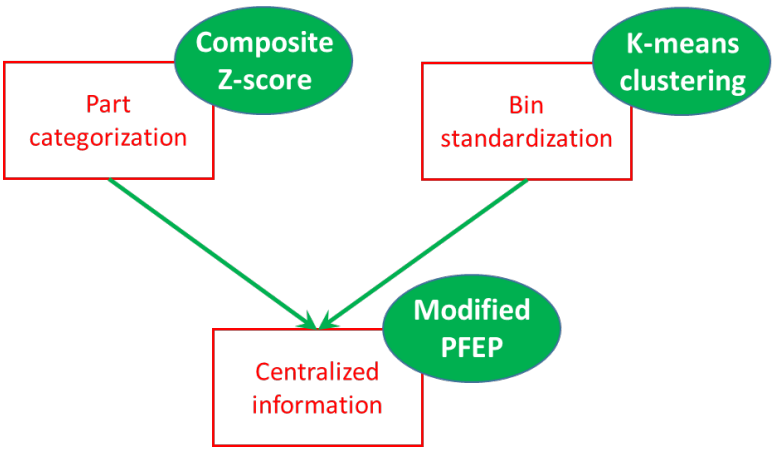


Figure 4.1: Storage policy framework

The framework is validated by a case study conducted at a high-mix and low-volume manufacturing facility in the state of Tennessee.

4.4 Composite Z-score Formulation

4.4.1 Purpose

After identifying the parts that are needed in the warehouse, the first step is to plan space allocation and material handling requirements of the warehouse. The purpose of part categorization is to simplify these decisions.

4.4.2 Background

The class-based storage (CBS) is one of the popular categorization policies due to its consistent results when applied in most warehousing applications. Products are divided into classes and each class is assigned a dedicated storage. CBS policies generally utilize some form of base parameter for categorization such such as average consumption, popularity, cube-per-order index (COI), pick volume, etc. However, most organizations store material whose storage decisions may be influenced by more than one parameter. Hence, a technique that allows multiple parameters is needed for a comprehensive policy.

4.4.3 Method

For a broad CBS, a composite formulation of parameters (or variables) is used. In the first step, variables that influence the space and part handling requirements are identified. A technique called standard score or Z-score is used to standardize the variables and create a weighted score for each part from the inputs of the organization personnel. The parts are then categorized based on a choice of cut-off ranges. The structure of this section is shown in figure 4.2.

Figure 4.2: Z-score Methodology

4.4.3.1 Identifying Variables for Categorization

Stakeholders in the organization identify factors that contribute to part flow (ingress and egress) and stay time in the warehouse. These factors help in the selection of the categorization variables. Some of the key points taken into consideration while deciding the variables are as follows:

- Evaluation of procurement activity for a product to select high priority parts that may be vital to an operation.
- Determination of storage area for parts depending on consumption behavior and also to evaluate fixed versus random storage (also called floating storage).
- Evaluation of ordering patterns based on batch sizes and periodicity of order placement.

The key points for variable identification are consumption, procurement activity, and variations in order sizes. Standard variables such as SKU usage per unit time, total production orders per part, or volume space occupied per part can be used for categorization.

However, in this research, we focus on variables based on purchasing history that is readily available in most organizations. The variables in this research are as follows:

1. *Total annual consumption(x_1)*

   It is the total count of stock keeping units (SKUs) consumed for each part annually. This variable is a traditional indicator for prioritizing parts and used in most CBS policies. In some cases where product price is also a critical factor, total annual consumption may also be replaced by total dollar value of annual consumption.

2. *Number of annual orders (x_2)*

   It is the count of all purchase orders placed in a calendar year. This variable is similar to the 'total annual consumption,' but differs from it as it also helps determine the frequency of orders, and thus helps distinguish between parts that may vary in consumption rate. For example, when combined with the earlier variable, it helps evaluate fixed versus floating area decision for a part.

3. *Number of active months (x_3)*

   It indicates the count of the total months (out of twelve) in which all the orders are placed. This variable helps identify parts that may exhibit a certain level of seasonality. For example, it helps distinguish between parts that may have similar number of annual orders, but differ by the fact that one part is ordered mostly in the first quarter, while another part is ordered in all twelve months.

4. *Annual order size variation (x_4)*

   It indicates the overall population variation of total annual orders for each part. In the case of high consumption items, this variable helps distinguish parts which have a more consistent order size (indicating parts that are needed periodically) versus those that are occasionally ordered in bulk quantities (indicating parts that need an improved consumption forecasting to achieve optimum stock levels). It may also be a critical factor while determining floating storage for parts.

4.4.3.2 Standard Score or Z-score

The variables selected for the part categorization in the previous section may have different units of measurement or different scales. For example,"Number of active months" or "x_3" has a scale from 1 to 12, whereas"total annual consumption" or"x_1" may have a scale from 1 to couple of thousands. Z-scores allow users to convert scores from different data sets into scores that can be accurately compared to each other (Wu et al., 2001). Numerical data or scores from different distributions need to be standardized to provide a way of comparing them while retaining their respective distributions. Z-scores computed from samples with different units can be directly compared because these numbers do not express the original unit of measurement(Cheadle et al., 2003).

For a numerical data set, a Z-score is a statistical measurement of a data point's relationship to the mean in a group of scores. A Z-score can also be positive or negative, indicating whether it is above or below the mean and by how many standard deviations. A Z-score of 0 means the data point is the same as the mean. The formula to calculate Z-score is as follow:

$$Z = \frac{X - \mu}{\sigma} \tag{4.1}$$

where Z is the Z-score, X is the value of the element in the population, μ is the population mean, and σ is the standard deviation.

An advantage of using the Z-scores is that although they tend to be used mainly in the context of the normal curve, non-normal distributions can also be transformed into sets of Z-scores. Hence, it can also be used for skewed data sets. This means that there is no pre-screening required to check if the data for each categorization variable is suitable for analysis (or normally distributed). For example, if the original distribution of a variable's data is positively skewed, the distribution of Z-scores will also be positively skewed. The application of Z-scores in this research is primarily to standardize the variable data that don't need further analysis such as referencing the standard normal table (in the case of non-normal data) or interpreting deviations from the mean (e.g. understanding class exam performance). Hence, Z-scores are a viable option.

4.4.3.3 Weighted Z-score Rank

For a normal distribution, most of the Z-scores lie between the values 3.4 and +3.4. A Z-score with a magnitude larger than 6 is extremely unlikely to occur, regardless of the shape of the original distribution due to the central limit theorem (Abdi, 2007). Since each of these variables after transformation have the same maximum scale within limits mentioned above, it is easier to use the converted Z-scores of different variables in a linear summation to rank the parts.

The contribution of each of the four variables in the composite rank may be different for various types of warehousing scenarios. To make the composite ranking more adaptive to an environment, each variable is assigned a weight such that the summation of all the variable weights is 100. The user can control the role of each variable in the categorization.

The equation for calculating composite rank (R) for parts that have minimum three orders and exhibit variation in order size annually is as follows:

$$R = (W_1 x_1) + (W_2 x_2) + (W_3 x_3) + (-W_4 x_4) \tag{4.2}$$

given: $W_1 + W_2 + W_3 + W_4 = 100$

where W_1, W_2, W_3, W_4 are the weights assigned for the variables x_1 (total annual consumption), x_2 (number of annual orders), x_3 (number of active months), x_4 (annual order size variation) respectively. The negative sign for W_4 indicates that variation in orders has a negative impact on the overall rank of the product i.e. more variation leads to a smaller Z-score.

For parts that do not have any variation in annual orders or total number of orders are less than 3 (to calculate variation), equation 4.2 can be written as follows.

$$R = (W_1 x_1) + (W_2 x_2) + (W_3 x_3) \tag{4.3}$$

given: $W_1 + W_2 + W_3 = 100$

The four weights that are assigned in the equations impact the overall categorization. These weights are provided by an individual stakeholder based on his/her product storage priorities.

4.4.3.4 Scenarios for Variable Weight Assignment

For a standard categorization policy of the entire organization, key personnel such as warehouse manager, the customer (internal), operations manager, etc. are interviewed to understand their perspective of a variable's impact on the warehouse layout. Standard weights for the variables are established either by mutual agreement or averaging the weights provided by these contributers.

Based on the effects of the weights on the categorization, it is important to understand the conditions under which certain weight combinations would be used. A few scenarios to explain the effects of weight assignments are provided as follows:

Scenario-1: For a business that has to prioritize parts based purely on total annual cost or total material used in a calendar year due to the expensive nature of the parts stored, it is recommended to have a higher weight for W_1 (weight assigned to total annual consumption x_1) compared to others.

Scenario-2: For a warehouse supervisor of a plant where annual consumption is similar for most parts and the objective is to plan for storage bins or floating area for parts, it is recommended to keep a significantly higher weight for W_4 (weight assigned to annual order size variation x_4) to increase the impact of the variation variable over others.

Table 4.1 shows a chart that illustrates select weight combinations, including scenarios 1 and 2 discussed previously. These combinations may be used for a pilot categorization and refined iteratively based on inputs or feedback of the user. Each scenario is listed in the first column titled 'Type of categorization' and the corresponding weights for each type of variable are listed in the chart.

Table 4.1: Weight assignment combinations

Type of categorization	W1 (Total annual consumption)	W2 (Number of annual orders)	W3 (Number of active months)	W4 (Annual order size variation)
Based purely on consumption	100%	-	-	-
Based purely on total annual orders	-	100%	-	-
Based purely on seasonality	-	-	100%	-
Based purely on order size variation	-	-	-	100%
Based on uniform weight distribution	25%	25%	25%	25%
Based on overall annual activity	50%	50%	-	-
Based purely on periodical orders	-	50%	50%	-
Based purely on critical/urgent orders	50%	-	50%	-

4.4.3.5 ABC Category Assignment

A simple method to distinguish between ABC categories is to assign estimated percentages to each category based on a pre-decided ratio of parts in each category.

An alternative to this method is to use the magnitude of scores to set the cut off limits. Although the composite rank R accommodates multiple variables, it is essentially a Z-score and ranges from -3.4 to +3.4 is most cases. Cut-off ranges need to be assigned for each category to obtain a categorization from the composite rank. These cut off ranges can be either data driven or user defined based on the level of accuracy needed and ease of application.

Using the common Z-score scale (-3.4 to +3.4) as a reference, the following cut-off limits for each category are used for the first iteration.

- For "A" Category parts, R ranges from maximum value to 2
- For "B" Category parts, R ranges between 2 and -2
- For "C" Category parts, R ranges from -2 to minimum value

For each part, the R rank assigns it to a unique category based on the range. These rank ranges can be used for a pilot categorization. Based on personnel evaluation of part ranks and assigned categories, the cut-offs can be adjusted in the subsequent iterations to accommodate the parts that are closer to a particular category

4.4.4 Sample Implementation Phase

A user-friendly application is developed in MS Excel to demonstrate the above methodology with the company's part data for the case study. The variables from section 4.4.3.1 and the formulation developed in section 4.4.3.3 is incorporated into the spreadsheet using macro codes. The software used for this application is MS Excel 2013. Fig.4.3 shows a snapshot of the Excel tool.

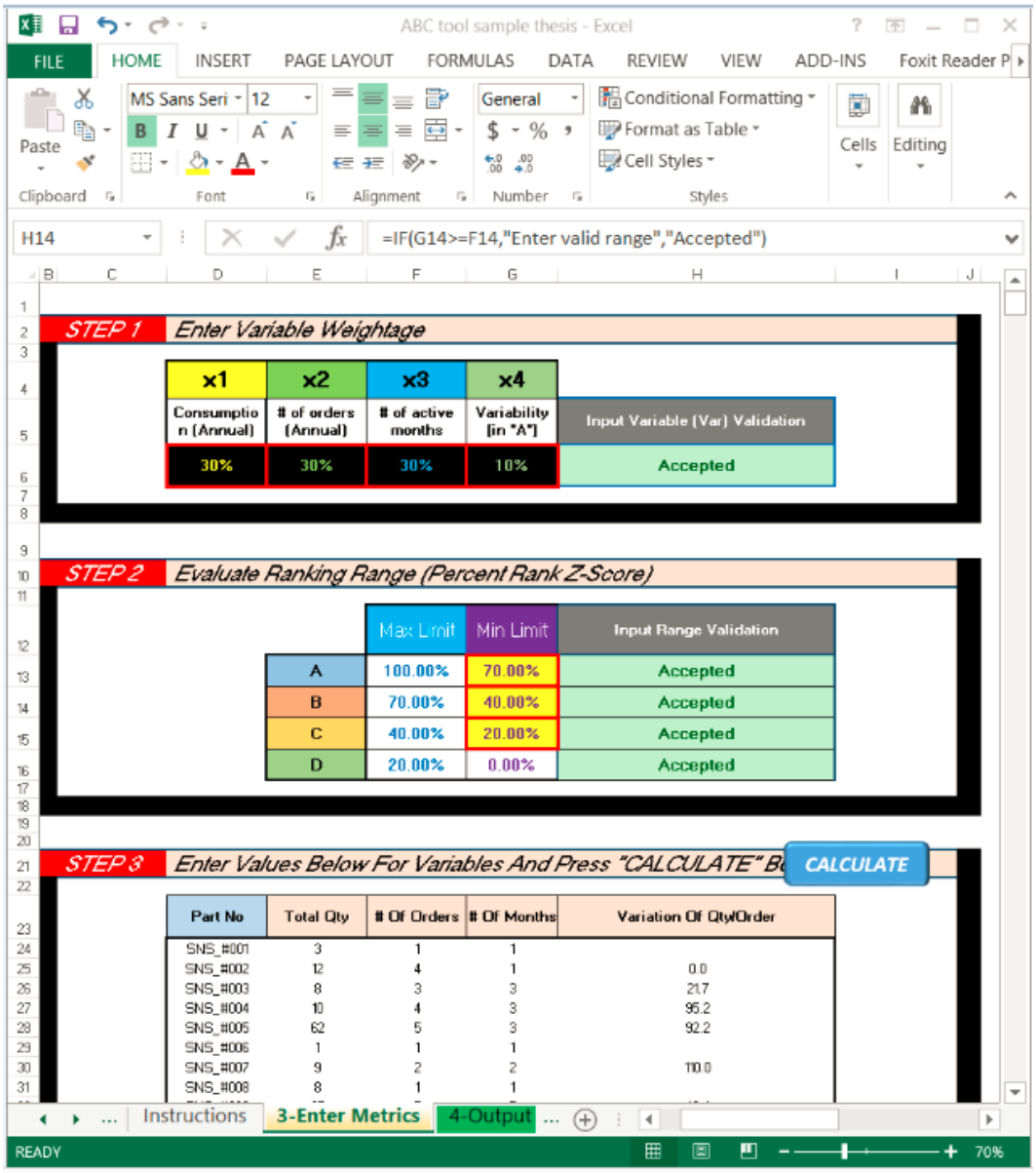


Figure 4.3: Part Categorization Tool

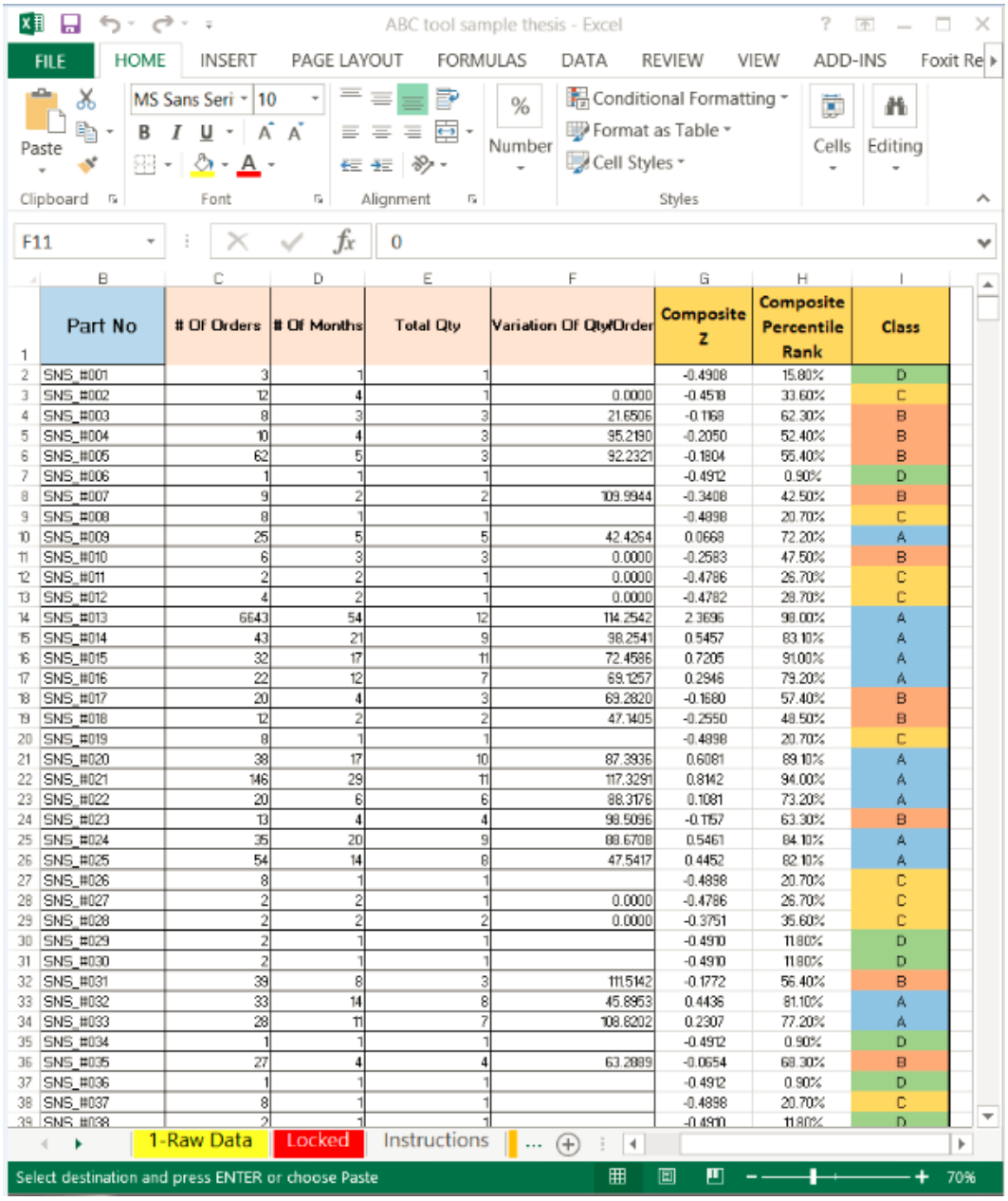
Fig.4.3 shows the "3-Enter Metrics" spreadsheet tab to input the information. There are three steps labeled "Step 1", "Step 2" and "Step 3" to be filled and a "CALCULATE" button to execute the analysis. A summary of steps to explain the functionality of the tool is given below.

1. In"Step 1", the user enters the weights for the variables based on categorization requirements. All the weights need to be entered correctly such that they satisfy the condition: $W_1 + W_2 + W_3 = 100\%$ (Please note that W_4 is an optional assignment for the user). If the weights entered do not satisfy this condition, the validation column generates an error highlighted in red.

2. In"Step 2", the cut-off limits for the categorization are entered manually.

3. In"Step 3", the information to be be analyzed is filled in the appropriate columns i.e. part data is entered for the four variables and the "Calculate" button is used to run the analysis.

Fig.4.4 shows output for the analysis. Each part receives a the composite rank R and is alloted to one of the part categories (color coded). This weighted categorization can be used by personnel for various tasks. For example, operations managers can use this analysis for identifying priority parts, slow moving parts in their inventory and take necessary actions while planning their purchase. Warehouse managers can use this analysis to design a more efficient storage layout that reduces overall space and part handling time.



Part No	# Of Orders	# Of Months	Total Qty	Variation Of Qty/Order	Composite Z	Composite Percentile Rank	Class
SNS_#001	3	1	1		-0.4908	15.80%	D
SNS_#002	12	4	1	0.0000	-0.4518	33.60%	C
SNS_#003	8	3	3	21.6506	-0.1168	62.30%	B
SNS_#004	10	4	3	95.2190	-0.2050	52.40%	B
SNS_#005	62	5	3	92.2321	-0.1804	55.40%	B
SNS_#006	1	1	1		-0.4912	0.90%	D
SNS_#007	9	2	2	109.9944	-0.3408	42.50%	B
SNS_#008	8	1	1		-0.4898	20.70%	C
SNS_#009	25	5	5	42.4264	0.0668	72.20%	A
SNS_#010	6	3	3	0.0000	-0.2583	47.50%	B
SNS_#011	2	2	1	0.0000	-0.4786	26.70%	C
SNS_#012	4	2	1	0.0000	-0.4782	28.70%	C
SNS_#013	6643	54	12	114.2542	2.3696	98.00%	A
SNS_#014	43	21	9	98.2541	0.5457	83.10%	A
SNS_#015	32	17	11	72.4586	0.7205	91.00%	A
SNS_#016	22	12	7	69.1257	0.2946	79.20%	A
SNS_#017	20	4	3	69.2820	-0.1680	57.40%	B
SNS_#018	12	2	2	47.1405	-0.2550	48.50%	B
SNS_#019	8	1	1		-0.4898	20.70%	C
SNS_#020	38	17	10	87.3936	0.6081	89.10%	A
SNS_#021	146	29	11	117.3291	0.8142	94.00%	A
SNS_#022	20	6	6	88.3176	0.1081	73.20%	A
SNS_#023	13	4	4	98.5096	-0.1157	63.30%	B
SNS_#024	35	20	9	88.6708	0.5461	84.10%	A
SNS_#025	54	14	8	47.5417	0.4452	82.10%	A
SNS_#026	8	1	1		-0.4898	20.70%	C
SNS_#027	2	2	1	0.0000	-0.4786	26.70%	C
SNS_#028	2	2	2	0.0000	-0.3751	35.60%	C
SNS_#029	2	1	1		-0.4910	11.80%	D
SNS_#030	2	1	1		-0.4910	11.80%	D
SNS_#031	39	8	3	111.5142	-0.1772	56.40%	B
SNS_#032	33	14	8	45.8953	0.4436	81.10%	A
SNS_#033	28	11	7	108.8202	0.2307	77.20%	A
SNS_#034	1	1	1		-0.4912	0.90%	D
SNS_#035	27	4	4	63.2889	-0.0654	68.30%	B
SNS_#036	1	1	1		-0.4912	0.90%	D
SNS_#037	8	1	1		-0.4898	20.70%	C
SNS_#038	2	1	1		-0.4910	11.80%	D

Figure 4.4: Sample Part Categorization Output

The part ranking obtained from this section for a given dataset is used in the PFEP section to categorize the parts. This addresses the part priority component of the storage policy.

4.5 Bin Size Standardization

4.5.1 Purpose

The purpose of bin standardization is to identify the minimum number of bin sizes that accommodates all the parts in the warehouse. It helps in easier planning number of racks needed and the actual bin arrangement on the rack.

4.5.2 Background

There are several situations where an organization needs to take decision regarding standard bin sizes. For example, a company has to select distinct size bins from an exhaustive list of choices. An estimated guess in this situation may result in bins with similar carrying capacities being selected instead of unique size bins. Another example is when the warehouse personnel assigns an available empty bin to a part based on an estimated guess of size and fit. Such ad-hoc assignments do not account for part consumption behavior and may result in over-utilization or under-utilization of the bin in the future. This leads to a new bin being assigned to that part. In both the cases, total bin sizes in the warehouse increases.

4.5.3 Method

Most companies can deduce the overall bin types needed for their operation (for example, three standard bins; small, medium and large). However, the bin size selection is a constraint, especially if the selection is manual. To address this issue of choosing the best bin size, a statistical approach of analyzing all available bins sizes and identifying unique bin size clusters helps in an easier selection. Hence, the k-means algorithm is used for this analysis.

k-means Clustering

k-means is a popular clustering technique that partitions n items into k clusters in which each item belongs to the cluster with the nearest mean. The objective of this algorithm is to minimize the sum of squared error relative to cluster mean. K-means algorithms need an assignment of the total number of clusters to be computed. Since the total bin types for a warehouse are based on the requirements of the warehouse, k is a pre-decided number for this problem. For example, unless a specific bin type is needed, most warehouses may need 3 or 4 types of bins of distinct capacities. The first step is to identify 3 or 4 clusters from the available bins. The number of bins needed or the number of distinct clusters needed is the k in this clustering algorithm.

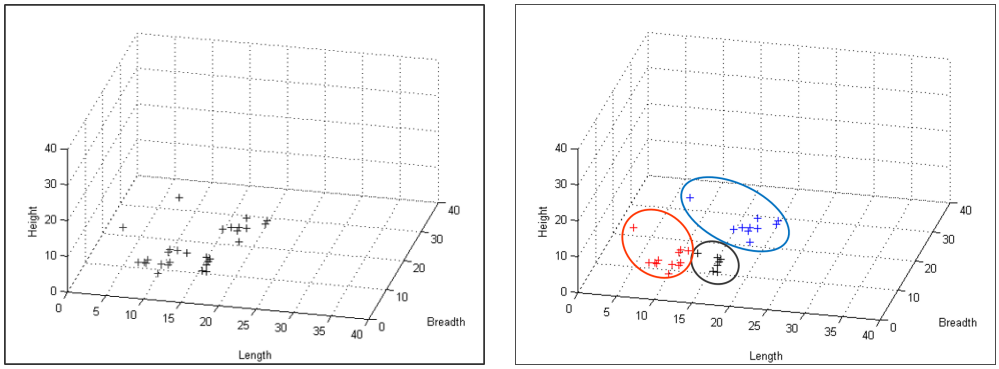
After mapping the bins in 3D space along length, breadth, and height, and assigning the value k needed(total bin types needed by company), the algorithm randomly initializes k cluster centers as the "initial mean." It then creates k clusters by assigning each bin to a cluster based on squared Euclidean distance criterion and assigns it to a cluster (Hartigan and Wong, 1979). Next, the centroid for the cluster is recalculated and a new bin size is assigned as the new mean. This process is iterative till a termination condition is met or the algorithm converges based on the distance criterion.

Thus, after the k clusters are identified, the maximum capacity bin in each cluster is selected as a standard bin. It is then assigned a bin category number from 1 to k where 1 represents the smallest standard bin and k represents the largest standard bin for the warehouse.

4.5.4 Sample Implementation

A k-means clustering program is developed in MATLAB for the case study. Bin sizes for this analysis are obtained from the company's bin data. The initial number of bins used for this analysis is 29 (total bin sizes in the case study organization) and they are plotted

in their dimensional space as shown in figure 4.5. Let the number of standard bin types or clusters k needed be three (small bin, medium bin, and large bin).



(a) Before clustering **(b)** After k-means clustering

Figure 4.5: k-means clustering of bins using bin dimension space

Figure 4.5 (a) shows the bins plotted in bin dimension space and it indicated that it is difficult to obtain a clear grouping by manual techniques as no clear clusters are identified visually. Figure 4.5 (b) however, can indicate the clusters and assist in picking the biggest bin/centroid in each cluster as the standard bin.

The results of clustering obtained from this section for a given set of bins is used in the PFEP section to assign standard bins to each part. This addresses the bin standardization component of the storage policy.

4.6 Modified PFEP

4.6.1 Purpose

With the completion of part categorization and bin standardization methodologies, the final step is to consolidate all part related information in a database that allows the user to modify these part related assignments

4.6.2 Background

Part related data such as storage location, bin type, purchase history, consumption, shipper, receiver, customer, etc. are needed for record keeping purposes. Each type of data is available from different resources/departments such as warehouse, purchase or production and in different databases. All this data needs to be consolidated at one place so that it is easier to manage any change associated with a single part. This can be achieved using a PFEP database. However, to make the PFEP a more useful tool, related data items need to be connected with formulations so that they automatically update with a single input (for example, change in monthly consumption of part automatically triggers a change in its bin type assignment or safety stock levels).

4.6.3 Method

This section begins with introducing the basic design of a PFEP sheet and its importance to the organization. Part categorization and bin standardization information is incorporated into the new PFEP design developed in MS Excel. User editable variables are used for analysis to obtain inventory parameters like total quantity, number of bins, bin capacity. This information along with a weighted ranking system for parts may be used to plan the racking layout in a warehouse.

4.6.3.1 PFEP

PFEP is a spreadsheet or a database containing essential information on every part and component used in the facility such as part name, description, part number, supplier names and locations, order frequencies, container types and dimensions, shipment sizes, transit times etc. When correctly tabulated, it allows the user to plan and make decisions regarding material flow and storage.

This database must be user-friendly, should have sorting capabilities, and be accessible for reading to all stakeholders in the organization. Most facilities traditionally start with an Excel spreadsheet and then transition into the company's ERP system. It is important to

designate individuals responsible for entering the information, updating, and controlling its accuracy.

The current structure of a standard PFEP offers limited analytical flexibility. It does not contain fields that are essential for planning the actual part layout such as calculating the total number of bins and their priority assignments in the layout.

4.6.3.2 Modified PFEP

To enhance the capabilities of standard PFEP, a modified PFEP that incorporates more inputs and analytical capabilities is developed.

Developing PFEP Fields

The modified PFEP contains information for 'n' parts. Few standard fields needed for this research are selected from an exhaustive list of PFEP fields from literature and are listed below.

- Dimensions of a single part (inches)
    1. Length (l)
    2. Width (w)
    3. Height (h)
    4. Radius (r)
- Shape of the part
    1. Cube (c)
    2. Sphere (s)
    3. Cylinder (c)
- Volume of a single part (v) in cubic inches
- Weight of a single part (wt) in ounces

- Average quantity per order (Q_o):Total annual quantity of a part purchased divided by the total number of annual orders for the part

- Average quantity per month (Q_m):Total annual quantity divided of a part divided by 12 months

The input and the output fields developed for the part categorization in section 4.4 are also included. The new fields developed are listed below.

- Average quantity per active month (Q_a):Total annual quantity of a part divided by the count of months (out of 12) that orders were placed for the part

- Average active storage volume (V_a): Total volume of a part stored per active month i.e average active quantity for a part multiplied by volume of the part
  $V_a = Q_a * v$.

Assigning Standard Bins to Parts

After calculating the total volume that would be stored for each part on a monthly basis, the next step is to choose an appropriate container or bin to hold the part. Each part needs to be assigned one unique bin from the available "standard bins" from section 4.5.4. Since the volume V_a is an average estimate of the volume that would be occupied by a part each month in the warehouse, this measure is used for bin assignments.

The assignments are done using a parameter called Bin Index (BI). It indicates the bin category derived from section 4.5.4. Thus if k standard bins are shortlisted in section 4.5.4, it is alloted a Bin Index from 1 to 'k' where 1 represents the lowest volume bin and 'k' represents the highest volume bin. Each part in the modified PFEP is assigned a Bin Index based on the following conditions.

1. Average active storage volume (V_a) of a part is lesser than volume of bin (V_{bin}) being compared.

2. Minimum and maximum dimensions of the part (l_{min} and l_{max}) are smaller than minimum and maximum dimensions of the bin (L_{min} and L_{max}) being compared

respectively. This condition ensures that at least one unit of the part under consideration fits in the selected bin.

Based on the above conditions, the equation for the Bin Index assignment for a part in the warehouse is given below.

$$Bin\ Index = \min_{k} \left[((V_a)_i \leq (V_{bin})_k) \cap ((l_{min})_i \leq (L_{min})_k) \cap ((l_{max})_i \leq (L_{max})_k) \right] \tag{4.4}$$

For i=1...n; where n is the total number of parts in the warehouse and k is the bin category number from section 4.5.4

Calculating Maximum Bin Carrying Capacity

After selection of bins, the next step is to evaluate the maximum capacity of bins for a given part. These following conditions are checked for volume and weight carrying capacities.

- Material that is stored in a bin may not be arranged in a certain order depending on the shape of the material. For example, some items that are cubic in shape can be stored in a certain arrangement to maximize the stored volume in the bin. However, in the case of other items like bolts, screws or bearings, there is no specific pattern of arrangement. The working capacities in terms of volume is adjusted to accommodate this staggered loading of material in a bin by adding a buffer. The maximum number of items for each part based on the volume constraint is N_{vol}.

- The maximum carrying capacities in terms of weight for each bin may also be adjusted with a buffer for certain cases. For example, constraints for manual handling for bins may need to be added in cases where handling or storing at a higher position manually on a rack is a safety issue. This may dictate the need to adjust bin weight accordingly. The maximum number of items for each part based on the weight constraint is N_{wt}.

To keep the loading capacity within both the limits, the minimum quantity between N_{vol} and N_{wt} for a part is selected as the maximum carrying capacity N_{max} of its assigned bin.

Buffer Quantity for a Part

A buffer quantity needs to be assigned for each part to be able to accommodate any variation that might occur in an order for that part. There are two ways in which this buffer quantity may be estimated.

The first way is to obtain an estimated buffer percentage from the warehouse personnel. This buffer quantity may be derived from company policy or minimum stock limits that need to be stored for a part. However, in organizations which do not have a defined demand model, minimum stock limits are difficult to estimate and are likely to be unreliable. Therefore a different method for the estimation of the buffer quantity needs to be developed.

The alternative is to use statistical information for the given part to estimate this buffer. By evaluating the historical behavior of the consumption or purchase orders, it is recommended to use the spread of these order quantities or the standard deviation of orders to develop this estimate. For a part, the standard deviation 'σ' of the cumulative consumption in active months can be used as a buffer quantity. In some cases where the total number of months is less than two (insufficient points to calculate standard deviation), a pooled variance can be calculated using the orders in each active month as the population.

Calculating Number of Bins Using Buffer

The next step in the process of the PFEP is to calculate the total number of bins for each part that will be stored in the warehouse. Although total cubic volume for a part drives the storage cost calculations, decisions on the total footprint or the total number of racks needed to store parts is based on the type and size of the bins in which the part is stored. In addition, decisions regarding the fixed space versus floating space for parts, or planning the total forward feed area (for part picking) also depend on the number of bins that have to be stored for a given period.To calculate the total number of bins, the user needs to provide the following three inputs to the PFEP.

1. Average active storage volume (V_a)

2. Bin Index assigned for the part

3. Buffer quantity for each part

Average active volume is obtained from historical data for a part. Bin Index for each part is previously assigned based on equation 4.4. The total number of bins required for the part is calculated as follows. M represents the total storage quantity for a given part. It is given by the sum of the average quantity per active month Q_a and the buffer quantity (selected from the above alternatives). The following conditions are used to estimate the number of bins.

- For a part, if M is less than or equal to N_{max} (maximum carrying capacity)of the assigned bin, then a single bin is assigned.
- Else, if M is greater than 1.5*N_{max} and less than volume of the next bigger standard bin, then assign the bigger bin. This step helps utilize the overall capacity of the total assigned bins for a part.
- Else calculate the total number of original bins using the ratio M/N_{max}.

The buffer quantities obtained from the two techniques explained earlier can also be used in tandem by assigning one of the buffer quantities based on certain part attributes.

4.6.4 Sample Implementation

A sample PFEP template is developed in MS Excel for the case study. A snapshot of the template is shown in figures 4.6 and 4.7. As shown in the figures, the data input and variable editing areas are developed in separate tabs and are connected using the formulation proposed in this section.

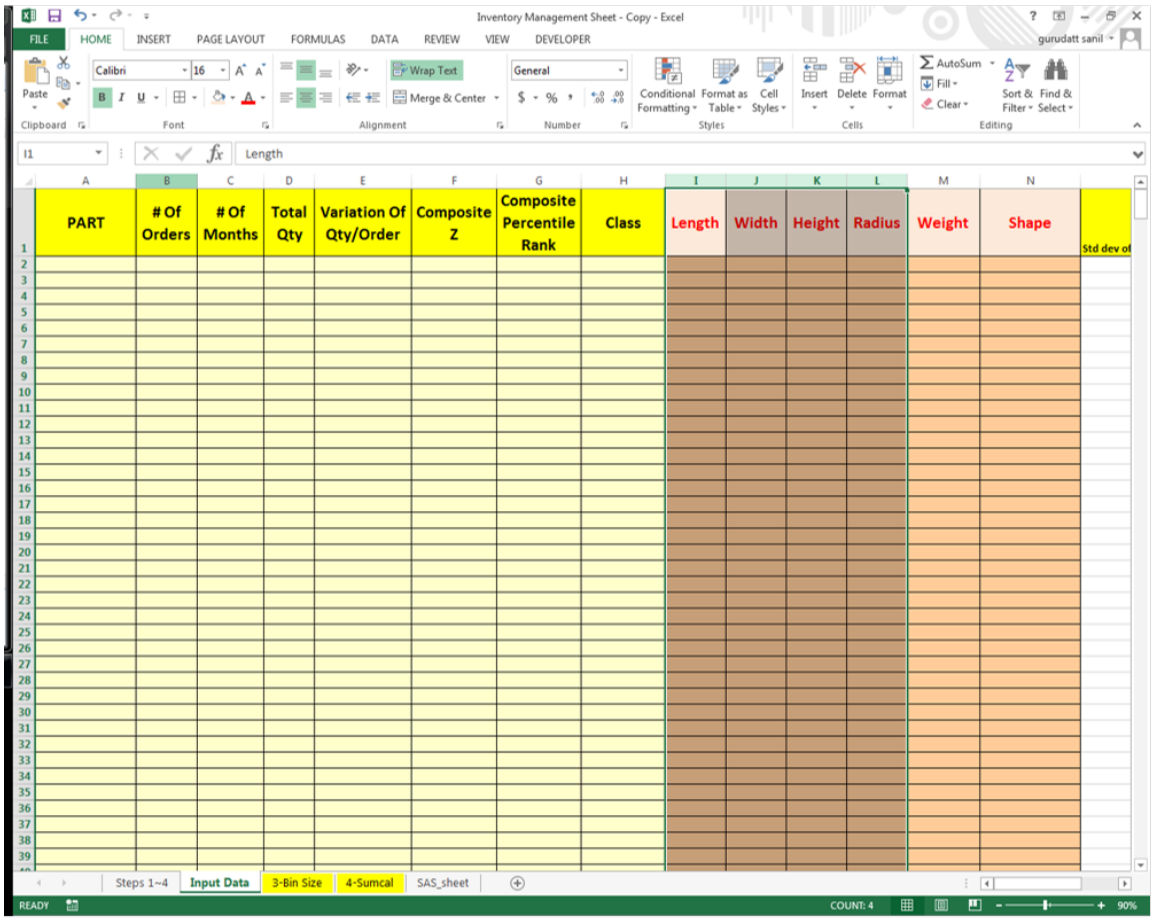
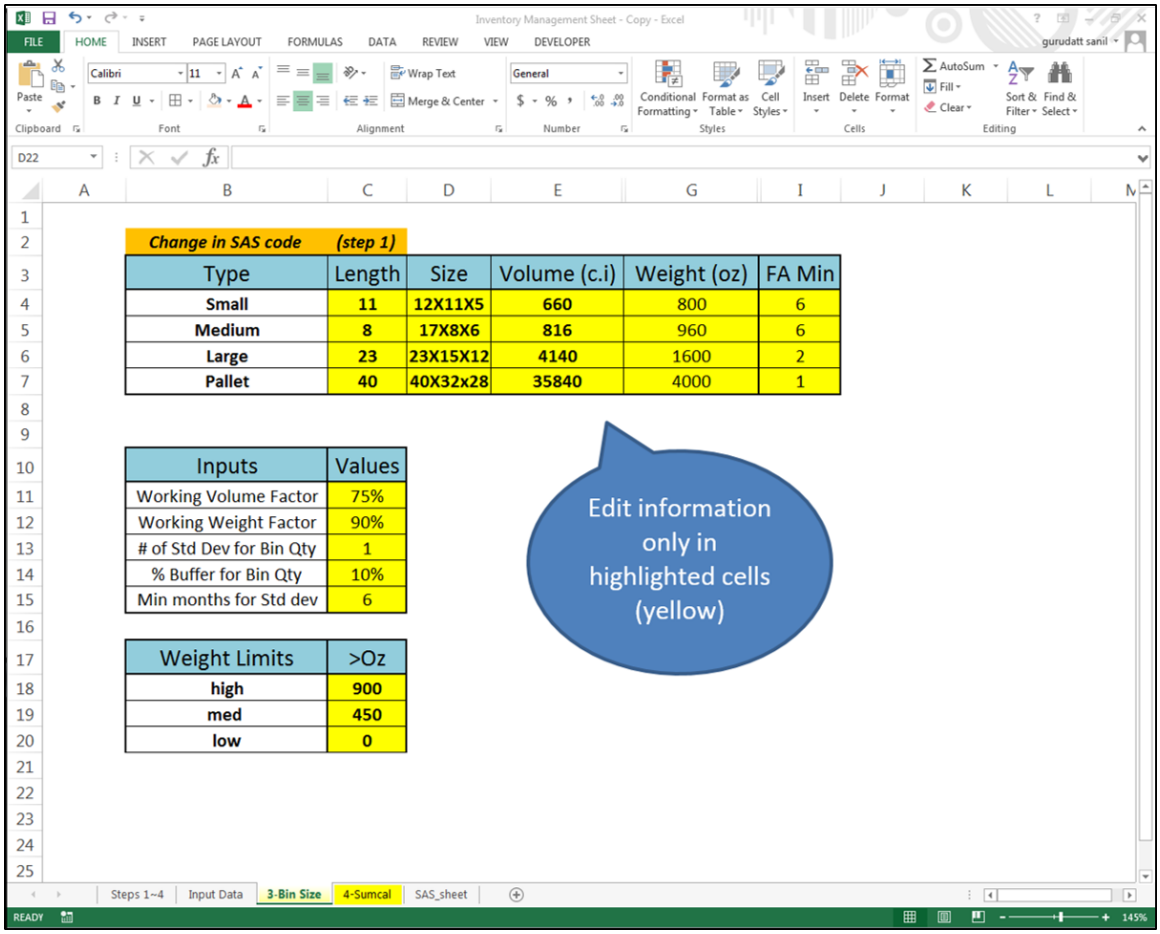


Figure 4.6: PFEP snapshot



Change in SAS code	(step 1)				
Type	Length	Size	Volume (c.i)	Weight (oz)	FA Min
Small	11	12X11X5	660	800	6
Medium	8	17X8X6	816	960	6
Large	23	23X15X12	4140	1600	2
Pallet	40	40X32x28	35840	4000	1

Inputs	Values
Working Volume Factor	75%
Working Weight Factor	90%
# of Std Dev for Bin Qty	1
% Buffer for Bin Qty	10%
Min months for Std dev	6

Weight Limits	>Oz
high	900
med	450
low	0

Figure 4.7: PFEP variables

The data samples used for the implementations in the part categorization and bin standardization sections are a part of the same warehouse analysis and hence used for this PFEP implementation. The steps for this PFEP execution are shown in figure 4.8.

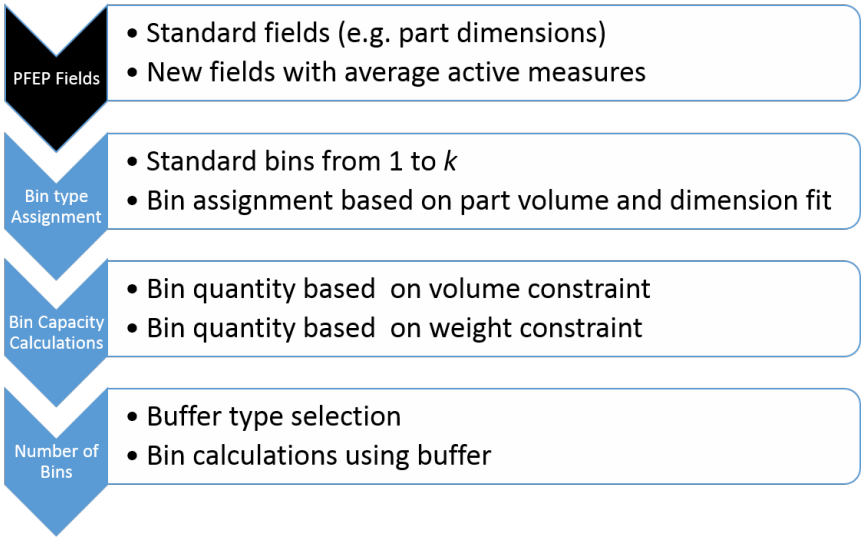


Figure 4.8: PFEP steps

1. The part information is filled up for all the standard fields such dimensions, shape, weight etc. Next, all the proposed fields (viz. average quantity per active month (Q_a) and average active storage volume (V_a)) are formulated as additional fields and their results are obtained for all the parts.

2. After calculating the active monthly measures, the next step is to assign a standard bin for each part. This bin assignment logic is shown in figure 4.9. The PFEP field formulation checks for the two constraints (viz. capacity of bin to accommodate V_a and the minimum and maximum dimensions of the part) and assigns a Bin Index to the part based on equation 4.4.

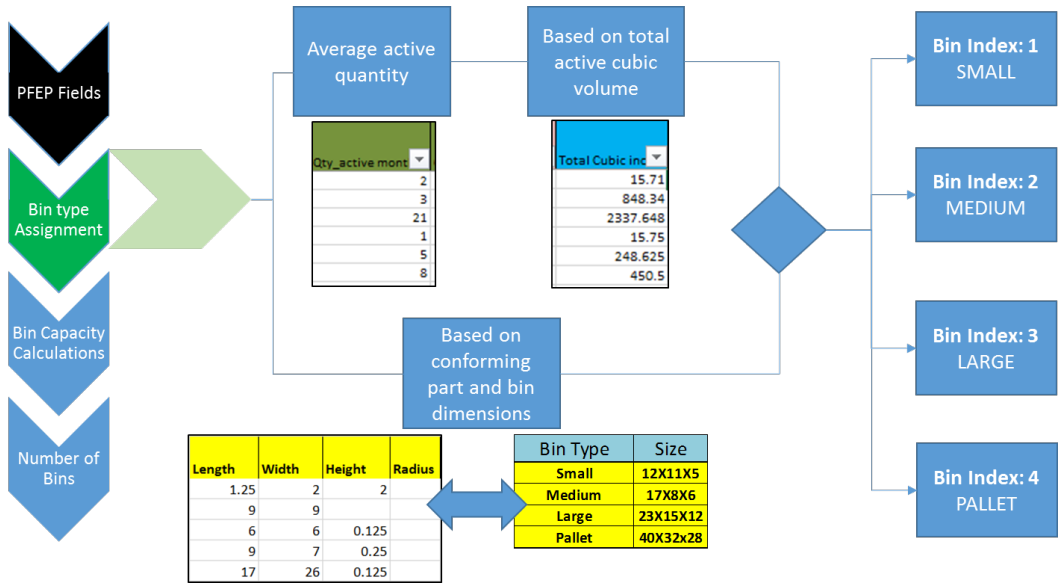


Figure 4.9: PFEP bin assignment

3. Once the part is assigned a standard bin, the next step is to calculate the maximum number of units that can be stored in it. Figure 4.10 shows the logic for bin capacity calculations. To compensate for the staggered loading and handling of the assigned bin, the working volume and weight factors are assigned in the variables input tab of the PFEP (75% and 90% respectively).

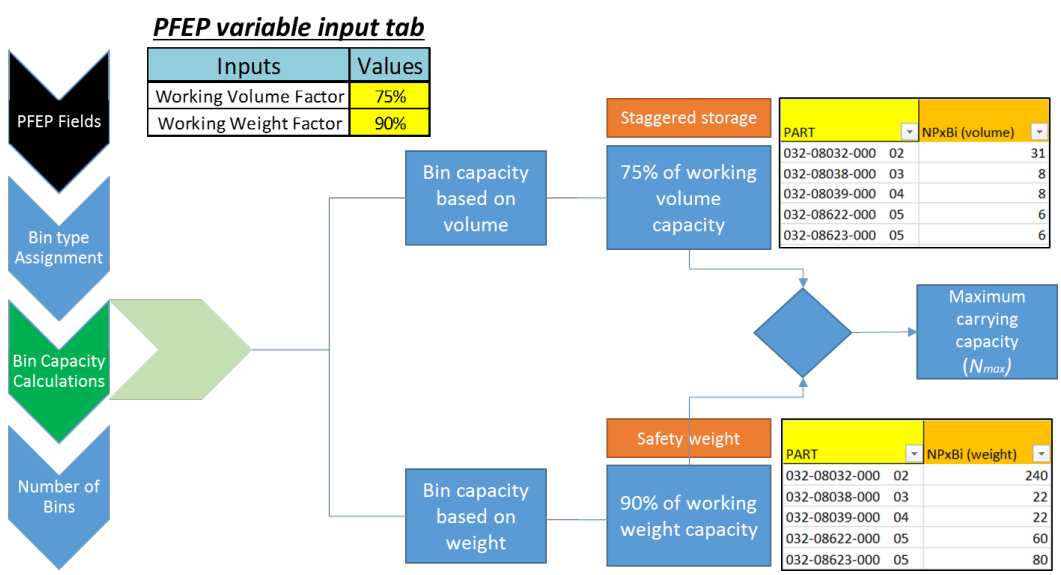


Figure 4.10: PFEP bin capacity calculation

The minimum of the two values (weight and volume capacities) is then selected as the maximum carrying capacity of the assigned bin for the respective part.

4. Next, the total number of bins is calculated based on the logic shown in figure 4.11. For this dataset, the total storage quantity M is obtained by choice of buffer quantities based on the part attributes. For parts that have minimum 6 active months of use, one standard deviation from the cumulative active month orders (total orders in each active month) is used. For rest of the parts, a user defined buffer quantity of 10% is added. All these variables are added to the variable input tab of the PFEP as shown. Based on the conditions given for the range of M, an appropriate number of bins are assigned to each part.

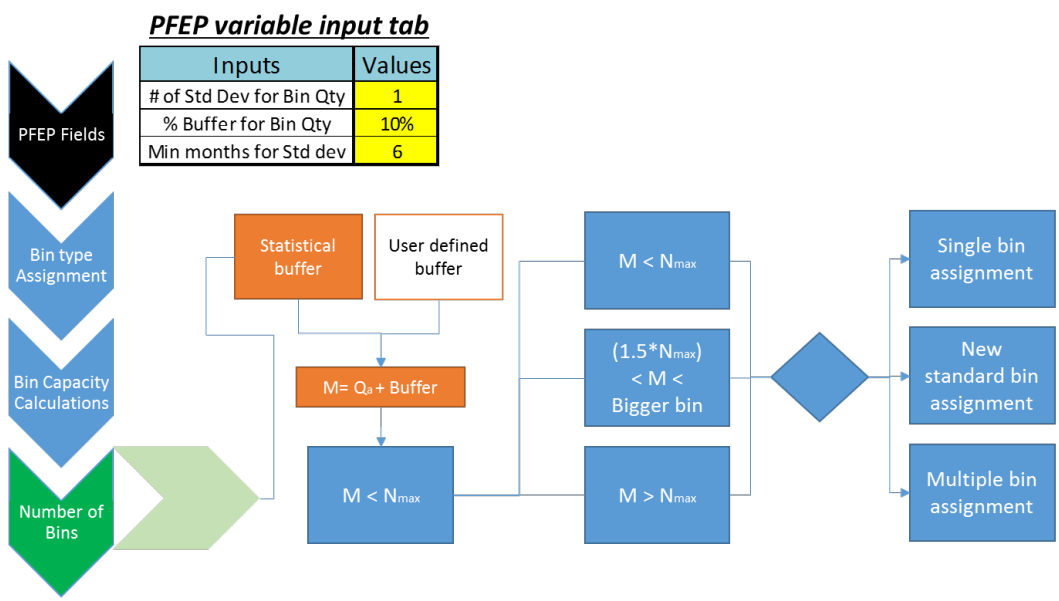


Figure 4.11: PFEP total bins calculation

Some of the output that can be obtained from this modified PFEP include weight category assignments for each bin-part combination, forward and floating area bins (based on a user-assigned threshold). This information can be used in planning racking layout of the warehouse.

By following the above methodology of allowing the user to edit variables, the PFEP can be used as a dynamic database for evaluations, instead of its conventional static form of pure data storage. This addresses the information consolidation component of the storage policy.

Chapter 5

Conclusions

5.1 Summary

This thesis is an effort to address deficiencies in traditional methods for part storage in a warehouse. A review of the literature on storage policies revealed significant drawbacks. For example, the travel distance while picking parts increases in case of random storage or more space is needed in case of a dedicated storage. The review also indicated the lack of a standard obsolescence elimination procedure to identify unwanted parts.

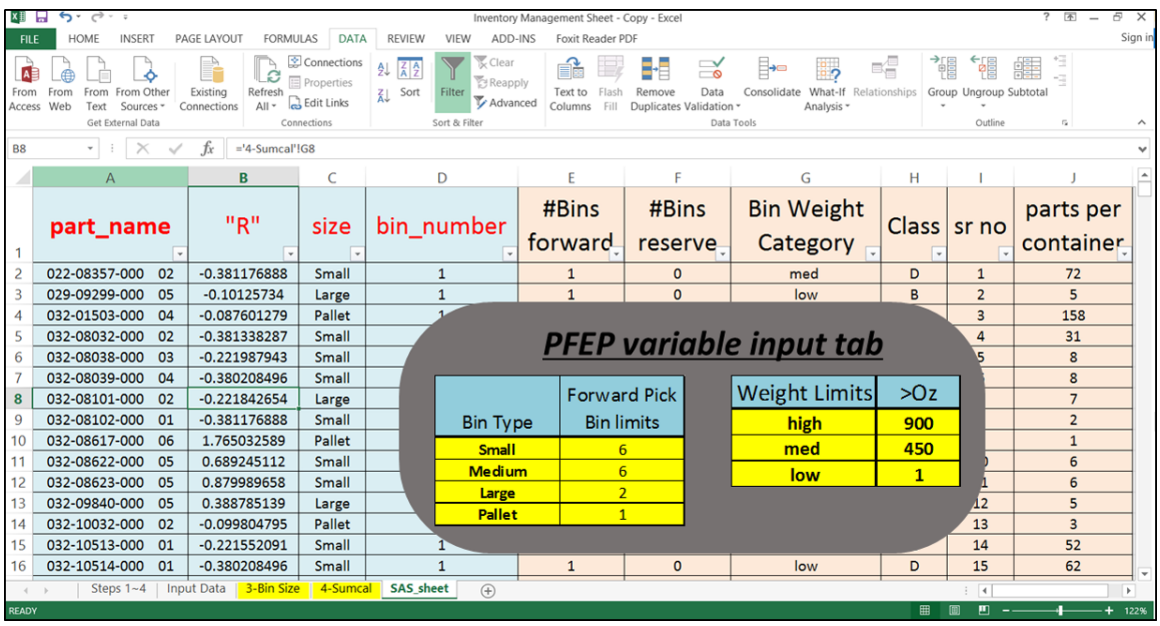
To address this gap, an obsolescence elimination guideline was created using surveys to capture operational information, swim lane mapping technique to show accurate process flow and SOP design for creating standard instruction. Next, a storage policy was created using a multi-parameter class based categorization for parts, k-means clustering for standardizing bins and a modified PFEP to ensure a closed loop system for iterative revisions in information consolidation.

This thesis addresses the two questions; "What to keep" and "How to keep" the warehouse inventory. The thesis will help companies to follow an informative structure coupled with case study examples where they can first reduce the number of parts that need to be stored and then organize the remaining parts efficiently.

Sample application

The results from the thesis may be extended to the problem of rack arrangement in warehouses. Organizations can use information from the PFEP to plan a systematic rack arrangement saves time and space.

Consider a warehouse that needs to arrange about 50 parts using the suggested PFEP. After the final step of in the storage policy, the total bins and bin type of each part are retrieved from the PFEP. It is relatively easy to manually arrange the bins on the shelf of a storage rack. However, most warehouses store at least a few thousand parts. It is cumbersome to manually compute bin layout or estimate the total number of racks needed for these parts in a short time. To reduce the computation time for arranging the bins, organizations can create an algorithm that uses the information from the PFEP such as part numbers, bin types, class etc as shown in figure 5.1.



part_name	"R"	size	bin_number	#Bins forward	#Bins reserve	Bin Weight Category	Class	sr no	parts per container
022-08357-000 02	-0.381176888	Small	1	1	0	med	D	1	72
029-09299-000 05	-0.10125734	Large	1	1	0	low	B	2	5
032-01503-000 04	-0.087601279	Pallet	1					3	158
032-08032-000 02	-0.381338287	Small						4	31
032-08038-000 03	-0.221987943	Small						5	8
032-08039-000 04	-0.380208496	Small							8
032-08101-000 02	-0.221842654	Large							7
032-08102-000 01	-0.381176888	Small							2
032-08617-000 06	1.765032589	Pallet							1
032-08622-000 05	0.689245112	Small							6
032-08623-000 05	0.879989658	Small							6
032-09840-000 05	0.388785139	Large							5
032-10032-000 02	-0.099804795	Pallet						13	3
032-10513-000 01	-0.221552091	Small	1					14	52
032-10514-000 01	-0.380208496	Small	1	1	0	low	D	15	62

Figure 5.1: PFEP output

The parts are first sorted in descending order based on their composite rank R that indicates part priority. The R ranks dictate the order in which bins are to be placed on the shelf of a rack. Figure 5.2 shows a storage rack with two shelves. The steps in the algorithm are as follows:

1. The part with the highest R occupies the first space on the highest priority shelf (upper). Total space occupied by the parts depends on the total number of bins for a part and the bin type.

2. A buffer space is created for each bin for ease of handling.

3. After this allotment, the next part with the second highest R is considered and its bins are stored on the current shelf in the next available spot, adjacent to the earlier part as shown in step 2. The parts are placed with this logic.

4. If all the space on the current shelf is occupied as shown in step 3, then the bins are stored on the shelf with the next highest priority (lower).

This process continues till all the parts have been stored on the racks. The algorithm is repeated for each category of parts as described previously.

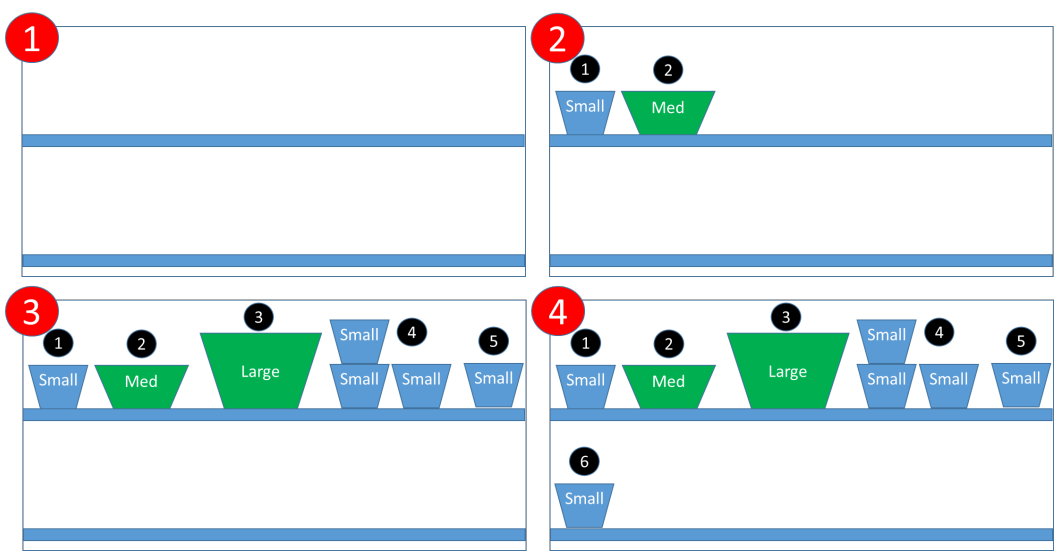


Figure 5.2: Bin allotment algorithm

This bin-based storage algorithm provides the following benefits:

- Bin assignments may be used by the warehouse personnel to plan the total distribution of the bins in the forward and floating areas.

- They can also estimate the number of shelves and racks needed to store the bins.

An example of rack arrangement for the warehouse in the case study is shown in figure 5.3. The shelves are color coded and denoted with their assigned part categories. The visual output shows the overall arrangement of the shelves in the rack, the part number and the corresponding bin type alloted to each space. Miscellaneous information such as shelf priority number and R ranks for the parts are also shown in the given example. This simplified visual format can be placed at easily accessible locations in the warehouse. It assists the warehouse personnel while storing and picking parts and reduces overall time spent in looking for parts.

Class	Category	shelf	minz	maxz	Space	Space	Space	Space	Space
CD	Low	2	-0.21661	-0.21574	125-013506219	125-013464655	125-015262199	125-013504064	125-013504064
					Small	Large	Small	Small	Small
CD	Low	1	-0.21559	-0.20862	125-015260694	125-015264365	125-015261548	125-013504171	843-08087-000
					Small	Small	Large	Small	Small
CD	Med	1	-0.21617	-0.20242	869-00270-000	125-009757569	125-013511567	125-013509033	158-07692-000 12
					Small	Small	Small	Small	Small
CD	High	1			125-002516513	125-015262352	125-013549025	125-015269679	125-013513323
					Large	Large	Large	Large	Large
AB	Low	2	0.95686	1.3062	125-013509101	125-002766098	125-014603404	125-009272972	125-010610710
					Large	Small	Small	Small	Small
AB	Low	1	1.37883	4.05339	125-010491559	125-000504203	125-008352037	125-013284878	125-013165096
					Small	Small	Small	Large	Medium
AB	Med	1	0.82943	1.58903	125-000213321	125-001962017	125-002769041	851-07655-000	125-004367329
					Small	Small	Small	Small	Small
AB	High	1	0.79704	1.45563	125-007979295	125-001794324	125-007638901	872-07532-000	125-015135934
					Large	Large	Large	Large	Large

Figure 5.3: Sample layout of parts and corresponding bins on a shelf

In a summary, the algorithm presented in this example provides a quick estimation of total racks needed, rack layout and distinguishes priority racks.

5.2 Future Work

In this thesis, each of the two methodologies explained in chapters 3 and 4 were applied to two independent case studies. Although this was a delimitation of the available project scope and time, it would be ideal to conduct a single case study in high-mix, low volume or service centric organization where both of them are applied in the recommended sequence. Taking a step ahead, the application of these new methodologies may also be repeated in different

warehousing scenarios in order to verify the extent of their usage. Other additional areas of the thesis that can also be looked into are; (1) The identification of methods to cluster bin sizes apart from K-means algorithm and compare results. (2) A cost benefit analysis of the redesigned warehouse after using these methodologies will be an area of interest.

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Appendix

Appendix A

Excessing SOP for Case Study

The following section outlines the obsolete part excessing SOP for the case study organization. The SOP is used to create a pilot trial for the organization. The feedback of from the pilot trial helps improve the quality of the SOP contents can be used to create the final version for company-wide implementation.

Conducting excessing activity

- One member of each group is appointed as team leader for the pilot. The team leader will assemble a team for the pilot and will be in charge of briefing team members about the study, monitoring its execution, and compiling results and feedback.
- The Excessing Folder has been created to serve as an instruction manual for executing the pilot study. This compilation contains detailed technical inputs which can be followed exactly to complete the study.
- The term SKU (Stock Keeping Unit) is used in the rest of the document. It is used in tagging to denote an inventory unit for a part or item. For example, a single item, a box with 20 items, or 4 pallets with 100 items each could all be an SKU from the point of view of the organization.

Obsolete Unit Identification and Excessing

- Preparation
- Tagging
- Excessing

During Preparation, a communication plan for obsolete identification and excessing is designed. This plan is key to successful, periodic obsolescence audits within the organization which will keep the level of obsolete SKUs at a minimum in a sustainable manner. We will assume that communication policies will be developed in parallel with the pilot study; in other words, testing the Preparation phase is only a limited objective of the pilot.

Tagging is the process of physically surveying the inventory and assigning tags to each SKU in the survey to determine whether it is obsolete. Tagging requires standard procedures for filling in tag details and assigning a tag to an SKU. In the absence of well-tested tagging policies, the entire obsolescence exercise fails. In the absence of a reliable tagging system, the operation runs the risk of either accumulating obsolete SKUs or discarding valuable assets. With this in mind, Tagging is the focus of the pilot study and each of the steps under Tagging are going to be executed during the pilot.

Finally, once obsolete SKUs have been identified during tagging, Excessing is the process of physically moving such SKUs out of the organization's stocks and inventory. Excessing is a logistics operation which involves formalities and communications which are well understood within the organization. Thus, these procedures and formalities will not be tested during the pilot study.

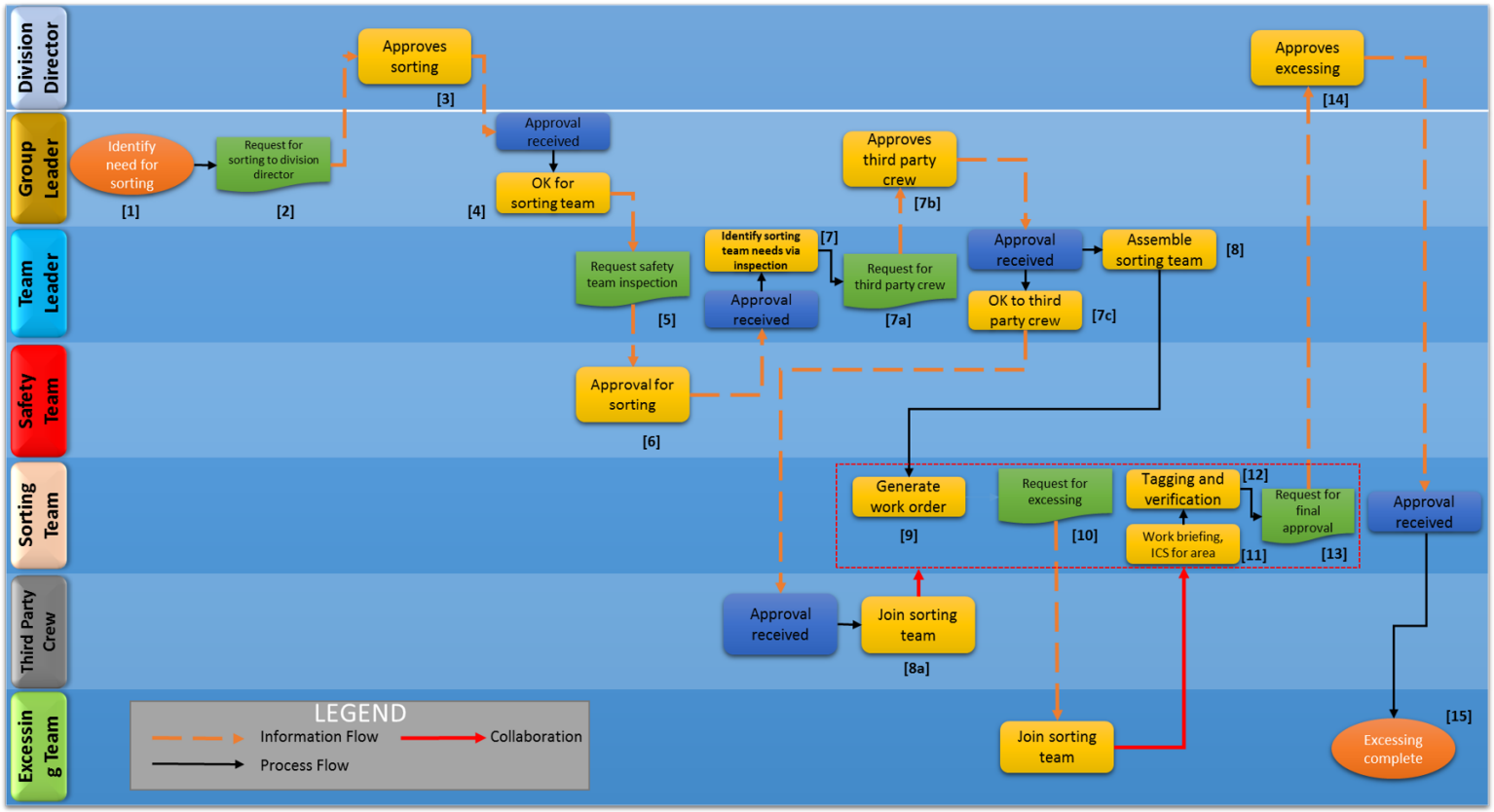

Figure A.1: Swim lane for excessing

The flowchart of these steps is shown in figure A.1. Although the pilot focuses on tagging and partially on preparation, each of the steps in the obsolete identification and excessing process has been explained in this section for completeness.

Preparation

Details in Preparation are visually represented as a swim lane chart in figure A.1. Please note that the swim lane notations developed in chapter 3 are not used here due to document size constraints. A simpler version of swim lane map is used instead for printing purposes. The modified swim lane should be developed in a compatible software such as MS Visio and shared with all stakeholders.

1. The group leader identifies the need for sorting to initiate the sorting process. Different groups within the organization could have different points of origin for identifying this need. For example, an engineer or technician could notify the group leader of accumulated inventory or stock levels.

2. The group leader requests the division director for permission to sort and tag SKUs. This information flow could be electronic or paper-based.

3. The division director sends an approval for sorting via email.

4. The group leader notes the sorting approval and appoints a team leader to organize and oversee the sorting exercise.

   *Pilot Study: Assemble team and prepare for tagging

5. The team leader assembles a safety team, tasked with determining whether there are any hazardous materials or conditions at the pilot study site.

6. The team leader instructs the safety team to inspect the materials to be sorted.

7. The safety team enter the site and looks for any hazardous or radio-active material; team leader is notified of the safety approval.

8. The team leader identifies sorting needs via inspection. This helps determine the composition of the sorting team such that all the expertise needed to make tagging decisions is available. Key points for selection are:

   (a) Experience with the types of SKUs being tagged.

   (b) Knowledge of the short and long term usage needs and history of an SKU

   .

9. The team leader checks whether a third party crew is required for sorting. If not required, step 10 is executed. Otherwise:

   (a) The team leader requests the group leader for a provision of the third party crew.

   (b) The group leader notifies team leader of approval for third party crew.

   (c) After the team leader receives the approval from the group leader, the third party crew is assembled.

10. The team leader assembles the sorting team based on sorting needs. If required by the team leader, the third party crew joins the sorting team.
    *Pilot Study: End team assembly phase.

Tagging

Each SKU in the pilot area is tagged and those marked obsolete are assigned an additional red tag. This section describes the details of the tagging process. These details have to be entered in a tabulated sheet to serve as a record for future tagging exercises and to act as feedback for the management.

1. The sorting team and the third party crew together generate a work order for excessing.

2. Request for excessing: Place a request in the system to an Excessing team based on excessing logistics at the organization. This will deliver an advance notice to excessing teams with a potential work order after the anticipated tagging timeline.

*Pilot Study: Team leader briefs team

3. Work Briefing: It is assumed that the pilot study area has been identified during the Preparation phase and that a Tagging kit is ready to be handed out to team members.

   (a) Tagging kit:

      i. Pilot Study folder (sufficient paper copies)

      ii. Red tags (for obsolete SKUs)

      iii. White tags (for details such as SKU number, location and misc. information)

      iv. Color Markers- (blue, red)

      v. Pen/pencil

      vi. Chalk (area marking)

      vii. Camera

   (b) Area allotment or sequence:

      i. Team leader identifies SKUs/areas that need specific expertise for identification, so that specific team members can be assigned these areas.

      ii. Team leader allocates work within the sorting team as per these specific needs. If no specific needs exist, allocate work such that the time to complete the study is minimized.

      iii. Team leader discusses the tagging task with each assignee and gets their final go ahead to proceed with the exercise.

      iv. The Team leader may mandate duplicate tagging exercises at a specific area (e.g. A safety assignee marks SKU as being safe for inspection. The second assignee then evaluates for obsolescence).

4. Tagging and verification:

(a) Each SKU should be assigned a WHITE tag with SKU details coded on it. Based on their attributes, some of the SKUs are deemed obsolete and are assigned a RED tag.

List No.	SKU Description	Assigned Control Number	Assigned Current Location	Value category	Non-Obsolete Attributes						Disuse Duration (Days)	Obsolete Tag #	Obsolete Attributes	Remarks
					Critical Spare	*Safety Related*	*Tracking Docs.*	*Available Shelf Life*	*Supplementary Attributes*	*Suggested Attributes*				
1														

Figure A.2: "Format for SKU Excessing"

(b) The "Format for SKU Excessing" sheet shown in figure A.2 is used to collect information about each SKU (A partial image is presented for brevity). Each SKU information is filled into a single row in the sheet.

(c) The team leader demonstrates the process of filling out a tagging sheet. This is done using either a real SKU or a mock up box with SKU attributes printed and attached to it.

(d) Each assignee is handed over a tagging kit and directed towards their designated section. The team leader notes down the time required for each assignee to complete their task.

*Pilot Study: End team briefing phase

(e) Each assignee fills out the"Format for SKU Excessing" sheet for their designated area.The details of each column in the sheet is explained as follows:

i. Column descriptions:

A. List No: This field is pre-filled. It is a unique SKU number for each SKU.

B. SKU Description: Company name and product/model name OR User-defined description:

- The length of description should be 4-6 words.

- Extra comments should be added in the remarks column.

C. Assigned Control Number:

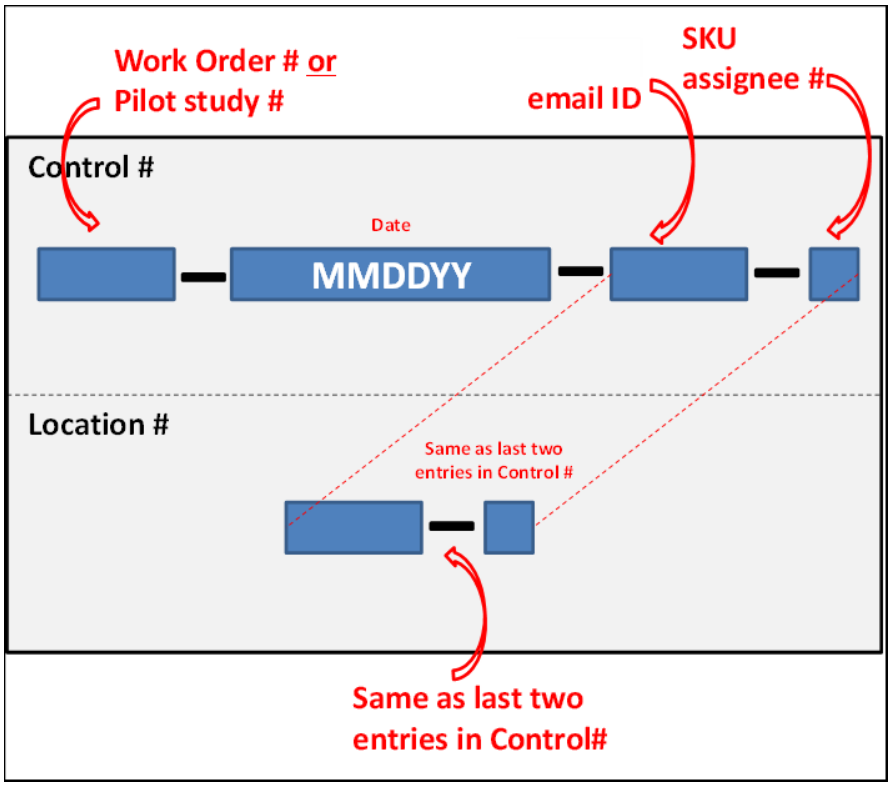

Figure A.3: Example of white tag

- This number is added to the Control Number section on the WHITE tag as shown in figure A.3.
- The first field is assigned by the team leader.
  - If the tagging exercise has an organization Work Order #, enter that number.
  - Else, the team leader generates an arbitrary number for the current tagging exercise and shares it with assignees.
- The second field is the date in MMDDYY format.
- Third and fourth fields are the Location Number, generated as described in the next section.

D. Assigned Current Location:

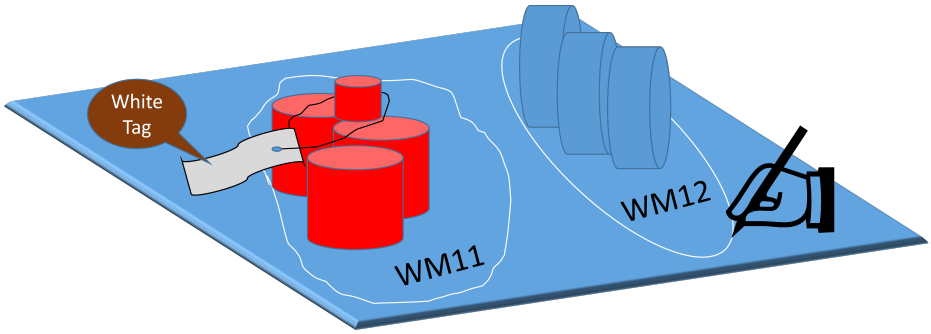

Figure A.4: Location marking example

- The periphery of an SKU is marked using a marker as shown in figure A.4.
- The third field of the Control Number on the WHITE tag is the employees ORNL email tag, e.g. jdoe@xxx.xxx will write jdoe in this field.
- Fourth field of Control Number is a serial number generated by assignee. For e.g., the first SKU to be tagged by assignee during this exercise will be 01, second 02, etc.
- Write the generated Location Number, e.g. jdoe 01, on the WHITE tag under Location #.
- Write the generated Location Number inside the SKU chalk periphery.

E. Value Category:

Table A.1: Value category codes

Part Value	Category	Highest Excesssing Authority
Less than $1,000	D	Team Leader
$1,000 - $25,000	C	Group Leader
$25,000 - $100,000	B	Group Leader
Greater than $100,000	A	Division Director

- Assign value category to the SKU using the table A.1.
- Value category denotes the highest value authority for an SKU. It helps in excessing decisions but does not influence the decision to tag an SKU as obsolete.

F. Non Obsolete Attributes:

- These attributes allow an SKU to be clearly identified as non-obsolete.
- The first four attributes are defined by the organization. Enter YES in the field if attribute valid for the SKU.

Table A.2: Supplementary attributes (X1)

Non-obsolote		**Obsolete**	
Attribute	***Code***	***Attribute***	***Code***
Commercial Availability	CA	System up-gradation/design change (for increased performance or demand)	DC
Excessive lead time of updated spare	LT	Extended disuse	ED
High cost of updated spare	CT	Cheaper spare	CS
Critical to operation	CO	Ease of implementation of replacement parts	EI
Mode/probability of failure	PF	Availability of replacement parts	AR
Functional spare(still used)	FS		

- 'Supplementary Attributes' are a list of other applicable attributes. Enter applicable Supplementary Attribute codes from figure A.2.
- 'Suggested Attributes' are additional non-obsolete attributes that the assignee may identify during the pilot. Enter a short description (4 to 8 words) and note additional comments in the remarks column.

G. Disuse Duration: Enter the number of days since last recorded usage. In the case of approximation, e.g. year, quarter, etc., enter whole numbers like 365 and 90 respectively.

H. Obsolete Attributes:

- If all the 'Non-Obsolete Attributes' fields are blank, a RED tag is assigned
- Under Obsolete Tag #, note the serial number on the tag.
- Under Obsolete Attributes, enter the appropriate Obsolete Attribute codes from figure 6.
- If no code matches the reason for obsolescence, enter a short description of the reason in the remarks column.

  If SKU is obsolete, attach RED tag to the SKU

I. Remarks: Additional details for an SKU that cannot be covered in the any of the fields (e.g. SKU description, location, attributes, company inventory number, etc.) in the excessing format are noted down in this column.

ii. Summarizing exercise:

A. A summary of the tagging operation is necessary for company records and for generating feedback.

B. Photographs: Each assignee takes multiple photographs of every assigned SKU. The photographs need to clearly show: (1) the SKU, (2) White tag, (3) Red tag if obsolete. This will help visually identify the SKUs for which the pilot was conducted.

C. Feedback Form:

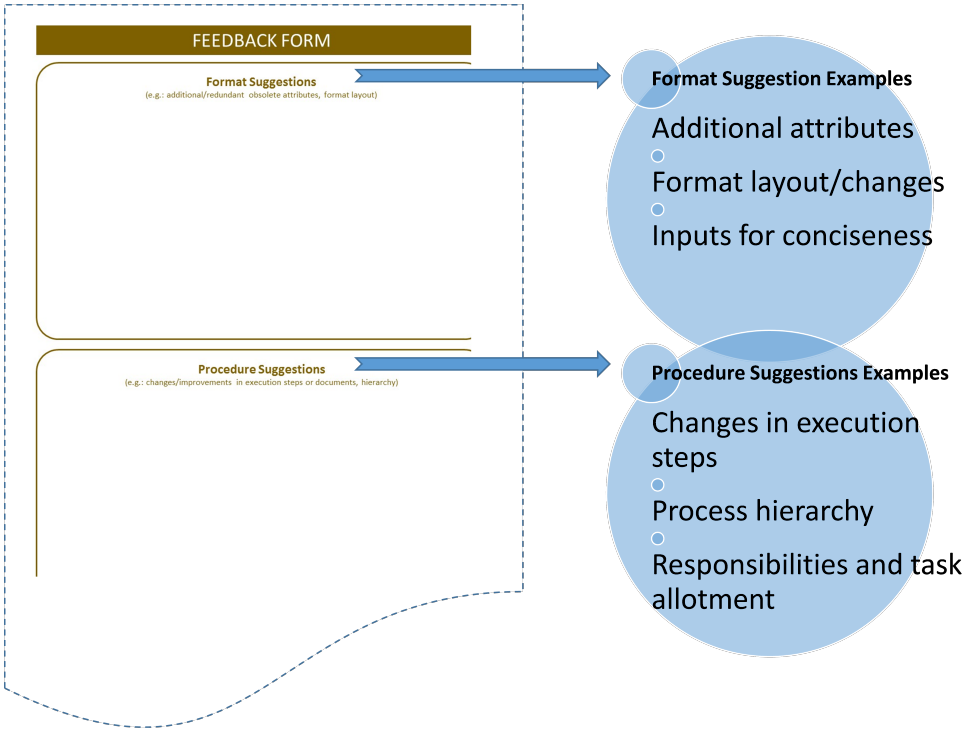

Figure A.5: Feedback form

- Figure A.5 shows a sample feedback form. Each assignee will record issues or suggestions in the feedback form to highlight deficiencies in the tagging process under 'Format Suggestions' and 'Procedure Suggestions.'
- The Feedback Form can also be used to explain issues for individual items, after correctly citing item references e.g. list number.
- This feedback is vital towards developing a long-term and sustainable obsolete tagging procedure.

  *Pilot Study: End of assignee tagging phase
- The team leader compiles all the assignee tagging results. The team leader also creates a consolidated summary of new attributes, issues, and suggestions following discussions with the group.

  *Pilot Study: End of Summarizing phase

Excessing

1. The sorting team sends an approval request to the division director so that final excessing activities may be initiated.

2. The division director either approves the excessing or sends back recommendations to the team. The team studies these recommendations and modifies the procedures if necessary. This feedback cycle continues until the division director issues final approval for excessing. Necessary changes are made further and sent back to the sorting team.

The pilot study does not incorporate any procedures or recommendations for SKU excessing. It is assumed that the excessing process is well understood and documented at the organization, and modifications, if necessary, will be made internally.

Vita

Gurudatt Sanil was born in Mumbai, India on December 18, 1986, to Revati Sanil and Bhaskar Sanil. He completed high school in 2002. He enrolled in Production Engineering Bachelors Degree program in Fr. CRCE (Mumbai University) in 2004 and graduated in May 2008. He came to Knoxville, TN in Fall 2011 to pursue graduate studies. Gurudatt started his Masters degree in Industrial Engineering at University of Tennessee, Knoxville. As a graduate research assistant working for Dr. Rupy Sawhney, he worked on projects in Lean, warehouse design and inventory management. He completed his Masters degree in Fall 2017.