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The Brazilian Air Force Uniform Distribution Process: Using Lean Thinking, Statistical Process Control and Theory of Constraints to Address Improvement Opportunities

Luciano A. Dos Santos

THE BRAZILIAN AIR FORCE UNIFORM DISTRIBUTION PROCESS: USING LEAN THINKING, STATISTICAL PROCESS CONTROL AND THEORY OF CONSTRAINTS TO ADDRESS IMPROVEMENT OPPORTUNITIES

THESIS
MARCH 2015

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Abstract

In the Brazilian Air Force, all enlisted Soldiers and Corporals (corresponding to USAF ranks from Airman Basic to Senior Airman) are entitled to receive their uniforms from their assigned, respective organizations, free of charge. An important portion of the uniform's distribution process is accomplished by the Brazilian Air Force Intendancy Central Depot (ICD). This organization carries the uniform inventory and performs the selection and distribution activities, following the guidance of the Sub-directorate of Supply. ICD process performance data for the peak distribution seasons of 2012 and 2013 was collected and analyzed. Several indications of inefficiencies became apparent, exemplified by a high number of late and partially fulfilled orders. This study applied fundamental principles of Lean Thinking, Statistical Process Control and the Theory of Constraints to identify potential areas for process improvement. Through statistical analyses, a simulation effort and capacity analysis, the negative impacts of variability throughout the process were assessed and several types of waste were recognized. Potential solutions to address the problems identified were suggested, as well as areas for further research.

To my dearly loved wife, for your patience and understanding throughout this endeavor. Your sacrifices did not go unnoticed. To my beloved children for your patience during the long hours of absence and dedication to this academic program. My love and gratitude will be yours forever.

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Luciano Antonio Araujo dos Santos

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I. Introduction

Purpose

The purpose of this research was to analyze a process performed by the Supply Division of a Brazilian Air Force (BAF) military organization named Intendancy Central Depot (ICD), under the lens of Lean Thinking, Statistical Process Control and Theory of Constraints. This study had the view of identifying opportunities for improvement, as well as applicable performance evaluation metrics that could be applied to the process, in order to drive management actions towards quality and performance enhancement.

Background

In the Brazilian Air Force, all enlisted Soldiers and Corporals (corresponding to USAF ranks from Airman Basic to Senior Airman) are entitled to the right of receiving their uniforms from the respective organizations they are assigned to, free of charge.

In order to accomplish the task of making the uniforms and other types of materials arrive at their correct destinations in due time and at the right quantities to meet all BAF organizations' requirements, the Air Force Directorate of Intendancy (DIRINT) has designed a system named

Provisioning System (PROVSYS). This system is responsible for planning and developing the provisioning activity for all types of items under DIRINT's scope of management.

A clear comprehension about what BAF understands as "provisioning activity" is very important at this point. According to the Provisioning System Norm (NSCA 168-1/2002), provisioning activity is the set of procedures composed of the determination of needs, purchasing, storage, distribution and management of materials under DIRINT's responsibility. The uniforms that are intended to be properly distributed to the various BAF organizations' troops constitute the largest volume of materials managed under PROVSYS' scope.

PROVSYS is composed of a number of organizations that work in a coordinated manner in the various steps of logistical support related to the items concerned. Each organization has a well-defined role in the process, with clear responsibilities, with the ultimate objective of making sure that the system works in a coordinated manner, so no airman would be left without the uniforms they are entitled to.

The process developed under PROVSYS management starts with the collection of all BAF Organizations' needs, in terms of what types of uniforms they will distribute to their troops in the following year and in which quantities. All the information is sent from the various organizations throughout the country to the main executive organization of PROVSYS: the Sub-directorate of Supply, located in the city of São Paulo. The transmission of those pieces of information is done in an electronic manner, via BAF ERP system, the Materiel and Services Logistics Integrated System (MSLIS).

After receiving all inputs from the various BAF organizations and consolidating their needs, the Sub-directorate of Supply performs the acquisition process, in accordance with

Brazilian purchasing legislation. By centralizing uniform acquisitions for the entire Air Force, some advantages like economies of scale and enhanced product standardization and quality control are attained.

Most of the uniforms purchased by the Sub-directorate of Supply are delivered by vendors at another BAF Organization: the Intendancy Central Depot (ICD), located in Rio de Janeiro. Only a small fraction of PROVSYS' total inventory is held at SDAB. The vast majority of items is received and stored by ICD, in one of its two warehouses, and from there they are distributed nationwide. The distribution is carried out either by ICD itself, using its own truck fleet, or by other BAF organization, named Air Force Logistical Transportation Center, also located in Rio de Janeiro. Sometimes the material is transported by its own organization where it is intended to go.

Since the Sub-directorate of Supply is the organization that holds the information on all Air Force needs in terms of uniforms to be distributed, it is also responsible for informing ICD about the types and quantities of pieces of uniform to be delivered to each organization. Even though most of PROVSYS' inventory is held at ICD, as mentioned before, the Sub-directorate of Supply is the organization that actually manages it, determining reorder points and authorizing the distribution by means of documents named Provision Orders (PO), issued electronically to ICD within MSLIS. Each PO relates to a particular organization and establishes which pieces of the uniform, identified by the respective Part Number (PN), are to be picked from the inventory and distributed to that organization. The issuance of a PO by the Sub-directorate of Supply authorizing the ICD to start the distribution of the items concerned is the event that triggers the process subject to the present research.

Every year, starting in the month of May, a three-month long manual count of ICD's inventory is carried out by ICD's Supply Division staff, with the help of members of other sections of the organization. The main objective of this count is to promote the necessary adjustments in the inventory records in MSLIS, and therefore, allow the Sub-directorate of Supply to issue the POs as accurately as possible, by including in each one only items and quantities actually existing in the inventory. The count process is partially automated by means of barcode scanning in one of ICD's warehouses (warehouse 2 – W2), but entirely manual in the other one (warehouse 3 – W3), which is also PROVSYS' largest warehouse.

Once the count is finished and the inventory level of each item is updated, the Sub-directorate of Supply issues all POs at once, which usually happens in the last week of July. Upon the POs' receipt, the Supply Division authorizes their selection at each warehouse according to a schedule previously planned by the Division management. Once the items of a particular PO are designated, they are accordingly packed and sent to their destination. From the moment a particular PO is authorized for picking by Supply Division management to the moment the related items are effectively received and approved by their destination set the boundaries that define the process subject to this study, which will be explained in more detail in chapter IV.

Problem statement

After collecting and analyzing the data from the process of distribution of PROVSYS' uniforms at the ICD level, during the years of 2012 and 2013, from the moment a Provision Order is authorized for inventory selection up to the moment the material is delivered to the destination, it was possible to conclude that there is much evidence of inefficiencies that are negatively affecting the process performance and quality. Apparently, variability also seems to play a detrimental role in the overall process performance and quality. Additionally, there doesn't appear to be a procedure or metric currently in place in the Supply Division to track those inefficiencies and variability, with a view to guiding management actions toward overall process performance and quality improvements.

Theoretical lens

The problem stated above was delineated after analyzing the data under some key concepts of Lean Thinking, Statistical Process Control and the Theory of Constraints. Therefore, these three theories constitute the basic theoretical framework that guided the research. Several performance and quality characteristics of the process under study, as well as related documentation were examined according to some of the main principles of these theoretical models in order to produce the results that will be explained further. Theoretical models of process performance measurement and appropriate performance metrics were also scrutinized and played an important role in this research. Further details on the theoretical background will be presented in chapter II of this paper.

Research objectives

The primary objective of this research was to identify potential inefficiencies that could be recognized as "wastes" under the Lean Thinking, proposing potential solutions according to the literature on this subject, with a view to enhancing overall process performance and quality standards. This was accomplished through the application of the theoretical framework outlined above to the share of the process of uniform distribution that was performed by the ICD's Supply Division.

Secondary objectives of the present research were as follows:

1. Establish how the process of distribution of PROVSYS' uniforms is structured and executed at the ICD level;

2. Study the impact of variability and the types of waste recognized in the process on overall process performance and quality;

3. Understand which metrics, if any, were in place at the ICD's Supply Division and how they have been used to guide behaviors toward process improvements;

4. Identify which performance and quality measures would be appropriate to allow Supply Division management to keep track of the different forms of waste and guide their actions towards process improvements;

Research Questions

In order to address the objectives outlined for this study, some research questions needed to be answered, as follows:

1. How is the process structured, from the moment a PO is authorized until the moment the material is received at the destination?

2. What factors are taken into consideration when the schedule of activities is planned by the Supply Division management?

3. What is the impact of variability in the process performance?

4. Which of the Lean Thinking's types of waste can be found in the process and how are they affecting the process performance?

5. What metrics are currently being taken from this process by the Supply Division Management Team?

6. What metrics could be implemented in order to better drive actions toward performance and quality improvement?

Methodology

The present research can be considered as a case study, according to Leedy and Ormrod (2013), once it reveals the conclusions after studying a particular event in depth for a defined period of time. Nevertheless, although primarily qualitative in essence, it was possible to perceive both quantitative and qualitative dimensions in this study. Therefore, the present research can be classified as a mixed-methods research. Still, according to the above-mentioned authors, “such research involves not only collecting, analyzing and interpreting both qualitative and quantitative data but also integrating conclusions from those data into a cohesive whole”.

The quantitative aspect of this research could be revealed, for instance, by the statistical tests, like Kruskal-Wallis for nonparametric data, that was applied to the collected data (related to the years of 2012 and 2013) in order to grasp important aspects of process performance.

Another important tool utilized on the quantitative side of the research was computerized simulation, for which it used the ARENA software, professional edition, version 12.00. By using this tool it was possible to obtain many important figures regarding performance and quality issues in the process.

Nevertheless, many important pieces of information for this research were also obtained by means of qualitative methods, like an unstructured interview, which was conducted by this researcher with the head of the ICD’s Warehouses Section.

Also, qualitative analysis on several documents and regulations issued by ICD and other BAF organizations were also developed, with a view to determine an as clear and accurate as possible understanding of the situation of the process under study. More details on the methodology used in this research will be provided in chapter III.

Assumptions and limitations of the study

This research was primarily based on data collected from ICD's Supply Division, which were manually-generated during the process of inventory selection and distribution that occurred during the years of 2012 and 2013. Therefore, since those data were produced by hand, they may possibly be prone to carrying some imprecision, but it is assumed that those inaccuracies are minor and do not interfere severely in the results of this research. Also, most of the records originally found containing errors were either corrected or eliminated from the analysis. Therefore, it is assumed that the dataset used in the analysis is a fairly accurate representation of the process performance during the years of 2012 and 2013.

As for the interview that was conducted, it is assumed that the answers provided by the head of ICD's Warehouses Section are accurate representations of reality, since the interviewee was directly involved in the process researched during the period under consideration and since he is a specialist in Supply Management, having many years of experience in this field.

It was not the intention of this research to address demand forecasting and inventory control issues that might be potentially occurring, once those activities are performed by an organization external to the process boundaries (Sub-directorate of Supply), with very little or no influence by ICD. Nevertheless, whenever an external factor could potentially be playing a role in the process, it was noted and considered, but in-depth investigations on them were out of the scope of this study, which was as much as possible strictly focused on internal aspects of the process.

Organization

The present paper is organized in the following manner:

Chapter I offers the necessary background to understand the context of the process under study as well as provides the purpose, the problem that was brought to this researcher's attention, the objectives of this research and the research questions. Chapter I also provides an overview on the theoretical background that guided the analysis and on the methodology, along with some of the assumptions and limitations applied to this study.

Chapter II outlines the theoretical framework utilized by this research for data analysis, by means of a comprehensive literature review on Lean Thinking, Six Sigma, Theory of Constraints and on metrics and measurement aspects.

Chapter III addresses in more detail aspects of the Methodology, particularly with respect to the procedure for data collection, statistical analyses and simulation efforts.

Chapter IV presents the analysis and the results obtained after applying the delineated methodology and theoretical framework in the attempt to address the research problem and questions.

Chapter V presents the conclusions of this research, as well as recommendations for further investigation in the area.

II. Literature Review

Overview

This chapter explores the theoretical background that guided the analysis performed in the present research. It contains aspects from Lean Thinking, Theory of Constraints and Statistical Process Control. It also provides an overview on the evolutionary course that has led to the modern view of work as a process or collection of processes, an underlying ground that pervades all the examined theories.

The division of labor versus the process view of work

Michael Hammer and James Champy, in their book *Reengineering the Corporation, A Manifesto for Business Revolution* (1993) provide an interesting case to exemplify that "often the efficiency of a company's parts comes at the expense of the efficiency of its whole":

> A plane belonging to a major U.S. airline was grounded one afternoon for repairs at airport A, but the nearest mechanic qualified to perform the repair worked at airport B. The manager at airport B refused to send the mechanic to airport A that afternoon, because after completing the repair the mechanic would have had to stay overnight at a hotel and the hotel bill would come out of manger B's budget. Instead, the mechanic was dispatched to airport A early the following morning; this enabled him to fix the plane and return home the same day. A multimillion dollar aircraft sat idle, and the airline lost hundreds of thousands of dollars in revenue, but manager B's budget wasn't hit for a $100 hotel bill. Manager B was neither foolish nor careless. He was doing exactly what he was supposed to be doing: controlling and minimizing his expenses (Hammer & Champy, 1993).

The example provided above is a good illustration of the fact that in many occasions an outstanding performance of isolated segments does not assure a good overall performance of a company. This assertion is one of the fundamentals of the Theory of Constraints, first presented by Eliyahu M. Goldratt in his book *The Goal* (1992), and actually constitutes the departing point the author uses for the whole construction of his theory.

The Goal, first presented to the public in 1984, occupies the tenth position in a list elaborated by the *Time* online magazine of the 25 most influential business management books of all times (Rawlings, 2011). Even though it is recognized as an important business book, it is presented in a quite unusual way for such kind of a publication. It is actually a novel, narrating in first person the three-month journey of the main character, the plant manager Alex Rogo, in his attempt to turnaround an unprofitable and inefficient plant. Therefore, he would hopefully be able to prevent it from being shut down by the vice president of the Division to where it belongs.

Alex is guided through this endeavor by Jonah, “the thinly-disguised alter ego of Eli Goldratt, who through the Socratic approach, assists Alex in finding his own solutions” (Trigger, 1990). In this way, as the story develops, the author explains his theory through Jonah’s exhortations for Alex to deeply analyze the process under his management and understand why almost no orders are shipped on time and piles of work-in-process inventory are accumulating throughout the plant.

The discussion between Jonah and Alex is triggered by an apparent contradiction between increasing local efficiencies and enhancing the company productivity as a whole. At a certain point, in a casual encounter between the two characters at the airport, Alex mentions to Jonah that the efficiency of his plant had a thirty six percent increase due to the installation of robots in some departments. However, Jonah questions this alleged improvement by making Alex think about what an increase in productivity really means. As the discussion develops, it becomes clear that the notion of productivity increase can be easily mislead by erroneous measurements or, even more seriously, by the incorrect concept of the real significance of the word productive. The conclusion is that even though local efficiencies are good, the whole plant is not more productive if it is not capable of earning more profits, shipping more products or reducing the total expense, just to name a few aspects.

In this way, this starting point for the discussion presented by Eli Goldratt reveals an underlying concept that is absolutely essential for the development of the Theory of Constraints and for many other management theories and Total Quality Management approaches, like Lean Thinking and Six Sigma: it is no longer acceptable for the managers of a company to focus their efforts on increasing the productivity of each sector separately. They need to take into consideration that each one is actually part of a whole system, whose parts need to work connectedly in order to achieve a purpose. In other words, "it is no longer necessary or desirable for companies to organize their work around Adam Smith's division of labor. Task-oriented jobs in today's world of customers, competition and change are obsolete. Instead, companies must organize work around *processes*" (Hammer & Champy, 1993).

The principle of the division of labor mentioned by Hammer and Champy was set by the economist Adam Smith in his book *Wealth of Nations*, published in 1776. According to him, "the key to economic efficiency is specialization – the division of labor" (Butler, 2011). Still according to Smith's theory, the enormous gain in productivity when the division of labor is implemented derives from three main aspects: (1) the skills of a person who performs the same task several times increase more rapidly; (2) it demands less time to move from one task to another; (3) specialization allows the usage of dedicated machinery, which cuts down production times and effort.

This approach has drastically influenced the way that companies organized themselves to perform their productive activities. Henry Ford's moving assembly line was actually an improvement on “Smith’s concept of dividing work into tiny, repeatable tasks” (Hammer & Champy, 1993).

The influence of Smith’s concepts remains important to the present days:

> Today’s airlines, steel mills, accounting firms, and computer chip makers have all been built around Smith’s central idea – the division or specialization of labor and the consequent fragmentation of work. The larger the organization, the more specialized is the worker and the more separate steps into which the work is fragmented (Hammer & Champy, 1993).

Adam Smith’s ideas had great influence not only over manufacturing activities themselves but also over management practices. Alfred Sloan, “the successor to General Motor’s founder William Durant, created the prototype of the management system that Ford’s immensely more efficient factory system demanded” (Hammer & Champy, 1993). According to Sloan’s method, each division of the factory was to be managed in a decentralized manner. Managers should aim their efforts at obtaining from their respective division the best possible production and financial numbers. By implementing such method, “Sloan was applying Adam Smith’s principle of the division of labor to management just as Ford had applied it to production” (Hammer & Champy, 1993).

It is undeniable that the division of labor model applied to production and management alike led to a great increase in productivity, which “suited the circumstances of the postwar times perfectly” (Hammer & Champy, 1993). In those post-Depression and postwar eras, demand for products and services was greater than production, regardless of how efficient it was. Therefore, there was no huge demands for quality on the goods that were offered to the consumers by companies. “After the war, during the late 1940s and early 1950s, the shortage of civilian goods in the United States made production a top priority, and the push to produce large quantities of goods led to a decline in quality” (Evans & Lindsay, 1996).

However, times have changed. There are no longer shortages of products. Increased global competition, enabled by advancements in technology, telecommunications and transportation methods amongst other factors, has brought a tipping point.

During the 1950s and 1960s, when "made in Japan" was associated with inferior products, U.S. consumers purchased domestic goods and accepted their quality without question. During the 1970's, however, increased global competition and the appearance of higher-quality foreign products on the market led U.S. consumers to consider their purchasing decisions more carefully. They began to notice differences in quality between Japanese- and U.S.-made products and they began to expect and demand high quality and reliability in goods and services at a fair price. (Evans & Lindsay, 1996).

This means that at the present time, consumers have the chance to choose from different products or services, those that will better fulfill their unique and particular expectations. And whenever a consumer has the opportunity to choose products of better quality, he or she probably will.

Another aspect that deserves consideration in today's business environment is the velocity with which change happens. The pace under which innovations are introduced to the market by its various competitors has dramatically increased over the past years. "As marketplace change accelerates, business strategies themselves will have to change fast enough for companies to respond to emerging market needs and competitive threats" (Keebler, Manrodt, Durtsche, & Ledyard, 1999).

The three Cs – customers, competition and change – have created a new world of business, and it is becoming increasingly apparent that organizations designed to operate in one environment cannot be fixed to work well in another. Companies created to thrive on mass production, stability and growth can't be fixed to succeed in a world where customers, competition and change demand flexibility and quick response (Hammer & Champy, 1993).

The current business environment poses a significant challenge to managers who have to lead their industries, most of them organized around Smith's division of labor. "As the number of tasks grew, the overall processes of producing a product or delivering a service inevitably became increasingly complicated, and managing such process became more difficult" (Hammer & Champy, 1993).

Generally, companies today are organized in functional silos, fragmented pieces that perform tasks that are necessary to the production of a whole product or the provision of a whole service. However, usually no person is responsible for bringing a sense of unity to the whole process, which almost always needs to cross several sectors of the organization to be completed. "The fragmented processes and specialized structures of companies bred for an earlier day also are unresponsive to large changes in the external environment – the market" (Hammer & Champy, 1993).

However, companies have been increasingly devoting more importance to *process management* as an absolute imperative for the adoption of whatever TQM approach they have decided to implement.

> Process management is a concept that forces a focus on the flow of work independent of whether work is a product or service and independent of organization. The product or service output of a firm is the result of a series of work activities that comprise transformation of material and information. This set of work activities that produce an output is known as a *process*. (Melan, 1993).

All the above said brings us back to Alex Rogo and the difficulties in his plant. It becomes undeniably clear that the core problem that he was facing by the time he started his conversations with Jonah actually lied on himself. His view of management was strongly influenced by the fragmented model, with roots reaching as far as Adam Smith's concepts. In this sense, the whole Theory of Constraints construction can be understood as a framework for understanding a production process as whole unity, consisting of a number of pieces that may be appropriately coordinated to deliver a product in the most efficient possible manner. This is absolutely in line with the process view of work advocated by Hammer and Champy, according to whom "trying to fix what's wrong with companies by tinkering with the individual process pieces is the best way we know to *guarantee* continued bad business performance" (Hammer & Champy, 1993).

The Lean Thinking also strongly relies on the understanding of work as a process or collection of processes. One of the core aspects of this theory is to identify the value stream, which means, according to Womack and Jones (2003), to identify "all the specific actions required to bring a specific product (whether a good, a service, or, increasingly, a combination of the two)" from concept (design) to the hands of the customer. In other words, to specify a product's value stream can be understood as mapping its production process. One of the objectives in doing so is to eliminate wasteful steps from the process to the maximum possible extent. This can be most certainly understood as a process management implementation approach.

As far as Statistical Process Control is concerned, the understanding of the production of a good or service as a process is also an important underlying assumption. According to Evans and Lindsay (1996), "Statistical Process Control, or SPC, is a methodology in which operators, supervisors and managers use control charts to monitor the output from a process to identify and to eliminate special causes of variation". Still according to them, SPC is an important tool to be used to "adjust a process that has fallen out of control" (Evans & Lindsay, 1996).

Therefore, understanding the work of uniforms distribution developed by ICD's Supply Division as a process was the fundamental departure point for all the analysis developed in this research. Thanks to this understanding, it was possible to apply a plethora of aspects of a number of management theories to the process under study, with a view to identify several improvement opportunities. In the next sections, the aspects of these theories that were the most relevant for the analysis will be addressed.

Theory of Constraints

The Theory of Constraints (TOC) "states that the capacity of any manufacturing process is limited by its capacity-constraining resource (CCR) or constraint" (Levinson, 2007). Therefore, a constraint can be understood as the resource whose capacity limits the rate at which the system can function. Trigger (1990), citing Schragenheim and Ronen from their book *The Drum-Buffer-Rope Shop Floor Control: An Application of Theory of Constraints*, defines constraint as "anything that limits a system from achieving higher performance relative to its goal". In other words, it is the resource that limits the throughput of a process.

The definition of throughput is very important, since this is one of the three TOC's key metrics (the other two are Inventory and Operational Expense). This study has adopted a definition of throughput slightly different from that one espoused by the author of the TOC. According to him, throughput is "the rate at which the system generates money through *sales*" (Goldratt, 1992). In other words, throughput "consists of finished goods with customers (as opposed to finished goods that sit in warehouses in the hope of finding customers)" (Levinson, 2007). However, the definition of throughput that was adopted by this research is the one stated by Anupindi *et al*. (2012), for whom throughput is a synonym of average flow rate. According to them, average flow rate is "the average number of flow units that flow through (into and out of) the process per unit of time". (Anupindi, Chopra, Deshmukh, Mieghem, & Zemel, 2012). This definition was considered more appropriate to this research since it brings the time component into it, making the throughput as a rate of process outputs over time, which allows the application of Little's Law, among other benefits.

Another important metric that must be used in the evaluation of a process performance according to TOC's principles is Inventory. Goldratt (1992) defines Inventory as "all the money that the system has invested in purchasing things which it intends to sell". Even though this definition seems to describe inventory under a strictly financial point of view, it can be understood in broader sense. In several passages of the book the term inventory refers to the amount of work-in-process accumulated throughout the process. Even the hiking event, in which Alex Rogo had many insights about the definitions previously discussed with Jonah, serves to demonstrate that this and other concepts can be understood outside the environment of a manufacturing plant. In this way, here once again the definition of Inventory that was considered was the one expressed by Anupindi et al (2012): the total number of flow units present within the process boundaries. Under the TOC thinking framework, the smaller the amount of inventory within the process boundaries, the better.

Regarding the third metric considered by TOC (operational expense), it was defined by Goldratt as "all the money the system spends in order to turn inventory into throughput". Since it was not possible to collect financial data related to the process under study, this and any other financial metric was left out of the scope of the present research.

The three metrics (throughput, inventory and operational expense) were presented in *The Goal* as being an efficient set of metrics aimed at driving the company to its primary goal, as opposed to conventional financial metrics, as net profits, return of investments or cash flow. According to Goldratt, even though simple and somewhat intuitive in their essence, those metrics not only express the goal of making money perfectly well, but also permit the development of operational rules for running the plant.

Once the measurements that need to be used to evaluate process performance under the TOC's conceptual framework were presented, it is important to establish what they look for. In essence, those metrics must be applied to identify the resources that are constraining the entire system, or, in other words, preventing it from generating a higher throughput.

In this regard, there is a concept that is in strict liaison with the idea of constraint, which is the *bottleneck*. *The Goal*'s definition for bottleneck is "any resource whose capacity is equal to or *less than* the demand placed upon it" (Goldratt, 1992). Another applicable definition is the one stated by Anupindi *et al*. (2012): the bottleneck is the "slowest" resource pool of the process. This definition, in connection with the throughput notion, produces one of the most important corollaries of the TOC: "no process can produce output any faster than its bottleneck" (Anupindi, Chopra, Deshmukh, Mieghem, & Zemel, 2012). Therefore, one of the most important applications of the metrics advocated by Goldratt, especially the throughput and the inventory, is to find what the process bottlenecks are.

The identification of the system's bottlenecks (or constraints, in a broader sense) is the first one of five steps that embodies the core management measures that need to be adopted if the TOC is to be implemented by any organization. In his book *What is this Thing Called Theory of Constraints and How Should it Be Implemented?* (1990) Eliyahu Goldratt explains about the five steps of focusing. This discussion is summarized as follows:

1. Identify the system's constraints: as explained before, this step means to recognize what resource in the system is preventing it from achieving a better performance.

2. Decide how to exploit the system's constraints: once the bottleneck and non-bottleneck resources are identified, it is necessary to determine which treatment will be given to any one of

those resources. Especially with regard to the constraints, this means for instance to take all the managerial actions possible in order to not waste capacity on them. Rather, it is imperative to make sure that all the available capacity at this resource is fully employed, since the performance of the whole process depends on the performance of the constraint. Goldratt exemplifies this idea in *The Goal* at the moment that Alex Rogo shows to Jonah the machine that was identified as the bottleneck during a tour in the plant. The machine was not working at that moment, so Jonah explains that it is expected from any non-bottleneck resource a certain amount of idle time. However, for bottlenecks, it is exactly the opposite. Since the bottleneck is, by definition, a resource whose capacity is not able to meet all the demand, it is absolutely mandatory not to waste any minimal amount of the available capacity of this resource.

3. Subordinate everything else to the above decision: once it was recognized that the capacity constraining resource is the one that dictates the throughput of the process, a natural consequence is that all the system's steps must run at its pace. "Non-constraints must be managed so that they provide exactly what the CCR requires, at the right time" (Ingram & Scherer, 1992). This statement contains a number of highly important implications. For example, if upstream resources provide the bottleneck with more inputs than its capacity for processing them, an increase in work-in-process inventory is likely to happen. On the other hand, if the upstream steps do not provide enough inputs to the bottleneck, due to a machine downtime for instance, it would cause idle time on the CCR, which is by no means desirable, as discussed before.

4. Elevate the system's constraints: this step means simply add capacity by any possible means to the identified constraint, with a view to turn it into a non-bottleneck resource. After adding capacity to the CCR, eventually a new bottleneck will be revealed, which brings us to the fifth step.

5. If in the previous steps a constraint has been broken, go back to step 1: this step is what enables understanding the TOC as a framework to implementing a process of ongoing improvement. If the bottleneck firstly identified is no longer constraining the system, then some other resource is now playing this role, which leads to the need of returning to step 1 and performing the whole process again, in order to identify the new bottleneck. As Jonah states in *The Goal*: "bottlenecks are not necessarily bad – or good. They are simply a reality".

There is another aspect that is very important for the whole TOC construction: the recognition that virtually any activity, regardless if it is performed by humans or by machines, is subject to a phenomenon called statistical fluctuations. "This is the variation that makes it impossible to run a balanced factory at 100 percent capacity" (Levinson, 2007). In combination with dependent events, statistical fluctuations have enormous impacts on management strategies.

In a process, dependent events can be understood as activities that must be executed in a predetermined sequence, for the system to perform its functions. This happens, for instance, whenever an activity in the process uses as inputs what a previous step delivers as outputs. For example, in the process studied under this research, the transportation of uniforms to their destinations can only be executed after the material is selected from the inventory. Thus, those two activities (inventory picking and transportation) are dependent events.

The time consumed by each activity in the process can surely be measured, but it is very far from being *deterministic*. Rather, even though it may be forecastable within a certain range, sometimes with a high degree of precision, it cannot be previously established with one hundred percent certainty. This is what constitutes the statistical fluctuations. When combined with dependent events in the process, the result is that the degree of uncertainty associated with the process behavior leverages up.   This uncertainty is due primarily to one of the two following possibilities (Levinson, 2007): (1) work may not be available when a step in the process has the necessary capacity to process it (especially if this step is a CCR, the wasted capacity is lost forever); or (2) too much work may arrive from an upstream step, leading to an increase in work-in-process inventory and waiting time.

Stochastic variability in the process is a phenomenon that has been subjected to massive studies by management theories, given its enormous impact on process performance and, therefore, in companies profitability and success. Even though statistical fluctuations are a reality that cannot be avoided or neglected by managers, it is a mistake to consider them as untouchable fatalities with which everyone needs to live with. In fact, all the possible effort must be aimed at not only finding and managing bottlenecks in the system, but also at determining and reducing, to the maximum possible extent, all assignable sources of variation. At this point, statistical process control concepts and techniques play a very important role, since they provide managers with some powerful tools that enable a better comprehension of the behavior of the several variables involved in a process.

Statistical Process Control is directly related to the context of process quality management. After all, "regardless if a firm is producing a service or a product, it is important to ensure that the firm's processes are providing the quality that customers want" (Krajewski, Ritzman, & Malhotra, 2010). Thus, a few words about quality become necessary at this point, with a view to provide the context in which SPC is inserted.

The meaning of quality and quality improvement

As discussed previously in this chapter, the 1970s represented a tipping point in the consumer – provider relationship. Consumers started taking charge of this relationship, mostly due to increasing competition, leveraged by technology advancements. And one of the most important aspects companies compete on is quality.

Quality has become one of the most important consumer decision factors in the selection among competing products and services. The phenomenon is widespread, regardless of whether the consumer is an individual, an industrial organization, a retail store, or a military defense program. Consequently, understanding and improving quality key factors are leading to business success, growth and enhanced competitiveness (Montgomery, 2005).

No single and universally accepted definition of quality exists. "Neither consultants nor business professionals agree on a universal definition" (Evans & Lindsay, 1996). Heizer and Render (2010) argue that several definitions of this term are user-based, meaning, that quality "lies in the eyes of the beholder". Still according to them, to production managers, quality means conforming to standards and "making it right the first time". The authors point out a third approach, which is product based, viewing quality "as a precise and measurable variable. In this view, for example, really good ice cream has high butterfat levels." (Heizer & Render, 2010).

Garvin, in his *Competing in Eight Dimensions of Quality* (1987) provides a discussion of eight components, or dimensions of quality. Montgomery (2005) summarizes those eight dimensions as follows: (1) performance – will the product do the intended job? (2) reliability – how often does the product fail? (3) durability – how long does the product last? (4) serviceability – how easy is it to repair the product? (5) aesthetics – what does the product look like? (6) features – what does the product do? (7) perceived quality – what is the reputation of the company or its product? (8) conformance to standards – is the product made exactly as the designer intended?

One traditional and broadly accepted definition of quality "is based on the viewpoint that products and services must meet the requirements of those who use them" (Montgomery, 2005). This notion brings the *customer* as the ultimate entity empowered to the capacity of defining what quality is. Derived from this understanding, "by the end of the 1980s, many companies had begun using a simpler, yet powerful, customer-driven definition of quality: *quality is meeting or exceeding customer expectations*" (Evans & Lindsay, 1996).

Evans and Lindsay (2006) bring to attention that the term customer can assume two different connotations: internal and external customers. An external customer is the one that most people think of as the ultimate purchaser of a product or service, and it can be a person or a company. However, "every employee in a company also has internal customers, who receive goods or services from suppliers within the company" (Evans & Lindsay, 1996). Most businesses, according to this understanding, consist of such "chains of customers". This understanding, as well as the broad scope of quality being widely recognized, enabled the emerging of the Total Quality Management (TQM) philosophy, as comprehended as "a people-focused management system that aims at continual increase in customer satisfaction at continually lower real cost. TQM is a total system approach (not a separate area or program)" (Evans & Lindsay, 1996).

The expression *continual increase in customer satisfaction* contained in the definition of TQM can be rewritten in other terms simply as *quality improvement*. Montgomery (2005) exemplifies what he understands about quality improvement by commenting about the results of a comparative study performed by one of the automobile companies in the United States about a transmission that was manufactured in a domestic plant and by a Japanese supplier. The study indicated that there were much lower costs related to warranty claims on the Japanese-produced transmission as opposed to the U.S.-manufactured one.   After sampling some critical characteristics of both transmissions and performing statistical analyses on the tolerances, the company found out that the items produced by the Japanese plant displayed a considerably lower amount of variability within the tolerance specifications. Therefore, Montgomery (2005) had the evidence to present what he calls a modern definition of quality: "quality is inversely proportional to variability". Consequently, for this author, "quality improvement is the reduction of variability in processes and products".

This is the fundamental departing point that justifies the implementation of Statistical Process Control approaches as a set of efforts aimed at driving a process towards a better performance.

Statistical Process Control

"No two things are alike". This is the axiom that Wheeler and Chambers cite when they first introduce the idea of statistical variation in their *Understanding Statistical Process Control* (1992). This axiom brings the inherent recognition that any products or services delivered to a costumer as outputs of a process are prone to carry some degree of variability. And, when meeting a customer's requirements, variability is almost always a synonym of poor quality, which brings the need of suppressing it to the maximum possible extent.

When it comes to variation, there is a very important distinction that must be made. This was primarily conceived by Dr. Walter A. Shewhart, one of the "early pioneers on quality assurance" (Evans & Lindsay, 1996), a group that also includes W. Edwards Deming. According to Dr. Shewhart, "while every process displays variation, some processes display controlled variation, while others display uncontrolled variation" (Wheeler & Chambers, 1992).

Controlled Variation is characterized by a stable and consistent pattern of variation over time. Dr. Shewhart attributed such variation to "chance" causes. Uncontrolled Variation is characterized by a pattern of variation that changes over time. Dr. Shewhart attributed these changes in the pattern of variation to "assignable" causes (Wheeler & Chambers, 1992).

Wheeler & Chambers (1992) illustrate the concepts of controlled and uncontrolled variation through figures 1 and 2 below.

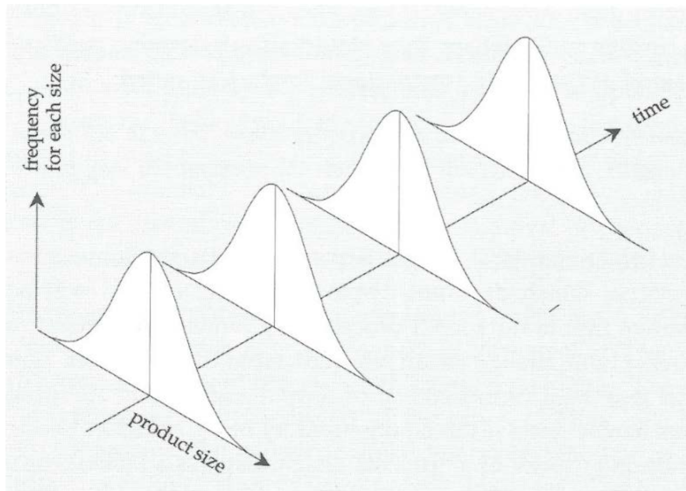


Figure 1. Characterization of controlled variation

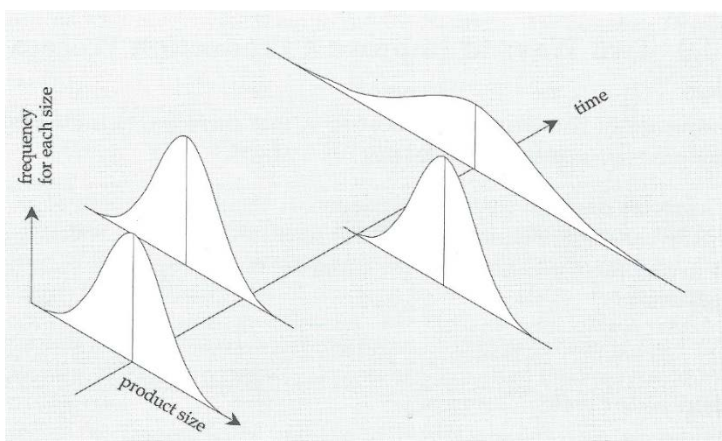


Figure 2. Characterization of uncontrolled variation

There are some practical consequences of the distinction between controlled and uncontrolled variation when applied to a process. First of all, it is possible to conclude that when the measurements of a particular variable of the process display inconstant patterns of variance over time, it can be classified as out of control, from the statistical standpoint. According to Dr. Shewhart, this requires the search for the assignable causes of the variation and the adoption of appropriate remedial actions to bring the variable (or the process) to a stable condition. The reason for this requirement is fairly simple and can be synthesized under one statement: "a process which does not display statistical control will be unpredictable" (Wheeler & Chambers, 1992). It becomes clear then that it would be immensely more difficult to pursue (or to assure, which is what a customer usually demands), the quality of a product or service when it is impossible to predict the behavior of a process within reasonably established limits.

However, this distinction also requires a careful consideration: *constant* variance does not necessarily mean, under any circumstance, *acceptable* variance. In other words, it is possible that an outcome from a process (or from a particular step of the process) displays a pattern of variation that is constant over time but too broad to be considered under an acceptable range. If this happens, it is true that the process may be predictable. However, this characteristic solely considered is not a synonym of good quality. The possibility to predict when a bad quality outcome will occur does not turn it into a good quality one. The Six Sigma concept of quality was a philosophy and a set of practices developed by the Motorola Company that aimed at shrinking the process of variation until an almost perfection is achieved, when it comes to percentage of defective parts produced.

Due to the fact that he was one of the pioneers in studying the effects of variability on manufacturing processes, Dr. Shewhart can be considered as a precursor of Statistical Process Control, whose primary objective is to "stabilize the process and reduce the variability" (Montgomery, 2005).

As for definition purposes, the concept adopted by this research was provided by Heizer and Render (2010), for whom Statistical Process Control "is the application of statistical techniques to the control of processes". Those techniques mostly comprise seven major analytical tools, as discussed by Beabout (2003), citing Montgomery (2005): histogram or stem-and-leaf plot, check sheet, Pareto chart, cause-and-effect diagram, defect concentration diagram, scatter diagram and control chart.

While those seven tools are an important part of SPC, Montgomery (2005) highlights that "they comprise only its technical aspects". According to him, it is also necessary a complete commitment by the entire organization, plant workers and managers, in order to obtain a successful implementation, resulting in improvement of quality and productivity.

Even though Statistical Process Control has been raised primarily to be applied in manufacturing plants, it is perfectly possible to apply those principles in service-driven businesses. "The most common quality characteristics in services, time (waiting time, service time, delivery time) and number of nonconformances, can be measured rather easily" (Evans & Lindsay, 1996). Still according to Evans & Lindsay, "Internal measurements of service quality are commonly performed with some type of data sheet or checklist. Time is easily measured by taking two observations: starting time and finishing time".

Montgomery (2005) also embraces the view that SPC can be applied to virtually any industry or sector. He advocates that the use of statistical methods can

> improve the quality of the products used by our society. These products consist of manufactured goods such as automobiles, computers and clothing, as well as services such as the generation and distribution of electrical energy, public transportation, banking, retailing and health care. Quality improvement methods can be applied to any area within a company or organization, including manufacturing, process development, engineering design, finance and accounting, marketing, distribution and logistics, and field service of products. (Montgomery, 2005).

As mentioned before, the detrimental effects of variation in a process is fundamentally what SPC aims at reducing to the fullest extent. Montgomery (2005) defends that one of the most frequent results that comes from excessive variability embedded in a process is waste.

Therefore, he concludes that reduction of waste is an alternate definition for quality improvement.

> This definition is particularly effective in service industries, where there may not be as many things that can be directly measured (…). In service industries, a quality problem may be an error or a mistake, the correction of which requires effort and expense. By improving the service process, this wasted effort and expense can be avoided. (Montgomery, 2005).

The word *waste* was certainly not randomly chosen by Montgomery. It establishes a direct connection with another management approach whose roots reach as far as the origins of the Japanese giant automobile manufacturer Toyota. This approach has its foundations on the Japanese counterpart for the English word "waste": *muda*.

An overview on this management model is presented in the next section.

The Lean Thinking

"The Toyota Production System (TPS) provided the basis for what is now known as lean thinking, as popularized by Womack and Jones" (Pepper & Spedding, 2010). It was pioneered by Taiichi Ohno, who was "a symbol of Japan's manufacturing resurgence after the Second World War" (Hindle, 2009).

One of the primary focuses of Ohno's TPS is banishing *muda* – waste – from the production process. In this context, waste can be defined as "any human activity which absorbs resources but creates no *value*" (Womack & Jones, 2003). As pointed out by Chongwatpol (2004), "the goal of lean thinking is to determine wastes (also called non-value added activities) in the value streams, to eliminate those waste activities, and to create and sustain value added activities".

As it can be perceived from the definitions provided above, the starting point for the classification of what activities are to be considered as waste in a particular process is the definition of *value*, which is deemed by Kang and Apte (2007) as the heart of the lean thinking. They also define value as "form, feature or function for which a customer is willing to pay". Womack and Jones state that indeed, the critical starting point for lean thinking is value. "Value can only be defined by the ultimate customer. And it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time" (Womack & Jones, 2003).

Therefore, as far as processes are concerned, the essence of lean thinking can be described as determining which activities actually add value to the final product or service when performed, and which do not, as well as eliminating the latter from the process or reducing them to the maximum possible extent. Womack and Jones, as cited by Kippenberger, argue that lean thinking "provides a way to re-specify value, line up value creating actions in the best sequence, ensure that such activities are conducted without interruption whenever they are requested, and all activity is performed more and more effectively" (Kippenberger, 1997).

In this way, after specifying what is value for a determined process, but before adopting actions intended to eliminate wasteful activities from it, a prior and necessary step is to map what Womack and Jones call the *value stream*.

The *value stream* is the set of all the specific actions required to bring a specific product (whether a good, a service, or, increasingly, a combination of the two) through the three critical management tasks of any business: the problem-solving task running from concept through detailed design and engineering to production launch, the information management task running from order-taking through detailed scheduling to delivery, and the physical transformation task proceeding from raw materials to a finished product in the hands of the customer. Identifying the entire value stream for each product (or in some cases for each product family) is the next step in lean thinking, a step which firms have rarely attempted but which almost always exposes enormous, indeed staggering, amounts of *muda* (Womack & Jones, 2003).

Once the value stream for a particular outcome of a process is appropriately mapped, Womack and Jones advocate that it will display, most of the time, three types of activities: (1) steps that create value for the customer; (2) steps that create no value to the customer but are unavoidable due to technical, legal or other considerations (Type 1 *muda*); and (3) steps that create no value for the customer and are immediately avoidable (Type 2 *muda*). From this distinction, it can be easily concluded that the ultimate goal of a lean endeavor is to reduce Type 1 *muda* as much as possible, as well as completely eliminate Type 2 *muda* from a process.

There are seven general forms of waste that were identified by Taiichi Ohno and are widely accepted by the literature. George (2003) provides a fairly comprehensive discussion about those forms of waste, summarized as follows.

Overprocessing.

Basically, "overprocessing is doing more work than is absolutely necessary to satisfy or delight your customers" (George, 2003). There are basically two elements of overprocessing: adding more value than what the customers want (this happens when there is not a clear understanding of what are the customers' needs or what they are willing to pay for); or allowing non-value-add work creep into a process.

Transportation.

Transportation can be defined in this context as unnecessary movement of materials, products or information. Excess transportation is an important type of waste to be considered, because "every move from one activity to another takes time (which is something Lean thinkers want to minimize), and creates a queue at the receiving activity" (George, 2003).

Motion.

Motion refers to needless movement of people. "Transportation refers to the movement of the work; motion involves movement of the workers" (George, 2003).

Inventory.

Inventory is understood in the present context as any work-in-process that's in excess of what is required to produce for the customer. According to George (2003):

> any work-in-process in excess of the amount actually needed causes non-value-add downstream costs of waiting, long lead times, and the failure to meet customer expectations. Besides all the other evils of large amounts of WIP (…), it increases the probability that the sequence in which work is done will not match the sequence in which it is needed downstream (George, 2003).

Waiting times.

George (2003) defines waiting times as "any delay between when one process step/activity ends and the next step/activity begins". According to him, process mapping techniques are of great importance in finding delays in a process, especially in a service one, since so much of the work is invisible to the naked eye. After mapping the steps of a process it is possible to identify more easily where work-in-process sits around, waiting for someone to do something with it.

Defect.

Defect can be defined as "any aspect of the service that does not conform to the customer needs" (George, 2003). The idea of defect may be more easily visualized when one thinks about products. In this sense, a defective product would be a good that does not perform what it is intended to do, or in the way it is supposed to perform. However, the idea of a defect can also be applied to services, as pointed out by George (2003). In this case, a defect could be understood as anything that causes the customer not to be satisfied with the service, like missing information or missing deadlines.

Overproduction.

Overproduction is the "production of service outputs or products beyond what is needed for immediate using" (George, 2003). This type of waste can manifest itself in a number of ways. It can exist, for instance, when an upstream step in the process produces non-priority parts that will not be immediately used, rather than a more urgent part that is needed by a downstream activity. Overproduction also occurs when any step produces more outputs than the next activity/step's capacity to process them, which leads to the growth of other types of waste, notably inventory and waiting times.

An eighth waste is frequently referred to in the lean literature. Gibbons *et al*. (2012) point out that this eighth waste has been the subject of many different descriptions in the lean literature. For example, Suzaki, as cited by Gibbons *et al*. (2012), proposes the eighth waste as "not utilizing people's talent", or "underutilizing people's skills and capabilities" (Gibbons, Kennedy, Burgess, & Godfrey, 2012). Gibbons *et al.* (2012) also mention that Womack and Jones define this waste as "the underutilization of employees". Finally, they also cite Liker, an academic specialist in the Toyota Production System, for whom the eighth waste is "unused employee creativity", which means "losing time, ideas, skills, improvements and learning opportunities by not engaging or listening to your employees" (Gibbons, Kennedy, Burgess, & Godfrey, 2012). (Kippenberger, 1997)

There are even broader views of waste adopted by some authors. Lambert (2014), for example, proposes a larger set of wastes, advocating that "failing to eliminate these business wastes will result in the forms of waste that Ohno identified". According to him the seven typical forms of waste form what he calls the tip of an iceberg, “when compared to the larger collection of wastes found in organizations” (Lambert, 2014). These “below the surface” wastes are, according to his view: (1) full cost allocations for decision making; (2) missed opportunities for value creation; (3) disconnects between promise making and promise keeping; (4) unclear expectations in business relationships; (5) late detection of action required; (6) misalignment of incentives; and (7) excessive product proliferation.

Despite the several types of waste that modern interpretations of the lean thinking have brought to our attention, this research will focus primarily on the seven original types of waste identified by Taiichi Ohno, for the sake of simplicity and objectivity of the work. Also, the original set of seven wastes is the one most widely accepted by the literature, even though many authors have expanded them, as demonstrated.

After the value is specified, the value stream for a specific product is mapped, and wasteful steps are eliminated, the next step in lean thinking is to “make the remaining, value – creating steps *flow”* (Womack & Jones, 2003). Their concept of flow is opposed to the traditional batch-and-queue approach, derived from our “instinctive preference for dealing with things in batches” (Kippenberger, 1997). According to Womack and Jones’ perspective, it is necessary “to fight departmentalized, batch thinking because tasks can almost always be accomplished much more efficiently and accurately when the product is worked on continuously from raw material to finished good (Womack & Jones, 2003). Kippenberger adds, citing Womack and Jones, that the adoption of this approach

avoids waiting, downtime and large piles of work-in-process at each step in the process. The authors argue that this enables product design time to fall from years to just months, order processing come down from days to hours and throughput time in physical production to collapse from months or weeks to days or minutes (Kippenberger, 1997).

Once a continual flow of value-adding work only is established, Womack and Jones advocate that it is possible to implement the *pull* approach, which

in simplest terms means that no one upstream should produce a good or service until the customer downstream asks for it (…). Instead of pushing completed products at customers, customer orders pull newly produced items through the plant. The result is no finished stock inventory, no complex tracking system, and no need to remainder unwanted goods (Kippenberger, 1997).

The fifth and final step in the lean thinking as brought by Womack and Jones is the continual pursuit of *perfection*, in line with the Japanese widely adopted concept of *kaizen*: continuous improvement. Kaizen, as defined by Anupindi et al. means "ongoing improvement of processes by continuously identifying and eliminating sources of waste in a process, such as inventory, waiting time, or defective parts" (Anupindi, Chopra, Deshmukh, Mieghem, & Zemel, 2012). Kippenberger mentions that this step seems to be a natural outcome of the previous four phases (value identification, value stream mapping, creation of flow and pull from customers). According to him, "these first steps lead to the discovery of new sources of value, fresh areas of waste and newly revealed impediments to flow or pull" (Kippenberger, 1997).

After presenting the key aspects of the theories that form the framework for the investigation carried out under the present research, it is necessary to provide the reader with the appropriate details regarding the methodology that was employed for both data collection and analysis. This is the subject of the next chapter of this paper.

III. Methodology

Overview

This chapter provides details about the data collection, as well as the methodology, used for the analysis. Specifics about the statistical analyses and the simulation effort that were performed are also provided.

Data Collection

According to Leedy & Ormrod (2013) "research is a viable approach to a problem only when data exist to support it." Data, according to the same authors, are "those pieces of information that any particular situation *gives* to an observer."

Leedy & Ormrod (2013) also classify data into two possible categories: primary or secondary. Primary data are those that constitute the closest layer of information to the phenomenon under investigation. Secondary data are those obtained not from the observation of the phenomenon itself, but from alternative sources.

The data used in the present research were obtained directly from the organization in which the studied process was developed. All the recorded pieces of information were made available by people that actually worked in the process and provided them as part of their daily routine of informing some facts about the work that was done. Therefore, following the classification of data proposed by the above-cited authors, a major part of the data used in this research can be considered primary.

The records of the daily activities performed by the process workers were made available through a MS Excel spreadsheet, which contained detailed information about each PO and their respective Selection List (SL), from the moment they entered the process through the moment they exited it. The data relate to the distribution peak season (from 1st of August to 31st of December) of the year of 2012 and 2013.

The pieces of information made available were the following: PO and SL identification numbers, dates of beginning and completion of each process step those documents went through, PO and SL sizes (in terms of quantity of items, measured both in cubic meters and in cubic feet) and the organization responsible for hauling the material to their final destination. Those data were mostly used for quantitative analyses and calculations.

Another source of primary data were documents and legal regulations issued by the Brazilian Air Force in general as well as, more specifically, by ICD. Those documents provided information about the process organization at the ICD level and the context in which it is inserted. The analyses made with a focus on those sources were mostly qualitative, aimed at figuring out how the process under study was structured, as well as other factors that might play an important role in it, like Air Force legal requirements to which the process must adhere.

A third source of information that substantiated the results and conclusions of this research was an unstructured interview conducted with the person who was the head of the ICD Warehouses Section during the timeframe of this analysis. The questions were electronically mailed to him, who then mailed his responses in return. The purpose of this interview was to provide information on some particularities of procedures adopted at the time, which were not completely depicted in the regulations.

Data admissibility is an important issue to be kept under consideration by one who goes through a research endeavor, since “not all data that come to the researcher’s attention are acceptable for use in a research project" (Leedy & Ormrod, 2013). Data imperfections are to be expected, and they must be filtered, because the admission of distorted, inaccurate or corrupted data may affect the validity of the researcher's conclusions.

Therefore, a comprehensive data cleansing had to be performed, in order to prepare them for this research. In this way, all the records that displayed some sort of inaccuracy or missing information were not considered by the researcher. The analysis only included those orders for which a complete and precise set of records were available. This was a necessary effort prior to the beginning of the study itself, since the data were manually generated, and therefore, prone to contain errors. Even though the data were comprehensively scrutinized, this effort did not result in a damaging elimination of data from the scope of this research. Out of the universe of 158 orders issued during the timeframe researched, the records concerning to 6 of them were deemed as not admissible, and thus were withdrawn. This represented a reduction of only 3.79 %, which means that this research has addressed 96.21 % of the entire population of Provision Orders issues during the timeframe researched. In this way, it is assumed that the dataset is a fairly close representation of the population and the results and conclusions achieved are believed to be likewise applicable.

Methodology used to address the research questions

This paper now describes the methods and procedures used to address the formulated research questions.

Research question #1.

The first research question addressed was *how is the process structured, from the moment a PO is authorized until the moment the material is received at the destination?*

The method used to address this investigative question was primarily documental research. For this purpose, several documents were used. The PROVSYS manual, a regulatory document issued by the Brazilian Air Force Directorate of Intendancy was used to understand the background on which the process relies, as well as to determine the role of each participant organization (group to which the ICD is part of).

ICD's Supply Division has a number of documents named Standardized Action Norms, which discipline the functions to be performed by each section of the Division. Structures, responsibilities and procedures pertaining to each section of the Supply Division are contemplated by those documents. They have provided the most valuable pieces of information that allowed the understanding of how the process works at the ICD level.

However, some important information, mostly about details on how determined procedures were carried out, was not available in those publications. Consequently, the interview with the head of the Warehouses Section (that integrates the structure of the Supply Division) was very important in filling those blanks.

Research question #2.

The second research question addressed was *what factors are taken into consideration when the schedule of activities is planned by the Supply Division management?*

The procedures regarding the planning of Supply Division's activities are not comprehensively stated in any of the examined publications. Therefore, the source of the data necessary to cover this research question was mostly the interview with the head of the Warehouses Section.

Research question #3.

The third research question was *what is the impact of variability in the process performance?*

The handling of this research question was mostly made through quantitative methods of statistical analyses. All the statistical analyses were performed using the JMP software, version 10.0.0. The confidence level of all the tests performed was set at 95% (alpha of 0.05).

Several aspects of variation regarding task completion times were investigated. Task lead times were computed as the time elapsed between the starting and the finishing day of the task. Then, patterns in the variation of those lead times were assessed by means of analysis of variance tests and measures of spread.

The measures of spread used were the coefficient of variance, associated with the interquartile range. The coefficient of variance was measured as the ratio between the standard deviation and the mean of a given dataset. However, since this type of measurement can be highly influenced by outliers, it was interpreted in conjunction with the interquartile range, which is a more robust measure of spread, less susceptible to the effects of outliers and more appropriate for nonparametric datasets, which constituted most of the cases analyzed. JMP graphical aids, like scatterplot matrices, histograms, outliers and quantiles box plots, were also used. Those measures of spread and graphical resources were used with a view to assess the amount of variability embedded into the various steps in the process.

As for the analysis of variance (ANOVA), it was noted that none of the datasets handled during this research met the minimum conditions allowing the application of a regular parametric method of ANOVA, like the Tukey's comparison of means. Therefore, the method used to evaluate the statistical significance of potential differences regarding samples was the Kruskal-Wallis test, for which assumptions like normal distribution and equality of variances across the samples are not required.

Research question #4.

The next research question addressed was *which of the Lean Thinking's types of waste can be found in the process and how are they affecting the process performance?*

The investigation about this research question relied both on qualitative and on quantitative methods. Some of the types of waste, like overprocessing and transportation, were identified by analysis of the ICD Supply Division's documents and regulations, as well as of the responses provided by the interviewee. However, the study of other forms of waste, like waiting times and inventory, relied also on quantitative methods, like simulation and inventory buildup diagrams.

The simulation was performed using the ARENA software, version 12.00, and was primarily aimed at providing insights about waiting times and capacity utilization, so the process bottleneck could be identified. The first step of the simulation effort was to determine the structure of the process, establishing the steps that would be considered.

Then, the next step was the definition of the most suitable flow unit. In this regard, since the dataset available displayed the records controlled in terms of Selection Lists, this was determined as the most appropriate flow unit. More details about Selection Lists are provided in the first section of chapter IV

Once the flow unit was determined, the interarrival times were computed, as well as the completion times of each of the steps included in the simulation, with the objective of obtaining the statistical distributions. The number of entities arriving the system was also modeled under a statistical distribution and used as an input parameter. For the purpose of modeling statistical distributions, the tool used was the ARENA Input Analyzer. The expression depicting each distribution was used as input parameters for the simulation. The statistical distributions, as well as the related p-values are demonstrated in Appendix 1.

The simulation length established was 150 days, thus reproducing the time between 1st of August and 31st of December of each year (which is the annual distribution peak season). The system was set to run 30 replications of the simulation, with a view of achieving a minimally large sample size. Then, the results generated were obtained from the SIMAN simulation report and tabulated using Microsoft Excel for determination of the averages.

As for the model reliability, it was verified that the all the averages of the measurements of interest obtained from the real datasets (flow times and waiting times) fell into the 95% confidence intervals generated from the simulation outputs. No warm-up concerns appeared to be necessary, since the scatterplot constructed using the simulation outputs did not depict any upward or downward trend prior to the steady-state was reached, as exemplified in figure 3.

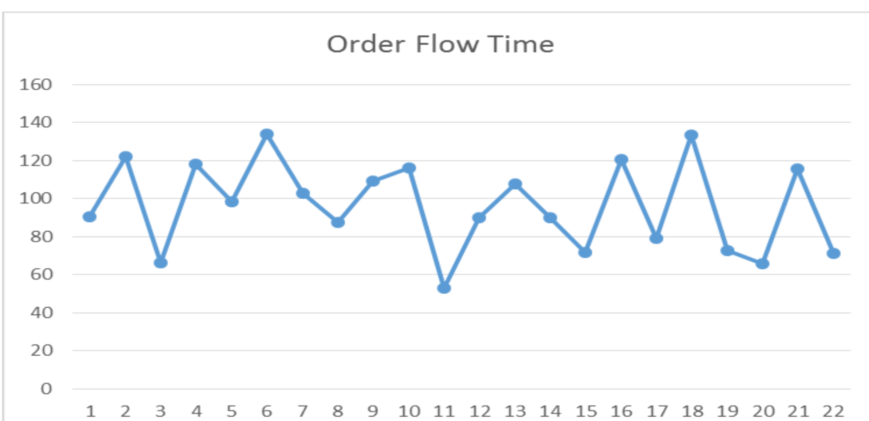


Figure 3. Scatterplot of order flow time obtained from simulation outputs

Research question #5.

The fifth research question was *what metrics are currently being taken from this process by the Supply Division Management Team?*

Both the PROVSYS and ICD regulations were carefully scrutinized in order to identify what kinds of metrics were in place at the timeframe researched. It was then discovered that none of the documents examined state anything about metrics. Consequently, the information regarding this aspect of the research was obtained from the responses provided by the interviewee, as well as from files gotten from the Supply Division depicting some indicators that are presented to the ICD Director as part of the monthly accountability process.

Research question #6.

The final research question was *what metrics could be implemented in order to better drive actions toward performance and quality improvement?*

For the purpose of this question, the most impacting aspects of waste identified throughout the research were considered in order to propose measurement methods that would help the Supply Division management staff make decisions toward performance improvements. Most of the measures proposed are constituted by a ratio of some process output over time (for instance, throughput, measured as the ratio of the number of process output per unit of time) or a numerical relationship between two figures (for instance, the number of defective orders over the total number of orders).

Once the aspects of the methodology of this research are delineated, the analysis and the results can be presented.

IV. Results and Analysis

Overview

This chapter provides the reader with details on the analysis performed and the results achieved after applying the theoretical framework explored in chapter II to the data collected, according to the methodology discussed in the previous chapter.

Firstly, the process under study is explained in detail, from the moment a PO is issued by the Sub-directorate of Supply until the moment the concerned material reaches the destination. After the process description, this chapter presents the results of the application of some of the main principles of Statistical Process Control, Lean Thinking and Theory of Constraints in order to evaluate its performance. Finally, the identified opportunities of improvement are presented, as well as the research questions are answered.

Description of the process

As explained in chapter I, the process of distribution of uniforms across the Brazilian Air Force is performed by a number of organizations, which work in a coordinated manner. This system operates under the supervision of the Directorate of Intendancy (DIRINT), through its main executive organization, the Sub-directorate of Supply. The Provisioning System Norm is the document issued by the Brazilian Air Force that establishes the responsibilities of the various organizations pertaining to the PROVSYS. Even though the process involves several organizations, only the part that is performed by the ICD's Supply Division was contemplated in this study. However, an overview of previous steps will be presented, in order to provide the reader with a better comprehension of the entirety of the process. The information presented in this section was obtained from the PROVSYS Norm, as well as from a number of ICD's Supply

Division regulations and from an interview conducted with the manager of ICD's warehouses, a Lieutenant whose specialty is supply operations. He has been in charge of ICD warehouses since December of 2011. Therefore, he was an active participant in the process, and his inputs are believed to reflect a fairly precise picture of reality.

The process starts with the collection of all BAF organizations' needs in terms of uniforms by the Sub-directorate of Supply. In order to provide as accurate as possible information to the Sub-directorate of Supply, each organization must consider the number of uniforms' beneficiaries that are expected to be working at that organization in the following year, as well as which pieces of uniform and in which quantity each one of them is entitled to receive. Information about sizes is also to be collected. By doing this, each organization calculates the number and the types of pieces of uniforms of each size it needs. This information is then passed to the Sub-directorate of Supply, which compiles the data received from all BAF organizations and consults the PROVSYS' inventory (which is mostly held at ICD), in order to determine acquisition requirements.

The acquisition process is performed by the Sub-directorate of Supply in accordance with the Federal Government laws and regulations on this matter. Contractors usually deliver the purchased uniforms to ICD, which performs receiving verifications on quantity and, at some degree, on quality of the items. However, most of the items are sampled, and the samples are sent to the Sub-directorate of Supply for laboratorial analysis, with a view to determine if the material is in accordance with BAF specifications. Upon approval, the material is stored at ICD warehouses for later distribution. If not approved, the material is returned to the supplier, which has a certain period of time, according to each contract, to provide new items, which will again be subjected to laboratorial analysis.

Before the distribution process itself starts at ICD, there is a prior procedure that is carried out with the involvement of both ICD and the Sub-directorate of Supply, which is the PROVSYS's inventory count. This procedure is mandatory according to the PROVSYS Norm, and it is aimed at making sure that the recorded quantities in the MSLIS reflect as accurately as possible the actual quantities of each item on the ICD's shelves. In this way, no PO issued by SDAB should contemplate items or quantities not available in stock. Or at least, it should be expected that the number of those kinds of errors would be minimal, even though the entire count process is developed manually.

The count process is usually three months long, beginning in May of each year. After it is completed and the MSLIS's records are updated, the Sub-directorate of Supply issues all the POs at once. In this way, the majority of the uniforms are distributed to the various BAF organizations from August to December each year. The uniforms distributed in a particular year are intended to be stored in the various organizations and handed out to the soldiers in the subsequent year, according to distribution maps that are elaborated by each organization and approved by the Sub-directorate of Supply. Normally, the first batch of uniforms must be ready to be tendered by all organizations to their soldiers by the beginning of February, which is usually when the year's first group of soldiers is to be incorporated by the Air Force. In this way, by each February the uniforms are ready in order to allow each organization to get at least one month for preparing their respective distribution process. It is imperative that all of them have all the uniforms from ICD no later than December 31st. of the previous year.

It is important to notice that the distribution process does not contemplate the physical items only, but also their respective monetary amount, which is transferred to the various destinations accordingly, by an electronic system, named Integrated System of Budgetary and

Financial Administration (ISBFA). However, the monetary value of the items is also recorded in MSLIS, and this value also needs to be transferred. One point worth mentioning is that frequently the amounts recorded in ISBFA and in MSLIS for the same items differ. This brings the need for adopting reconciliation procedures, since the regulations on this matter forbid those types of discrepancies, as well as the rework that is necessary that duplicating financial records demands.

Normally, while the inventory count develops, the ICD's Supply Division manager, with the collaboration of the warehouses manager, elaborates the inventory picking schedule, which is to be followed by the warehouse teams, after approval by the ICD Director. This schedule contains the sequence in which the items are to be selected from the inventory, and it is sorted by the destination organization, with the work normally beginning with the locations that are farther from ICD (and thus more likely to take advantage of unadvertised air freight missions). Those locations first have their items selected from the inventory. Therefore, the schedule remains fairly constant over time, with minimal modifications from one year to the following one, as the distance criteria is rarely abandoned. Additional considerations regarding this procedure will be provided later on in this chapter.

Usually, the POs are issued by the Sub-directorate of Supply during the last week of July, and the procedures at the ICD level regarding the distribution itself start in the first week of August. During the years of 2012 and 2013, this was the same, according to which the records obtained from the ICD' Supply Division demonstrates (in those years, the inventory picking season started precisely on the first of August).

The POs generated by the Sub-directorate of Supply are firstly handled by the clerical staff of the Sub-division of Storage and Distribution (SSD), which coordinates the work of the two ICD warehouses and the cargo terminal. It is the SSD that determines the sequence of the work to be executed by the warehouses staff, according to the schedule previously approved. In this way, as the weeks go by, the SSD releases to the warehouses the batches of POs that are to be worked on in that respective period, following the schedule determinations. Therefore, it can be noticed that the picking work related to a particular PO does not start automatically once the PO is received by the Supply Division. It is also necessary to highlight that, as informed by the interviewee, the scheduled work is frequently interrupted by rush orders, due to a number of reasons. The most frequent ones are the urgency demanded by an organization that has an utmost need for an item ahead of schedule (frequently due to lack of accuracy in demand forecasting) or the need to take advantage of an unpredicted air freight mission. Whenever those situations occur, the SSD emits a special order to the warehouses, determining the immediate interruption of the work being done and the rush fulfillment of the POs concerned. This is usually characterized as a very stressful situation, since it frequently demands high amounts of afterhours work from a number of ICD's sections, like the warehouse, the cargo terminal and the garage, to name a few.

Once a PO is authorized by the SSD for inventory selection, it is broken down into Selection Lists (SL), which are forwarded to the coordinator of the warehouse (s) concerned. One PO may generate only one SL, or it may be broken down into several SLs. Then, the coordinator hands a printout of the SLs to a team or teams of pickers. Since the warehouse coordinator is responsible, among other tasks, for supervising the picking process, he has the notion of which teams are the busiest at any given moment. Therefore, new SLs arriving at the warehouse are usually directed to the least busy team. It is interesting to notice that at the warehouse level, all the control of the activities is not done by PO but by SL. The SLs are manually generated by the SSD staff, and they may or may not contain all the items from the respective PO. Therefore, additional managerial effort is demanded in order to make sure that every item from the PO is included in some SL, or otherwise it will not be selected. Also, it is necessary to make sure that all SLs from a particular PO are "reassembled" later on into the system by the SSD staff, in order to make sure that no items were left behind in an unselected status.

Once the work of a SL is done, the items are prepared to be shipped to the cargo terminal. Then, a new kind of document is generated, the Material Movement List (MML). This is the document that transfers the material from the warehouse to the cargo terminal's responsibility. Afterwards, a request is sent by the cargo terminal staff to ICD's garage with a view to have the material transported from the warehouse to the cargo terminal by one of the ICD's trucks. Upon arrival at the cargo terminal, its staff compares the physical items with the correspondent MML, in order to make sure that no items were left at the warehouse. One important observation is that, as example of the Selection Lists, the MMLs are also manually generated by the administrative personnel working at the warehouses, and not necessarily all the SLs pertaining to a particular PO will be included in the same MML.

After the material is checked and stored at the cargo terminal, the possibilities are twofold: either the material is supposed to be transported by the ICD's truck fleet or by the Air Force Logistical Center (AFLC). AFLC is an organization whose primary objective is to perform freight movement between the various BAF organizations, either by road or air transportation. What primarily defines the organization that will provide transportation, as well as the mode to be used is the distance of the location from the city of Rio de Janeiro to which the material is intended. In this way, whenever the receiving destination is located in the First (COMAR I), Second (COMAR II) or in the Seventh (COMAR VII) Air Force Regional Commands, a transportation request is issued to AFLC. Figure 4 illustrates the division of the Brazilian territory into Air Force Regional Commands. The red arrows indicate the locations to where the transportation is normally provided by the AFLC, most of the times by the air mode. Nevertheless, this organization occasionally provides transportation to other locations as well, but most of the times, these are served by the ICD's truck fleet. When there is enough material at the cargo terminal intended for one of the regions usually served by ICD's truck fleet, a transportation request is sent to ICD's garage. Transportation will be provided at the garage's earliest convenience, depending on truck and driver availability. It is worth mentioning that there is a high demand put on ICD's truck fleet, not only by the Supply Division, but also by the Operational Intendancy Division. That being said, conflicts of missions between those two Divisions, demanding the same resources from the garage are not rare events.

Figure 4. Air Force Regional Commands

Whenever possible, a cargo caretaker is designated to accompany the material being transported, regardless of the mode or of the transportation provider. The caretaker is responsible for making sure that the material arrives intact at the destination, as well as for inspection procedures, that are to be carried out in conjunction with some representative from the receiving organization. However, on several occasions, most of the times due to lack of availability of an authorized caretaker at the moment the material is being embarked to be transported by the AFLC, the cargo goes unaccompanied. And, according to what was reported by the interviewee, the amount of missing items at the destination is notably higher when the cargo goes unaccompanied.

While the material is being transported, ICD provides the transfer of the monetary value of it to the receiving organization. After the material is physically received and accepted by the organization it was intended for, it must also record the acceptance of the transferred amount both in MSLIS and in ISBFA systems. It is only after this step is accomplished that the responsibility for the material is officially transferred to the receiving organization. This whole receiving and acceptance process must not exceed thirty days, according to the Air Force regulations on this matter. Also, it is not allowed by law to end the fiscal year (which, in Brazil finishes at December 31st) with pending monetary transfers between organizations. In order to accomplish this mandatory regulation, all the material must be delivered by ICD at least thirty days prior to the end of each fiscal year, in order to allow the receiving organization the legal time they are entitled to proceed with the receiving and acceptance process.

The receiving and acceptance process that is carried out by the destination facility was mentioned in order to highlight the importance of a straightforward distribution process at the ICD level. It was possible to observe, from the data collected, that in many cases this process exceeds the legal thirty-day timeframe. In addition, considering the period of time researched, it was observed that a substantial amount of materials was not delivered by ICD in due time, considering the fiscal year closure procedures. That means that, in several occasions, the receiving organizations did not have the necessary time to proceed with the acceptance procedures and the receipt of the monetary amount before the end of the fiscal year, which certainly brought administrative inconveniences to them. Even though this last step is the one that actually represents the end of ICD's participation in the distribution process, it was not considered in this research, since it is performed by organizations outside the ICD's responsibility, and no accurate data regarding them could be gathered. For this reason, this study focused exclusively on the ICD's share of the process, which is represented by figure 5 below:

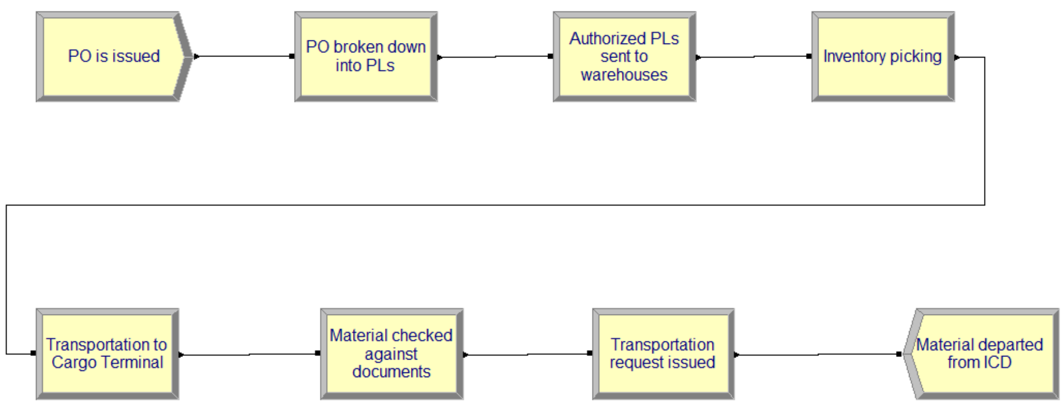


Figure 5. ICD's distribution process

This way, after studying the pertinent regulations, as well as the responses from the interviewee, it was possible to address the first research question, which was *how is the process structured, from the moment a PO is authorized until the moment the material is received at the destination?* Therefore, the first research objective, which was to *establish how the process of distribution of PROVSYS' uniforms is structured and executed at the ICD level* was equally achieved. This was the first and necessary step of the analysis, and constituted the cornerstone that enabled the comprehension of the process under the theoretical framework that guided this research.

The second research question (what factors are taken into consideration when the schedule of activities is planned by the Supply Division management?) could also be addressed by the interview. As mentioned by the interviewee, it became clear that the inventory picking schedule is elaborated with a view to coping with the uncertainty of the transportation, once there was no transportation schedule in place beforehand. In this way, the work is prioritized considering the destinations that would most likely be affected by missed transportation opportunities (the locations to which the access is only possible by air and to where air freight missions are less frequent). Since the ICD Supply Division did not have a date or at least a time window for transportation defined by AFLC with a reasonable level of certainty, the Supply Division management opted for starting the picking process by the material intended for those locations, so they could most likely take advantage of eventual air freight missions headed to them.

This fact itself led to great evidence that variability would be playing an important role in the process under study. The next topic addresses the results of the investigation that were carried out in order to address the third research question, which was *what is the impact of variability in the process performance?*

The effects of variability on the process

At this point it is appropriate to revisit Dr. Shewhart's distinction between controlled and uncontrolled variation. According to him, controlled variation is the one whose pattern is consistent and stable over time, while uncontrolled variation displays a pattern that changes with the passing of time. This is the variation with *assignable causes*, as opposed to the controlled variation, attributable to the effects of chance.

This way, the first step that was performed under this phase of the research was an attempt to determine whether the process displays symptoms of uncontrolled variation, which is the one that inflicts the most detrimental threats to the process' performance. As explained in the literature review, this is due to the fact that uncontrolled variation adds a considerable amount of unpredictability when it comes to the process outcomes.

The inventory picking was found to be a task in the process with a lot of variation embedded in it when it comes to time required for completion. During the timeframe researched, there were nine teams of pickers, each one composed of 4 people, with one designated as the team leader. For the purposes of this research, they were designated as Team 1 to Team 9.

The time required to complete the selection of the items pertaining to each one of the provision orders analyzed during the timeframe considered by this research was recorded, and a histogram was generated, as well as the related summary statistics. The result can be seen in figure 6 below.

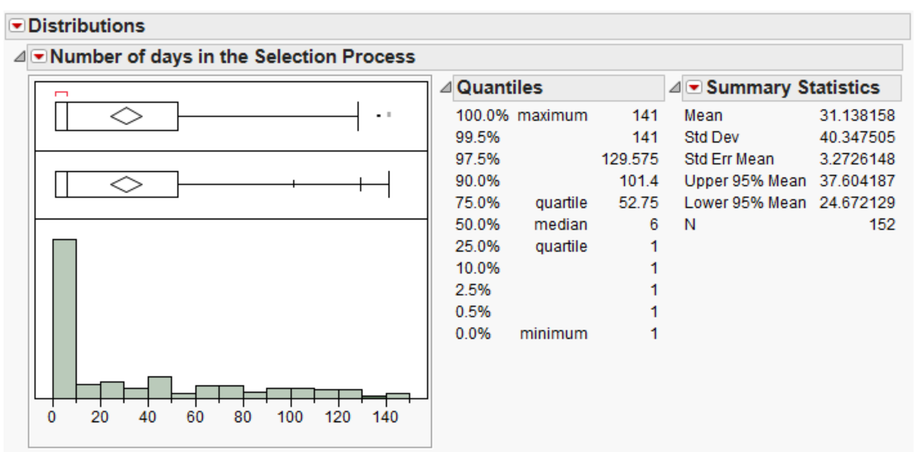


Figure 6. Statistics on PO completion times

It is possible to note from the figure above that the PO selection lead times varied in a considerably wide range (whilst there were POs whose items were selected in one day, there were others that took more than 100 days to be fulfilled). Another remarkable figure is the standard deviation of 40 days in a dataset whose mean is 31 days. These numbers imply a coefficient of variation of approximately 1.30, or 130 %, which constitutes a warning that there is a great chance of a huge amount of variation in these data. The Outlier Box Plot indicates three data points as potential outliers, corresponding to two provision orders that were completed in 141 days and one that was completed in 137 days. Nevertheless, the interquartile range is enormous, from 1 to 52 days. Also, the 90th percentile is 101 days, which means that it took longer than this to complete the selection process of 10 percent of the orders.

It may appear at first glance that this huge difference in completion times might be attributable to the size of the order, meaning that the larger the number of items pertaining to a particular PO, the longer it would take to select the items included in it. However, after further investigations on the size of the orders and the time required fulfilling them, it was possible to find several cases of incongruence that refute that apparently logical conclusion. Table 1 below exemplifies some POs with very close sizes but considerably discrepant selection times (all the POs selected in the table below are within the interquartile range. Thus, none of them are potential outliers).

Table 1. Selection lead times of POs with close sizes

PO	Volume (m^3)	Volume (Ft^3)	Selection Lead Times (days)
201230500337	0.20	7.029	47
201230500344	0.20	7.029	3
201330500197	0.20	7.029	1
201230500336	0.22	7.732	3
201230500463	0.24	8.435	1
201230500404	0.25	8.787	6
201230500306	0.27	9.490	36
201230500311	0.28	9.841	2
201230500425	0.30	10.544	2
201230500451	0.33	11.598	1
201230500279	0.35	12.301	31
201230500435	0.35	12.301	1
201230500434	0.35	12.301	1
201230500332	0.37	13.004	99
201230500317	0.39	13.707	47
201230500427	0.41	14.410	1
201230500300	0.48	16.870	49

A scatter plot is a very useful tool that allows the identification of possible patterns when relating two sets of data. Therefore, this graph was generated in JMP and analyzed with a view to assess whether the order selection lead time and the order cubic footage might be somehow related. The result can be seen in figure 7. It is noticeable that no particular trend can be positively established concerning the relationship between those two variables besides the concentration of plots on the left bottom side. This cluster represents the high number of small orders, mostly up to 7 cubic meters (approximately 245 cubic feet), that took less than 5 days to be completed by the pickers. The coefficient of correlation of 0.4913 also indicates very little linear relationship between the variables.

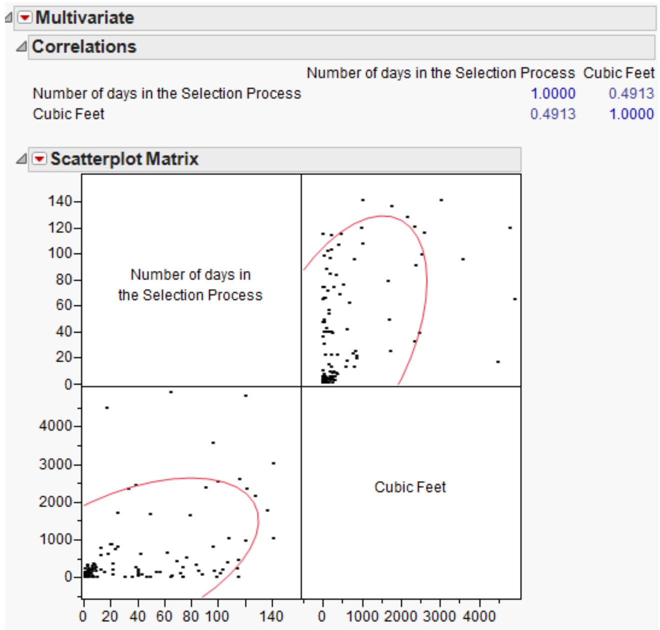


Figure 7. Scatterplot matrix of selection lead times vs. order sizes

Since it was not possible to assertively determine the size of an order as a key driver of the variability in the selection process, a deeper look into the details of this step was necessary. In this way, the number of labor hours required for each team to complete the selection of items pertaining to each Selection List assigned to them during the period researched was recorded, as well as the quantity of materials, in terms of cubic footage (as a reminder, each PO may be broken down into several Selection Lists). Whenever a team was able to work on more than one selection list per day, the total time consumed by each Selection List was averaged, by dividing the time consumed by the number of selection lists prepared. For instance, if in one day, a given team prepared 4 Selection Lists, it was assumed that each list consumed 0.25 day (this is the theoretical flow time of the Selection List). Then, the capacity with which the team selected that particular order was calculated by dividing the volume in cubic feet by the time obtained, resulting in the effective capacity of that team at that particular point, in cubic feet per day. Then, the result was divided by 6.2, which is the average number of labor hours per day, after considering the standard daily or weekly work interruptions (lunch time and physical training dedicated time). The figure obtained was the effective capacity in cubic feet per hour. Then, the results of each team were averaged, and the numbers are presented in table 2.

Table 2. Average effective capacity of picking teams

Warehouse Teams	Avg. Effective Capacity (Ft^3/hour)	Std. Deviation	Coefficient of Variation
Team 1	34.249	36.339	106.10%
Team 9	20.667	23.556	113.98%
Team 5	19.815	31.758	160.27%
Team 6	18.411	31.892	173.22%
Team 7	16.981	29.361	172.91%
Team 3	14.642	31.738	216.76%
Team 4	12.357	33.390	270.21%
Team 8	11.652	23.841	204.61%
Team 2	6.821	31.756	465.57%

It is possible to perceive from the table above that there is a considerable discrepancy amongst the teams in terms of average effective capacity. For instance, while team 1 was able to prepare more than 34 cubic feet per hour on average, team 2 was only able to prepare roughly 7 cubic feet per hour. In order to provide a better assessment of how much variability those differences actually represent, the effective capacity presented by each team when picking the items of each Selection List was computed throughout the timeframe researched, with the purpose of obtaining the histograms and the summary statistics of those capacities. The results are presented in Appendix 2. It is possible to perceive, especially from the interquartile ranges and the quantile box plots, that there is no uniformity between the groups when it comes to performance while accomplishing the selection task. The considerable spread of data demonstrates that there is indeed a substantial amount of variability in this activity, which makes it practically unpredictable to determine how long it will take for a selection list to be completed, even if the team and the order size are determined. Table 3 below summarizes the interquartile ranges (IQR) of all teams.

Table 3. Interquartile ranges of the capacity of the picking teams

Team	25th percentile	75th percentile	IQR
1	5.4395	31.483	26.0435
2	0.3225	7.6525	7.33
3	0.752	13.469	12.717
4	0.35625	20.7883	20.43205
5	0.835	21.208	20.373
6	0.7685	25.978	25.2095
7	0.6495	13.236	12.5865
8	1.082	16.67	15.588
9	1.10975	25.6503	24.54055

One final effort to assess the importance of the variability in the warehouse teams' capacities was attempted. After building histograms of the capacities of each team over time, it was possible to conclude that the conditions necessary to perform a parametric Analysis of Variance (essentially normality and constant variance) were not present. In this way, it was necessary to perform a nonparametric test in order to assess whether those differences in capacities are statistically significant. Therefore, for this purpose the Kruskal-Wallis test was the one chosen. As can be observed in figure 8 below, the p-value of 0.0014 obtained in the Kruskal-Wallis test allows the conclusion that there are significant statistical differences among the groups.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Team 1	32	9255.50	6864.00	289.234	3.552
Team 2	56	9329.50	12012.0	166.598	-3.108
Team 3	57	11015.5	12226.5	193.254	-1.392
Team 4	34	7021.00	7293.00	206.500	-0.392
Team 5	51	11118.0	10939.5	218.000	0.215
Team 6	68	15627.5	14586.0	229.816	1.113
Team 7	57	11852.5	12226.5	207.939	-0.430
Team 8	33	6869.50	7078.50	208.167	-0.305
Team 9	40	9717.00	8580.00	242.925	1.526

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
25.3459	8	0.0014*

Figure 8. Kruskal-Wallis test on the capacity of the picking teams

As was mentioned above, it was not possible to establish neither a positive nor a negative correlation between the size of the order and the items selection lead times. In reality, it was possible to find an indication that the number of teams that worked in a particular PO affected the selection lead times considerably more than the size of the order. Figure 9 below depicts the Scatterplot Matrix comparing the number of teams that work in a PO with the selection completion time. As can be seen, the coefficient of correlation of 0.7586 indicates that there is much more correlation between the number of teams working in a PO than properly the size of it, when it comes to selection times.

Correlations

	Number of days in the Selection Process	Number of teams working
Number of days in the Selection Process	1.0000	0.7586
Number of teams working	0.7586	1.0000

Scatterplot Matrix

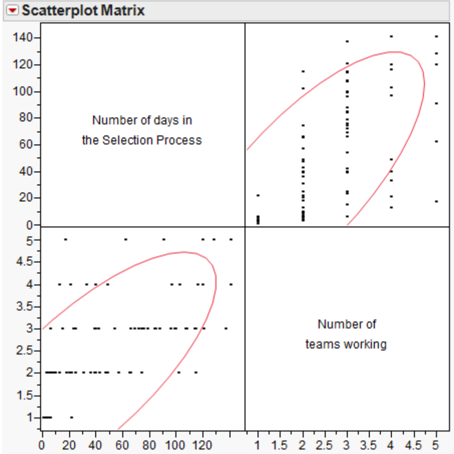


Figure 9. Scatterplot matrix of selection lead times vs. number of teams

The Points Spread graph provided by JMP, demonstrated in figure 10 below, also provides an interesting visual insight about the variability increase when the quantity of teams working in a PO increases. Those results seem to indicate that it would be preferable to designate only one team per order, regardless of its size, instead of splitting it into different groups.

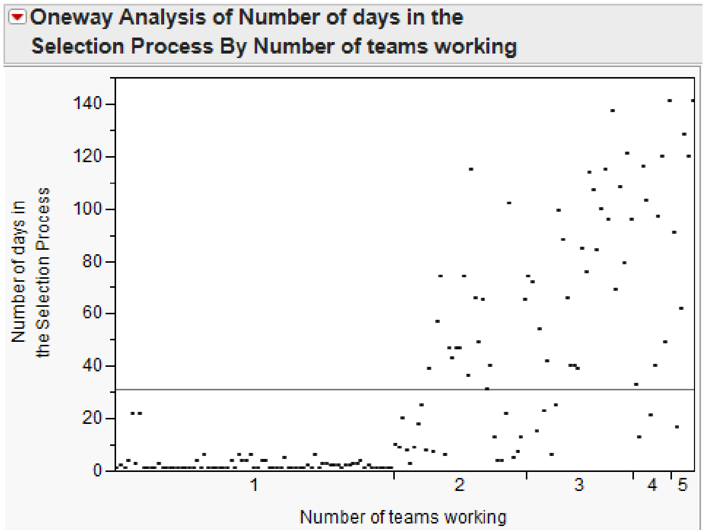


Figure 10. Points spread graph of selection lead times vs. number of teams

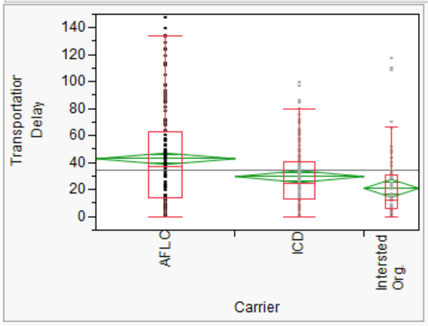
From all that was exposed so far, it is possible to conclude that there is enough evidence that the different performance levels of the warehouse teams constitute an important assignable cause of variation of the process. This result is by no means surprising. According to Doty (1991), people are the greatest source of variation in the process, mainly due to "personal, emotional and mental problems of the operator, along with inattentiveness and lack of understanding", among many other possible causes.

Therefore, given that a PO may be split into several selection lists that may be distributed to different teams with different capacities, and with a lot of variation when it comes to those capacities, it is possible to conclude that it is practically impossible to determine how much time it will take for a particular PO to have all its items selected from the inventory. Consequently, the way that the selection process is structured seems to add layers of variability to the process, making it unpredictable, and consequently out of control.

The selection activity is not the only step in the process that suffers the devastating effects of variability. After the selection of items of a list is done, they are forwarded to the Cargo Terminal, to wait for the proper transportation. However, according to what was reported by the head of the ICD's Warehouses Section during the interview, there was no transportation plan in place during the timeframe of this research. Therefore, there is another source of variation and unpredictability in this process: it is impossible to predict how long an order would have to wait in the Cargo Terminal until a carrier is designated to transport it to its destination.

It was found that, after a selection list is made available for transportation by the warehouse, it has to wait, on average, 34 days until it is transported (with standard deviation of 29 days). It was hypothesized that the wait time for transportation might have been impacted by the carrier (the ICD itself, through its own truck fleet, the AFLC, through their truck fleet or air mode or the organization to which the material was intended, by their own means). In this way, in order to verify whether the carrier had a statistically significant impact in the wait time, another non-parametric Kruskal-Wallis test was made (again, the wait times, as computed by the carrier displayed no parametric distribution, thus preventing the use of parametric ANOVA). The result of this test is presented in figure 11 below. The test results (low p-value on the Kruskal-Wallis and on the pairwise comparisons using the Steel-Dwass method) are an indication that there is significant statistical variability in the average time an order has to wait in the cargo terminal, depending on the organization that is responsible for its transportation.

Oneway Analysis of Transportation Delay By Carrier



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
AFLC	0	5	13.75	37.5	63.25	91	147
ICD	0	6	13	25	40.75	63.1	99
Intersted Org.	0	1	6	12.5	31.25	49	117

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
AFLC	182	44168.5	38493.0	242.684	4.574
ICD	168	34580.5	35532.0	205.836	-0.776
Intersted Org.	72	10504.0	15228.0	145.889	-5.013

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
33.1088	2	<.0001*

Nonparametric Comparisons For All Pairs Using Steel-Dwass Method

q*	Alpha
2.34370	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
ICD	AFLC	-32.9899	10.82364	-3.04795	0.0065*	-8.0000	-16.0000	-2.00000
Intersted Org.	ICD	-38.3036	9.77489	-3.91857	0.0003*	-10.0000	-16.0000	-4.00000
Intersted Org.	AFLC	-54.1281	10.22619	-5.29309	<.0001*	-17.0000	-28.0000	-9.00000

Figure 11. Kruskal-Wallis and Steel-Dwass tests on transportation delays

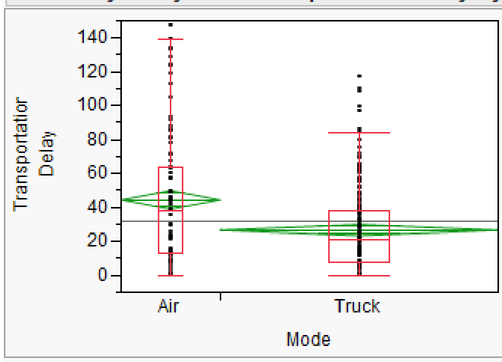
It is also possible to observe in the figure above that the data related to the AFLC are considerably more spread, as expressed by the interquartile range, when compared to the other carriers, as demonstrated by table 4 below.

Table 4. Interquartile ranges of transportation waiting times

Carrier	25th percentile	75th percentile	IQR
AFLTC	13.75	63.25	49.5
ICD	13	40.75	27.75
Interested Org.	6	31.25	25.25

Similar results were obtained when the comparison of transportation delays was made in terms of mode of transportation. Figure 12 below displays the results.

Oneway Analysis of Transportation Delay By Mode



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Air	0	5	13	38	64	105	147
Truck	0	4	7.75	21	38.25	61	117

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Air	99	22482.0	18711.0	227.091	4.051
Truck	278	48771.0	52542.0	175.435	-4.051

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
22482	4.05052	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
16.4110	1	<.0001*

Figure 12. Analysis of transportation delays by mode

It is observable that there is much more variability related to the air mode than there is in the transportation by trucks. A more detailed study of the process developed at the ICD's cargo terminal level allows the understanding of these results. Whenever an order arrives at the cargo terminal from the warehouse, the possibilities are twofold, as explained in the first section of this chapter: if the destination is within the range of locations attended by ICD, a transportation request is forwarded to ICD's Transportation Section. It is quite common that, at the moment the transportation is requested, no trucks are available at ICD's garage. According to the information provided by the interviewee, this usually occurs due to two main reasons: maintenance or missions conflict (in this case the truck fleet is being used by other sections of ICD, executing other missions). If, otherwise, the cargo is to be delivered to a location usually not attended by the ICD's fleet, the transportation request is sent to AFLC. This center concentrates transportation requests from all the Air Force bases and organizations, trying to conciliate the demand with the availability of transportation. In this way, whenever a pending request form ICD matches an air freight mission in terms of destination, and there is space available in the aircraft, ICD is contacted by AFLC and requested to forward the cargo, most of times to the Galeao Air Cargo Terminal (in Rio de Janeiro). Here again there is room for potential problems with ICD's trucks' availability. It is not unusual to miss those transportation opportunities due to lack of trucks available in ICD.

It was possible to conclude that the uncertainty about the transportation phase is the main assignable cause of variability in the entire process, because it is the key factor that drives the way the process is designed. The decisions about the inventory picking schedule and the efforts to prepare the highest possible amount of items to be transported (thus elevating the work-in-process inventory), are entirely guided towards addressing the variability characteristic of the transportation.

In this way, it became very clear, from the analysis of data, of the procedures established in the process and of the pieces of information provided by the head of the Warehouses Section, that variability, allied with lack of proper planning, especially in the transportation phase, is an important detrimental factor in process performance. The most important outcome of this is that a considerable amount of orders are overdue, considering the legal timeframe of thirty days that must be allowed to the receiving organization to perform the receiving and acceptance procedures, as described in the first section of this chapter. For instance, in the year 2012, more than 70 % of the orders had their items completely transported after the appropriate timeframe. In February 2013 (when the first class of soldiers were already incorporating to the Air Force), there were roughly 37 % of orders still waiting for transportation in ICD's cargo terminal. The 100% mark was only achieved in May of 2013.

Therefore, it was possible to conclude, addressing the third research question, that variability represents a considerably harmful factor in overall process performance. When it comes to the order selection, it increases the times required to accomplish this task, thus reducing its efficiency. Regarding the transportation phase, it poses a high level of uncertainty as to when the material will be transported, leading to the increase of work-in-process inventory, bringing additional managerial burden to the process and allowing the growth of several types of waste. The identification of those types of waste, according to the Lean Thinking theoretical framework is the object of the next section of this paper.

Identified forms of waste in the process

As explained in chapter II of this paper, there is consensus in the literature about seven major types of waste that can commonly be found in processes: overprocessing, transportation, motion, inventory, waiting time, defect and overproduction. A brief explanation on those forms of waste was also provided.

After analyzing the process under study, it was possible to positively detect at least six of these forms of waste, as will be further explained. The only type of waste that was not possible to observe, from the available data for this research, was motion.

Overprocessing.

The main aspect when it comes to overprocessing is a disconnection between the tasks performed in the process and the value attributed by the customer to those activities. Whenever the customer does not credit value to an activity, and it is performed anyway, it is possible to conclude that the system is overprocessing.

Therefore, in order to assess if a system is overprocessing, the first thing that should be made clear is what does the customer value. This information might most certainly be inferred. However, as it is frequently argued, quality is something that lies in “the eyes of the beholder”. As mentioned in chapter II, the customer is actually the ultimate entity capable of determining what level of quality is expected from a product of a service. Hence, only he or she can provide the truly reliable information of what is valuable to him or her. For this purpose, it is very important that the service provider keeps feedback channels open with the customers, so their expectations can be addressed, and most important, the decision on what activities should be performed in order to meet those expectations can be properly made.

According to what was informed by the interviewee, there was no formal customer feedback process in place in ICD during the timeframe researched. In this way, specific aspects that might be potentially valuable to ICD customers could not be addressed. Thus, the analysis was based on the assumption that the minimum valued aspects with respect to the distribution process were timeliness and completeness of orders. Therefore, considering those two aspects, all the steps of the process that do not contribute for the orders to arrive on time at their destination and in the right quantities ordered should be eliminated or minimized to the maximum possible extent.

Some examples of overprocessing are approval steps and numerous handoffs. George (2003) invites us to think critically about those steps in an attempt to determine if the customer would say that those steps are adding value. In other words, he encourages us to think that if less checks or handoffs were made, would the value of the product diminish for the customer.

It was possible to find these kinds of overprocessing activities in the process under study. The volume of documents generated by the process is enormous. Firstly, a Provision Order generated by the Sub-directorate of Supply is printed out and signed by ICD's Director and then forwarded to the Supply Division. Then, depending on the size, the PO may be broken down into several Selection Lists that are handed to the warehouse manager. Then, the warehouse manager distributes the various Selection Lists among the teams. After the items are selected, each team manually generates one or several Material Movement Lists (each one in two copies) to transfer the material from the warehouse to the cargo terminal. After being checked by a member of the cargo terminal against the related material, one copy of each MML is signed and returned to the warehouse, and the other copy stays in the cargo terminal. Even after the transportation is made available, all the items of a MML are not necessarily hauled at the same time, due to lack of space in the truck or airplane. Therefore, when the exact quantity of materials to be transported was determined, a Final Provision List is issued, with the discrimination of all items and respective quantities that are effectively being shipped.

Depending on the quantity of materials being transported, the Final Provision Lists may be huge documents, with hundreds of pages. These documents are issued in two copies, and every page of each copy needs to be signed by the manager of the Supply Division and by the ICD's Director.

Another aspect of this process that denotes overprocessing is the need of duplicate records of the monetary value of the items. As explained in the first subsection of this chapter, those values are included in two different systems, the ISBFA and the MSLIS, which require constant efforts of reconciliation, given that those values differ very frequently.

Considering the basic assumption that all the ICD's customers care about is timeliness and completeness of orders, it is reasonably arguable that the proliferation of documents and signatures in the process add absolutely no value to them.

The material hauling between the warehouses and the cargo terminal is another step that seems to add absolutely no value to the customer. It is really not possible to find a reason why he or she would care if the material comes from the cargo terminal or directly from the warehouse, as long as it arrives at the right time and in the right quantity. This process step in particular, leads us to the next type of waste identified.

Transportation.

As a reminder, transportation, conceptualized as a form of waste, can be understood as the "unnecessary movement of materials, products or information" (George, 2003).

It is fair to assume that customers in general do not care about how their goods are being delivered, as long as deadlines, quantities and expected quality are met. Therefore, whenever possible, transportation times should be minimized.

It was possible to detect in the process under study at least one step related to this type of waste, which is the movement of material between the warehouses and the cargo terminal. According to what was provided by the interviewee, this activity is performed with the aim of making the largest quantity of items available to be hauled, whenever transportation becomes available.

Not only the transportation itself is a form of waste, but also in the case of the process under study, it frequently leads to other delays, because the transportation of materials between warehouses in ICD is subject to truck availability, which is not always the case. This fact contributes to another type of waste which is waiting time.

Waiting time.

As mentioned in chapter II waiting can be defined as "any delay between when one process step/activity ends and the next step/activity begins" (George, 2003). This is essentially the more pervasive type of waste found in the process.

The first and more obvious source of waiting in the process is the cargo terminal procedure itself. This warehouse serves uniquely for the purpose of accumulating work-in-process inventory that is waiting for the next action, which is the transportation to its appropriate destination.

The waiting time of each Selection List at the warehouse is, on average, 34 days as demonstrated in the previous subsection of this chapter. Considering that the average total flow time of each selection list is 58 days, it is possible to conclude that this step is responsible, on average, for only 58.62% of the total average time that a Selection List spends in the process.

The simulation that was performed also revealed that, after 30 replications, there is an average waiting time of 16.34 days at the inventory picking step of the process. This is the time lapse that occurs between when a Selection List is approved by the Supply Division clerical staff and when the selection process effectively starts at the warehouse. It was also possible to collect these delays from the existing data, once the dates of authorization and the beginning of the selection of each Selection List are available. The average delay as measured from the existing data is 18.69 days, which falls into the 95% confidence interval generated for the simulation result.

Actually, it is possible to conclude that, from the moment the process is triggered, all its steps besides the inventory picking are essentially characterized by waiting. After an order is authorized by the Supply Division, it waits until a team starts its selection. After the selection is finished, the items wait to be transported to the cargo terminal, where they wait again to be hauled to their destination.

The effects of waiting can be more accurately assessed in terms of flow time efficiency, calculated as the ratio between the theoretical flow time and the actual flow time of the process. Anupindi et al. (2012) define flow time as the sum of theoretical flow time and waiting time. Still according to them, theoretical flow time is the time actually required to perform a task, without any waiting.

The process of obtaining the flow time efficiency demonstrated that even the inventory picking activity itself is full of waiting time. The theoretical flow times were obtained by computing the actual time required by each team to select the items pertaining to each Selection List. Then, all the theoretical flow times were aggregated at the Provision Order level and compared with the actual time that the order spent in the selection process. This way, the ratio between the number of days actually required to select all the items of a given PO and the number of days that PO spent in this step of the process provided the flow time efficiency of the inventory picking activity. The results demonstrated that, on average, the flow time efficiency of the inventory picking for the 2012 season was 27.85%, which means that, on average, more than 70% of the flow time of this step actually represents waiting.

Once it was determined that the only step in the process that actually involves a certain amount of activity other than waiting is the inventory picking, the theoretical flow time of this step can also be considered in the calculation of the overall process flow time efficiency. After performing the calculations, it was found that the average flow time efficiency of the whole process was 0.05%, meaning that 99.95% of the time that a PO spends within the process boundaries is represented by waiting.

George (2003) proposes a similar metric, naming it Process Cycle Efficiency (the ratio between value-added time over total lead time). He also defines as “un-Lean” any process with a Process Cycle Efficiency of less than 50%.

All this amount of waiting is directly linked to the next type of waste to be discussed: inventory.

Inventory.

The conception of inventory as a type of waste used by this research is the one provided by George (2003): “any work-in-process that is in excess of what is required to produce for the customer”.

In this way, every unit produced by the process that is not immediately consumed by whoever the customer is, contributes to build up inventory. The growth of work-in-process inventory increases the managerial burden necessary to manage the process, since it requires more control in order to avoid, for instance, “that the sequence in which work is done does not match the sequence in which it is needed downstream” (George, 2003).

In the process under study, it was found that the high number of items selected waiting to be transported brings a number of managerial issues to the process. It was reported by the interviewee that it is very common that materials are left behind among the piles of boxes, when they should have been transported. Confusion regarding the exact location of materials is also common.

In order to illustrate the growth of work-in-process inventory, an inventory buildup diagram was constructed, considering the year 2012. The results are presented in tables 5 and 6 and in figures 13 and 14.

Table 5. Inventory buildup along 2012 peak season

Month	Inbound Inventory (Ft^3)	Outbound Inventory (Ft^3)	Resulting WIP Inventory (Ft^3)
Ago/12	12801.21	7808.43	4992.78
Sep/12	7976.52	2129.47	10839.83
Oct/12	10971.56	7316.85	14494.54
Nov/12	1238.49	11584.98	4148.05
Dez/12	2547.95	2063.79	4632.21
Jan/13	0.00	1365.27	3266.94
Fev/13	0.00	2170.79	1096.15
Mar/13	0.00	575.28	520.87

Table 6. Inventory buildup along 2013 peak season

Month	Inbound Inventory (Ft^3)	Outbound Inventory (Ft^3)	Resulting WIP Inventory (Ft^3)
Ago/13	14230.75	2623.53	11607.22
Sep/13	9799.82	6686.48	14720.56
Oct/13	2424.71	4178.08	12967.19
Nov/13	5622.09	2727.7	15861.58
Dez/13	198.12	11268.56	4791.14
Jan/14	0.00	4084.85	706.29
Fev/14	0.00	0	706.29
Mar/14	0.00	706.29	0.00

Figure 13. Inventory buildup diagram - 2012 peak season

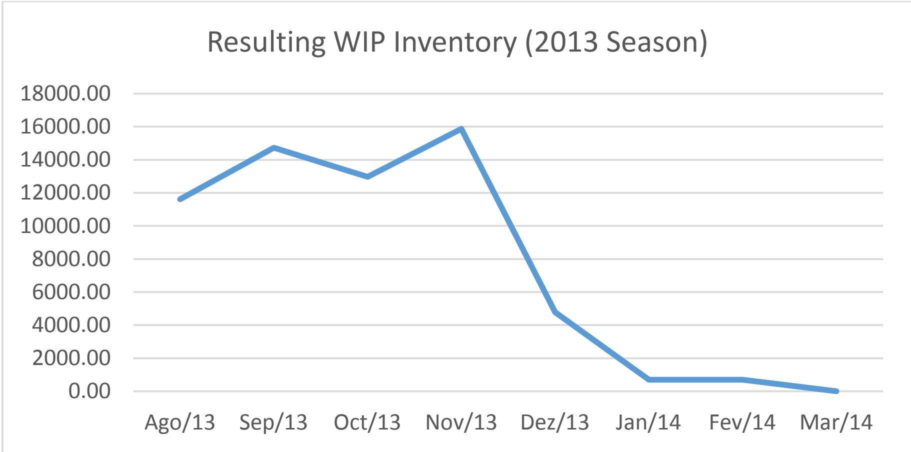


Figure 14. Inventory buildup diagram - 2013 peak season

George (2003) advocates that excess inventory is often the result of another type of waste, which is overproduction.

Overproduction.

George (2003) defines overproduction as the "production of service outputs or products beyond what is needed for immediate use".

If we consider the transportation phase as the "customer" of the previous steps in the process, this type of waste becomes immediately apparent. The inventory buildup is indeed the result of overproduction, since the process actually produces more items than its capacity for transportation.

Defect.

Defect can be considered as "any aspect of the service that does not conform to customer needs" (George, 2003). Here again, the assumption of what is valuable to the ICD's customers (timeliness and completeness of orders) plays an important role.

Therefore, for the purpose of this research, a Provision Order was considered as defective for either an Order that was shipped after the deadline of 30 days prior to the closing of the fiscal year (1^{st} of December) or an Order that was not fulfilled in its entirety (orders partially fulfilled).

Considering the first case (orders that were not entirely shipped before the date of the 1^{st} of December), it was possible to verify that, during the timeframe researched, 116 out of 152 orders (76.31 % of the orders) were defective. On the other hand, 43.42 % of the orders (66 out of 152) were not entirely fulfilled, meaning that there were items from those orders that were not found in the inventory.

It is possible to conclude that all the types of waste identified in the process are somewhat connected and also a product of variability. Since there is uncertainty as to when the transportation will be provided (variability), the whole process is designed to produce high amounts of work-in-process inventory. This conclusion is in line with what is advocated by Byrne and Markham (1991): "variability in transit times also contributes to the need for inventory. Unpredictable service from certain carriers prompts the company to carry additional safety stock". This inventory is transported to a facility where it can be accumulated without excessively interfering with the activities in the warehouses. The excess inventory sits idle in the process with long waiting times, which reduces dramatically the process efficiency and increases the number of defective orders (especially those ones shipped after the due date). The huge amount of inventory demands more control and the adoption of unnecessary steps (overprocessing), all of this is a result of the lack of capacity of the process for immediately processing all the units produced (overproduction).

Regarding the capacity of the system, an analysis under the framework of the Theory of constraints also demonstrated that the transportation phase can be considered as the process' bottleneck, as demonstrated in the next topic.

Determination of the system's constraint through capacity analysis

"Capacity analysis involves determining the throughput capacity of workstations in a system and ultimately the capacity of the entire system" (Heizer & Render, 2010).

One of the important outcomes of a capacity analysis is the determination of a process constraint, or bottleneck, thus enabling the adoption of managerial actions toward constraint elevation and other applicable measures.

As stated in the literature review, the concept of throughput adopted by this research is equivalent to the notion of average flow rate. The average flow rate was calculated in terms of cubic feet per month, for both the inventory picking activity and the transportation phase. For this intent, it was considered the total amount of time, in months, required for each step to process all the inbound flow units. Then, the average of processed units per month was calculated.

The results of the calculations demonstrated that the average flow rate of the inventory picking phase was 5,730.16 cubic feet per month, while the average flow rate of the transportation phase was 3,734.67 cubic feet per month.

This result suggests that, as the transportation phase is the one with the lowest throughput, it can be considered the process bottleneck, thus, the step that actually limits the overall process throughput. Therefore, the average flow rate of the transportation phase can be understood as the effective capacity of this process. This is in line with what advocates Anupindi et al. (2012), who define "the effective capacity of a process as the effective capacity of the bottleneck".

The simulation results have also confirmed that the distribution phase can be considered as the bottleneck of the process. After running 30 replications of the model, the average capacity utilization obtained for the inventory picking phase was 24.40%, while the one obtained for the transportation step was 71.20%. "A workstation in a process is a bottleneck if (1) it has the highest total time per unit processed, or (2) it has the highest average utilization and total workload" (Krajewski, Ritzman, & Malhotra, 2010).

After performing the analyses under the theoretical framework that guided this research, it was possible to conclude that the performance of the process under study suffers from problems due to variability issues, waste generation and lack of appropriate management of the system's constraint. It became clear that some managerial actions are required, towards improvement of the process' performance.

However, "to improve the performance of any business activity, you must understand how well it performs today. In other words, you must measure it" (Keebler, Manrodt, Durtsche,

& Ledyard, 1999). Therefore, the investigation of metrics that might potentially be in place at ICD's Supply Division in order to allow the managers of the process under study to evaluate and keep track of the waste and inefficiencies observed is the subject of the next topic.

Metrics in place at ICD's Supply Division

The fifth investigative question of this research was *what metrics are currently being taken from this process by the Supply Division Management Team?*

This issue was addressed in the interview conducted with the head of the warehouses Section. According to the information he provided, there were no metrics in place in the Supply Division in order to measure aspects of process performance.

Nevertheless, it became clear that the Supply Division management staff collects several data from the process, organizing them into spreadsheets and graphs. This research was only possible because of those data. Therefore, the interviewee was asked whether some kind of statistical treatment was given to those data. The answer to this question was that no statistical treatment was given to the data collected.

According to the interviewee, the data collected from the process is mainly used to populate the monthly accountability process, in which each division of ICD reports to the Director their monthly activities.

Those monthly reports depict the current situation in terms of how much material has been shipped up to the moment the report is provided (in cubic meters), but without comparing the figures to the total amount that has yet to be shipped. Therefore, they have no idea about how the work is progressing during the season.

Another measurement that is usually taken provides a comparison between the inventory level in a given month and the historical inventory level in the same month in past years. It was not possible to establish a clear connection between this measurement and the distribution process performance.

Therefore, it was possible to conclude that, even though there are a number of measurements that have been taken from the process, they did not seem to be used in order to understand the process and guide actions toward improvements. Since no statistical analysis is done on the data, it is possible to conclude that the management staff of ICD's Supply Division does not have the tools that would enable them to have a better knowledge about important aspects of process performance concerning variability effects and waste production.

After addressing the several issues found in the process brought by the detrimental effects of variability, waste production and capacity constraints, this paper presents in the next chapter the summary of the conclusions reached by this research, as well as a number of recommendations for potential improvements in the process under study.

V. Conclusions and Recommendations

Overview

This chapter summarizes all the findings of this research, addressing each one of the research objectives. Recommendations regarding metrics, potential process improvements, as well as areas for further investigations are also provided.

The addressing of the research objectives

The first objective of this research was to establish how the process of distribution of PROVSYS' uniforms is structured and executed at the ICD level.

After studying the several documents related to this process, as well as interviewing the head of the ICD's Warehouses Section, it was possible to understand that the process starts with the issuance of the Provision Order by the Sub-directorate of Supply, dictating which materials and in which quantities are to be distributed to each BAF organization. A schedule for the inventory picking is elaborated by the Supply Division management staff, according to which the materials are selected from the inventory. After selection, the pieces of uniform are forwarded to the cargo terminal, where they wait to be transported to their respective locations.

The second research objective was to study the impact of variability and the types of waste recognized in the process and its effects on overall process performance and quality.

By applying a number of statistical analyses it was possible to conclude that variability inflicts a considerably detrimental impact on the process performance. In the inventory picking step, it was identified that the teams are very heterogeneous with respect to their capacities while performing this activity. Histograms of their capacities measured over time were built and the respective interquartile ranges were analyzed, leading to the conclusion that the degree of variability with which each team performs its tasks is considerably high. It was also demonstrated that the number of different teams handling an order apparently has more impact over the total time spent by the order in this step than the actual size of it, in terms of number of items to be selected. Both variables (size of the order and number of teams working on it) were plotted against the order selection lead times, and the latter displayed a higher correlation coefficient than the first one, leading to the conclusion that it is more predictable over the response than the size of the order.

It was also perceived that variability plays an important role when it comes to the transportation phase. The times the items need to wait for transportation are on average very long, and also have a lot of variability. It was identified that those times are longer when the transportation depends on arrangements with AFLC, especially when the air mode is the one to be used. The degree of variability was also assessed by building histograms on the order waiting times and obtaining the interquartile ranges. Statistical significance of the differences in waiting times by carrier and by mode was assessed through the Kruskal-Wallis test.

As a result of the huge variability, especially in the transportation phase, it could be observed that the way the process was designed and has been performed has led to several types of waste.

At least six of the seven types of waste more commonly espoused by the literature were identified: (1) overprocessing, as a result of performing steps that do not add value to the customer (proliferation of documents, signatures and execution of unnecessary tasks in the process); (2) unnecessary transportation, when moving items between warehouses; (3) waiting times, as a result of lack of capacity of processing all the flow units entering the process and as a result of lack of planning in the transportation phase; (4) inventory, as a resort to coping with the uncertainty regarding when the material will be transported; (5) defect, as a result of high number of partially fulfilled orders and many overdue orders; and (6) overproducing, once the upstream steps in the process produce more units than required for immediate transportation.

As a result of all the factors mentioned above, the performance of the process, as measured by flowtime efficiency (also known as process cycle efficiency) was calculated as 0.05%, on average, meaning that an average of 99.95% of the time a flow unit spends within the process boundaries is non-value adding.

The next research objective was to understand which metrics, if any, were in place at the ICD's Supply Division and how they have been used to guide behaviors toward process improvements. After addressing this issue in the interview and analyzing the performance indicators used monthly by the ICD's Supply Division, it was possible to conclude that no effective metric was in place during the timeframe researched. No statistical treatment was given to the data collected from the records of the daily activities performed by the Supply Division's employees.

The last research objective was to identify which performance and quality measures would be appropriate to allow Supply Division management to keep track of the different forms of waste and guide their actions towards process improvements. This research objective will be addressed under the next topic of this paper.

Recommendations regarding metrics

This research revealed high amounts of variability and waste throughout the process under study. It was also identified that the Supply Division management staff does not have an appropriate set of metrics in place or a set of guidelines regarding which statistical treatment should be given to the data, in order to keep the process under control and monitor the amount of waste generated. Therefore, it is imperative that there be the implementation of a minimum set of metrics that would help management to adopt procedures towards performance improvements.

It was identified that one important source of variability in the inventory selection process is the difference between team performances, in terms of capacity. Therefore, the first suggested metric is Effective Capacity of the teams, measured as a ratio between cubic meters or cubic feet selected and the chosen unit of time (week, for instance). Therefore, by having this metric applied over time to each team, the management staff would have a clear picture of the variability in the performance of the different teams, on a weekly basis, thus being able to adopt corrective procedures before a severe impact is felt.

In order to properly address the variability problem regarding the process lead times, it is necessary to have constant monitoring of the time spent by each flow unit at each step in the process. Therefore, activity flow time is the next suggested metric to be taken. This metric should be obtained by measuring the total time spent by a flow unit in each step of the process. Total process flow time is also a metric that could be obtained, by recording the number of days passed between the date an order is authorized and the date it departs from ICD. By taking those measurements over time, it would be possible to give proper statistical treatment to them, in order to better comprehend the amount of variability involved. In this regard, histograms are primary and useful tools that allow managers to have a better understanding of how a particular variable behaves over time. Also, obtaining means, standard deviations and interquartile ranges help in comprehending the amount of variability embedded in the processes. These statistical processes should be applied to every measure taken from the process, in order to allow managers to address the variability issues faced.

One of the most negative impacts of variability that was encountered in the process under study was waste generation. The most evident and measurable forms of waste, whose metrics could be easily obtained from the data that have already been taken from the process, is wait times, inventory and defect.

One particularly effective metric that would allow management to address the impacts of wait times in the process is flow time efficiency. This metric can be obtained as a ratio between value adding time and the total flow time a flow unit spends in the process. The closer this metric gets to one, the closer to perfection the process gets. It is easily arguable that it would be impossible to obtain 1 from this metric. Therefore, the goal of the managers, in pursuing constant improvement, should be to drive all efforts in order to get as close as possible to 1.

Regarding the measurement of the amount of work-in-process inventory, one metric that managers should implement is inventory buildup, measured as the difference between throughput and inflow rate. This metric could also be taken on a weekly basis, and could be applied either to each step of the process or to the process as a whole. Since work-in-process inventory is a form of waste, the management goal should be a zero inventory buildup, meaning that all the flow units entering in the process in a given week were able to be processed within that same week. If a zero inventory buildup is also arguably unreachable, the target should be to keep this metric as close as possible to this value.

Finally, about defect, a simple metric named defect rate could be easily obtained by calculating a ratio between the number of defective orders and the total number of orders issued.

The defects in the case of this process can be categorized in two groups: late orders (the ones shipped after the first of December) and partially filled orders (those ones for which some item or items were not found in the inventory by the pickers). The goal of management should obviously achieve a defect rate as close as possible to zero.

Recommendations regarding variability, waste reduction and areas for future research

"Quality is inversely proportional to variability" (Montgomery, 2005). This definition implies that "if variability in the important characteristics of a product decreases, the quality of the product increases" (Montgomery, 2005).

Therefore, considering the two aspects of quality previously assumed as important to ICD customers (timeliness and completeness of orders), it is imperative to reduce by all possible means, every aspect of variability that could threaten the process performance regarding these factors. This would certainly provide a good overall perception of quality about ICD's work, by its customers.

Concerning the inventory selection process, the research made clear the necessity of addressing the high variability regarding the capacity of the teams. As this is an activity entirely conducted by humans, there is a plethora of possible causes for this sort of variability. Motivational issues, lack of training of some teams, lack of standardization procedures are some of the likely causes. This is certainly one area that demands further research in order to identify the root causes of such diverse performance patterns.

Another recommendation that could reduce variability, as well as the lead times of the inventory selection task, would be the implementation of some sort of Warehouse Management System (WMS). Lahmar (2008) defines a WMS as "a computer software package that collects, analyzes and reports the information necessary to move goods through a warehouse or distribution center. He also points out that "from this information, a WMS is able to instruct employees on the best ways in which to perform warehouse activities (e.g. where to put or where to find an item)" (Lahmar, 2008). Lahmar (2008), citing Lindgaard, exemplified one use of a WMS in a grocery distribution center. There, the WMS calculated the time to pick and assemble each order, and workers were required to perform within 5 percent of the estimated time.

However, a WMS requires extensive work before implementation. Therefore "given the potential complexity of a WMS implementation, a major question is whether the buyer of a WMS should purchase a standard package or a customized version" (Lahmar, 2008). In this way, a feasibility study regarding the implementation of a WMS could potentially be an area for further research.

Regarding warehouse procedures, it is possible to seek for improvement opportunities even if the implementation of a WMS is, due to some reason, out of sight. "Storage and order picking form the heart of most warehouse operations. Warehouse efficiency depends to a large extent on the methods used for storing products and picking orders." (Lahmar, 2008). This author provides several strategies for optimizing warehouse operations. The most important and applicable to the process under study are summarized as follows.

1. Storage of products at their appropriate locations, with fast-moving items located at easily accessible locations at short distances from the dispatch position.

2. Dynamic use of locations, constantly (e.g. on a monthly basis) reassigning locations based on turnover frequency, to reduce travel time.

3. Apply family-grouping to storage, with the objective of making the process efficient. This would be achieved by grouping items that are frequently ordered together.

Even though it was possible to learn from the interviewee that none of these factors seem to be considered in the daily warehouse activities at ICD, further detailed investigations on this matter could also be a potential area for future research efforts.

Since the transportation phase was identified as the most important source of variability in the process, since it is the key driver determining the process design and procedures adopted, one recommendation that seems to be very pertinent is the attempt of reducing, to the maximum possible extent, the uncertainty as to when the materials selected would be hauled to their destinations.

Developing a transportation plan and schedule, prior to the determination of the inventory picking schedule, would certainly be the most beneficial measure to be adopted by managers of the process. This would dramatically reduce the amount of variability in the process. As reported by the interviewee, it would be perfectly possible to obtain, both from ICD's garage, and from AFLC, a preliminary schedule of available transportation to the various locations to where the materials need to be transported. In this way, the demand for transportation would be transformed from unpredictable to predictable (thus reducing the necessity of producing work-in-process inventory to cope with this uncertainty).

Revisiting the concept that processes have both external and internal customers, the comprehension that the transportation phase is an internal customer of the upstream phases of the process (like inventory picking), would enable the adoption of one of the key Lean leverages of process performance: the pull approach.

By dramatically reducing variability of transportation, by implementing a transportation plan, and by adopting the pull approach, the process would be able to produce the exact amount of units that would be necessary to meet the transportation schedule, rather than the current approach of flooding the process with inventory. The process would be able to be simplified, even with the elimination of the whole cargo terminal step. The materials would be able to depart from the warehouse, if the inventory picking is synchronized with the transportation schedule (here again, it would be crucial to reduce the variability in the inventory picking process). The implementation of this approach would most likely result in the reduction of unnecessary transportation, work in process inventory, waiting times, overproducing, overprocessing and defect (especially regarding overdue orders).

As for the partially fulfilled orders, another area of potential future research refers to the reasons why the number of them are so high, as compared to the total of orders issued by the Sub-directorate of Supply (as pointed out in chapter IV, more than 43% of the orders were not entirely fulfilled during the timeframe researched). Investigations about inventory management procedures, as well as the picking process itself, would certainly cast some light on the reasons for such a negative indicator.

Finally, a potential area for future research relates to a Business Process Reengineering approach. The results of the present research demonstrated that the PROVSYS could certainly benefit from a full redesign of the way it is structured. Procedures at the Sub-directorate of Supply level, or at the whole PROVSYS' supply chain, could certainly be reviewed in order to allow the Directorate of Intendancy to satisfy its customers in the most efficient and cost-effective way.

Appendix 1: Theoretical distributions used in the simulation

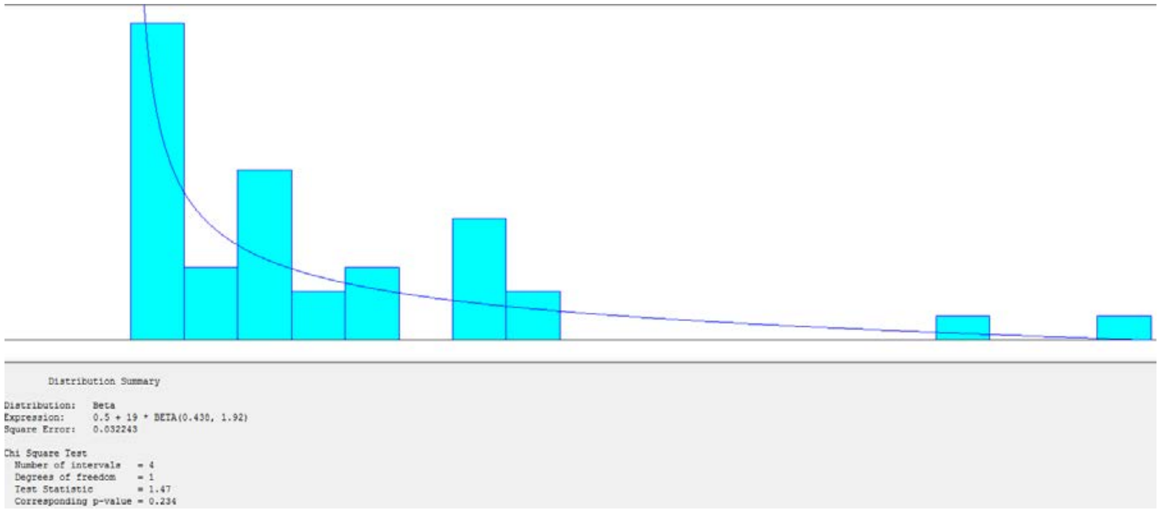


Figure 15. Interarrival times - beta distribution, p-value 0.234

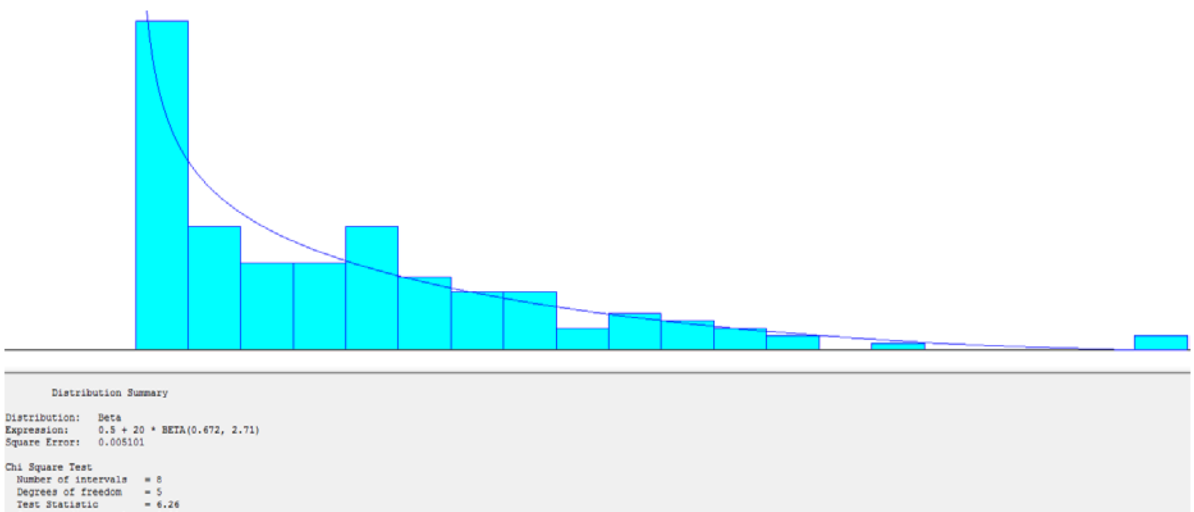


Figure 16. Inventory picking times - beta distribution, p-value 0.290

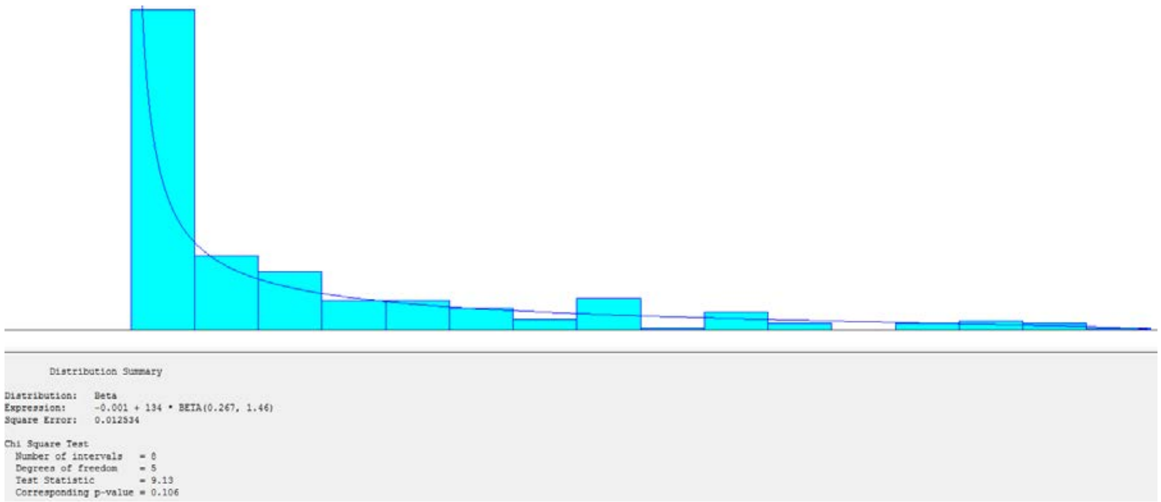


Figure 17. Cargo terminal procedures - beta distribution, p-value 0.106

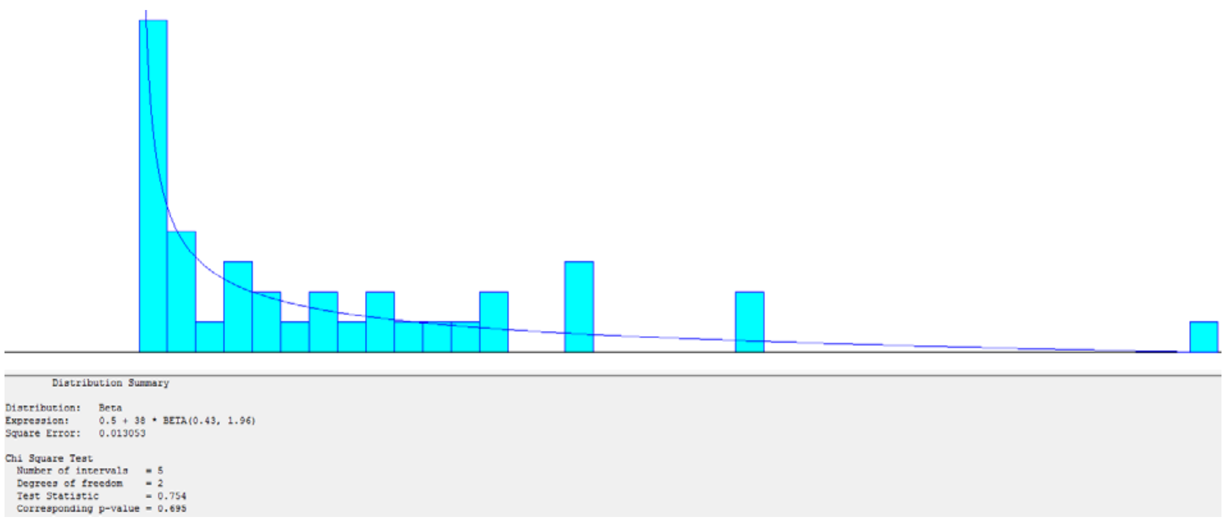


Figure 18. Number of entities arriving the system - beta distribution, p-value 0.695

Appendix 2: Histograms and summary statistics of teams capacities

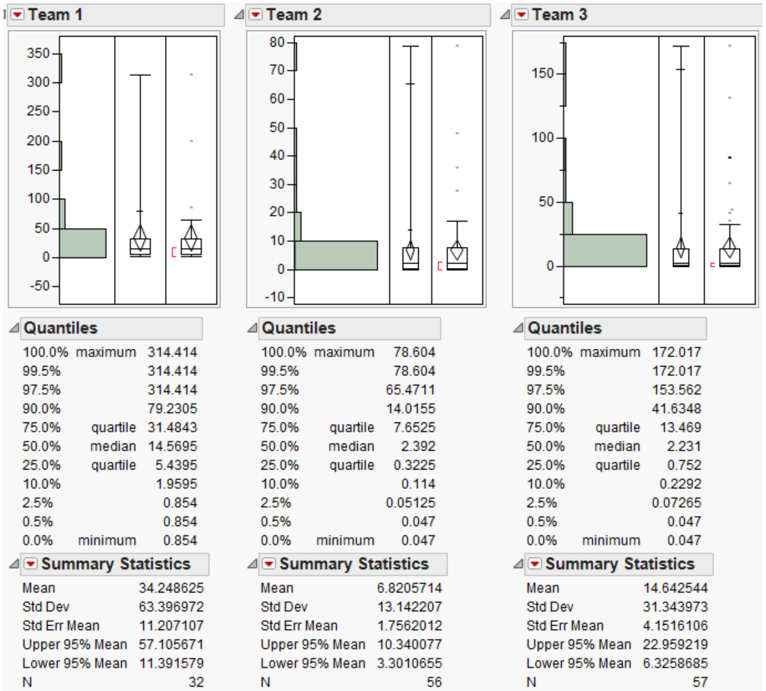


Figure 19. Teams 1 through 3 capacity histograms and summary statistics

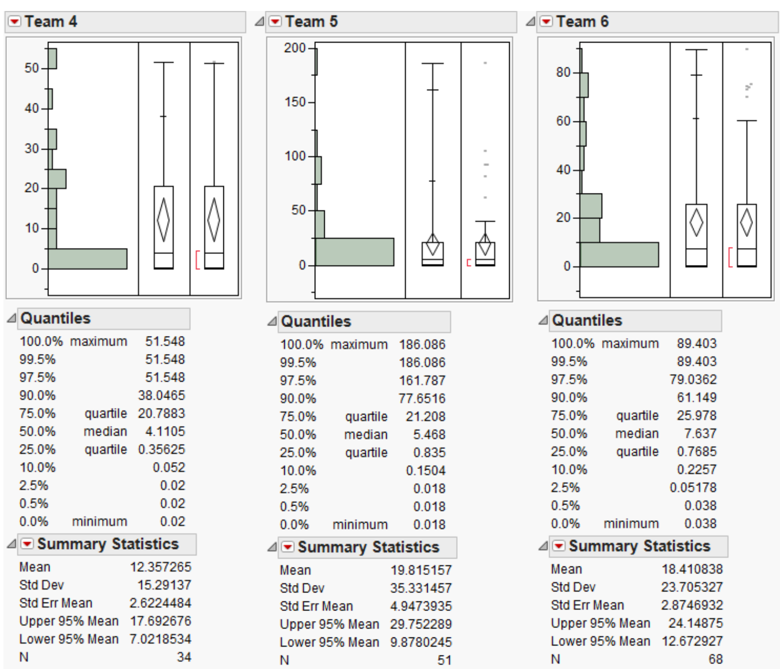
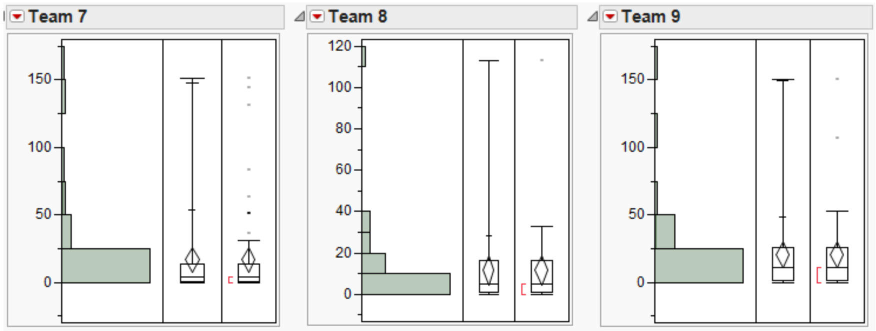


Figure 20. Teams 4 through 6 capacity histograms and summary statistics



Quantiles

	Team 7		Team 8		Team 9
100.0% maximum	150.865	100.0% maximum	113.144	100.0% maximum	150.543
99.5%	150.865	99.5%	113.144	99.5%	150.543
97.5%	147.809	97.5%	113.144	97.5%	149.448
90.0%	53.6098	90.0%	28.5912	90.0%	48.8062
75.0% quartile	13.236	75.0% quartile	16.67	75.0% quartile	25.6503
50.0% median	4.101	50.0% median	5.24	50.0% median	10.936
25.0% quartile	0.6495	25.0% quartile	1.082	25.0% quartile	1.10975
10.0%	0.228	10.0%	0.1252	10.0%	0.1155
2.5%	0.13485	2.5%	0.057	2.5%	0.0208
0.5%	0.129	0.5%	0.057	0.5%	0.02
0.0% minimum	0.129	0.0% minimum	0.057	0.0% minimum	0.02

Summary Statistics

	Team 7	Team 8	Team 9
Mean	16.980439	11.651515	20.66715
Std Dev	33.917457	20.457393	29.962874
Std Err Mean	4.4924769	3.5611751	4.7375464
Upper 95% Mean	25.979951	18.905391	30.249742
Lower 95% Mean	7.9809259	4.3976389	11.084558
N	57	33	40

Figure 21. Team 7 through 9 capacity histograms and summary statistics

Appendix 3: Questions made on the interview

1. What is your current position at DCI?

2. How long have you been in the current position?

3. What criteria are used to store incoming materials in the warehouses?

4. What factors are considered when planning and scheduling picking activities at the warehouses?

5. Is a transportation planning considered before picking activities are scheduled?

6. What measurements/tools do you use to assess the efficiency of the process?

7. What metrics are currently used by the Supply Division Management?

8. How do you use those metrics in your management activities?

9. What kind of statistical treatment is given to the data collected through the Supply Division spreadsheets?

10. How often are the customers of DCI's activities inquired about the quality of the services provided by DCI?

11. In your opinion what are your customer's most valued quality aspects regarding Supply Division activities? At the best of your knowledge, is there any document or regulation stipulating minimum quality standards to be met by DCI Supply Division activities?

12. What criteria are used by the warehouse coordinator to distribute the POs to be picked through the teams?

13. What procedures inventory pickers adopt when they find out that a PO is partially attended? Is some type of rework aimed at finding the missing pieces of uniform carried out?

14. After picked from inventory, the material is moved to the Cargo Terminal. What is the reason for this procedure?

15. After picked from inventory the material spends on average 16 days waiting to be moved to the Cargo Terminal. In some cases, this delay lasts more than 40 days. What factor or factors are responsible for this delay, in your opinion?

16. How often breakdowns on pieces of equipment occur? Is there some record about equipment downtime?

20. What are the most common errors in the process?

21. What procedures or adjustments need to be done when a Provision Order is left not fully completed? Considering the amount of labor hours devoted to these procedures, how time consuming would you classify them?

22. How often items depart from DCI but need to wait for transportation at the Airport cargo Terminal? Is it common to have the receiving organization reporting missing pieces of uniform when this happens, or when the cargo goes unaccompanied?

23. How often a cargo goes unaccompanied because no available caretaker could be found?

24. Does the accumulation of work in process inventory waiting to be transported to the Terminal Cargo have a negative impact on the performance of inventory pickers? Why or why not?

25. Have you had knowledge, or experienced yourself, any kind of problems caused by excess of WIP inventory (like, but not restricted to, items left behind in the warehouse when they should have been transported, or items being transported out of the sequence they were supposed to be, or items being delivered at the wrong destination). If the answer for this question is yes, please, feel free to mention any other negative impacts in the process caused by excess WIP inventory you may find appropriate.

Appendix 4: Thesis quad chart

THE BRAZILIAN AIR FORCE UNIFORM DISTRIBUTION PROCESS: USING LEAN THINKING, STATISTICAL PROCESS CONTROL AND THEORY OF CONSTRAINTS PRINCIPLES TO ADDRESS IMPROVEMENT OPPORTUNITIES

Maj. Luciano Antonio A. dos Santos
Advisor: Dr. Jeffrey A. Ogden
Reader: Dr. Alan W. Johnson
Department of Operational Sciences (ENS)
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INTRODUCTION

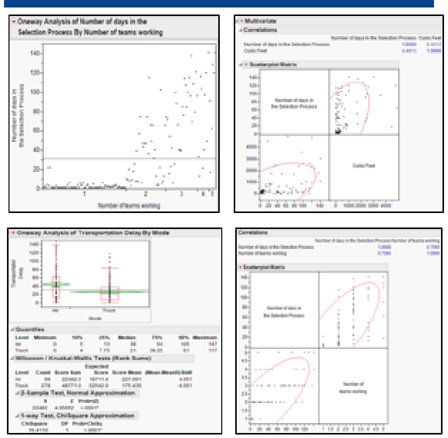
In the Brazilian Air Force, all enlisted Soldiers and Corporals are entitled to receive their uniforms from their assigned, respective organizations, free of charge. An important portion of the uniform's distribution process is accomplished by the Brazilian Air Force Intendancy Central Depot (ICD).

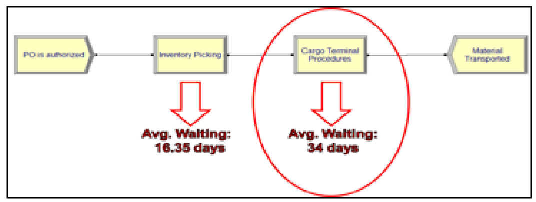
THE PROBLEM

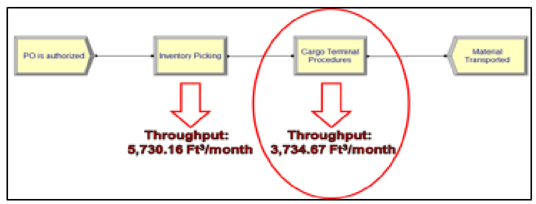
After collecting and analyzing the data regarding the peak distribution seasons of 2012 and 2013 potential detrimental impacts caused by variability, lack of proper constraint management and waste generation became apparent.

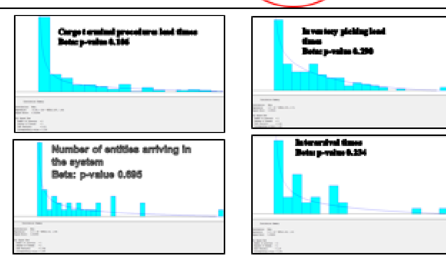
METHODOLOGY

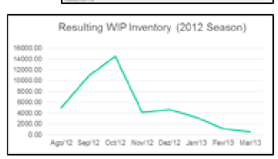
Statistical assessment of spread of the datasets through interquartile ranges analyses in conjunction with coefficient of variance, Kruskal-Wallis test for statistical difference between samples; simulation and inventory buildup diagrams for constraint determination and waste identification.

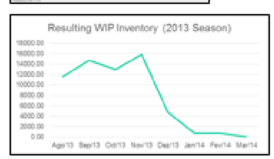












RESEARCH OBJECTIVES

1. Establish how the process of distribution of PROVSYS' uniforms is structured and executed at the ICD level;
2. Study the impact of variability and the types of waste recognized in the process on overall process performance and quality;
3. Understand which metrics, if any, were in place at the ICD's Supply Division and how they have been used to guide behaviors toward process improvements;
4. Identify which performance and quality measures would be appropriate to allow Supply Division management to keep track of the different forms of waste and guide their actions towards process improvements.

Results and Conclusions

1. Negative impacts of variability were found throughout the process;
2. Several forms of waste were identified, being waiting times and WIP inventory build-up the most important;
3. No performance-driven metric appears to be currently in place.
4. Adoption of a minimum set of metrics that would allow addressing key variability and waste generation issues, as well as implementation of a transportation schedule and the Lean Thinking's pull approach were the most important recommendations.
5. Areas for further research include inventory management procedures, implementation of a Warehouse Management System and feasibility study on Process Reengineering

DEPARTMENT OF OPERATIONAL SCIENCES

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14. ABSTRACT
In the Brazilian Air Force, all enlisted Soldiers and Corporals (corresponding to USAF ranks from Airman Basic to Senior Airman) are entitled to receive their uniforms from their assigned, respective organizations, free of charge. An important portion of the uniform's distribution process is accomplished by the Brazilian Air Force Intendancy Central Depot (ICD). This organization carries the uniform inventory and performs the selection and distribution activities, following the guidance of the Sub-directorate of Supply. ICD process performance data for the peak distribution seasons of 2012 and 2013 was collected and analyzed. Several indications of inefficiencies became apparent, exemplified by a high number of late and partially fulfilled orders. This study applied fundamental principles of Lean Thinking, Statistical Process Control and the Theory of Constraints to identify potential areas for process improvement. Through statistical analyses, a simulation effort and capacity analysis, the negative impacts of variability throughout the process were assessed and several types of waste were recognized. Potential solutions to address the problems identified were suggested, as well as areas for further research.

15. SUBJECT TERMS
Statistical Process Control, Lean Thinking, Theory of Constraints, Process Metrics

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