Compression Machines Relocation for Space Optimization

Omar Velazquez del Valle
Manufacturing Engineering
Edgar Torres, Ph.D.
Industrial Engineering Department
Polytechnic University of Puerto Rico

Abstract *— Pharmaceutical industries develop, produce and market drugs for use as medications. All pharmaceutical manufacturers are directed to produce in a high optimization environment to increase productivity and ensure product of high quality level. A design process was performed on the compression manufacturing area of a pharmaceutical industry in order to maximize the space to achieve the current production demand, improve the manufacturing process layout increasing the efficiency and the safety on the compression process. DMAIC (Define, Measure, Analyze, Improve and Control) methodology was used as a problem solving tool to identify how to optimize the space. Some of the tools used on this project include brainstorming and decision matrix to determine the best layout alternative to improve the work environment.*

Key Terms *— Compression Machines, DMAIC, Overall Equipment Efficiency (OEE), Tablet Monitoring Equipment.*

PROBLEM STATEMENT

The pharmaceutical industries develop, produce and market drugs or pharmaceuticals licensed for use as medications. The pharmaceutical industries are regulated and monitored by the United State (U.S.) Food and Drug Administration (FDA) to ensure that organization operates in a known state of control. FDA requires that the companies manufacture and deliver safe and effective products. All pharmaceutical manufacturers are directed to produce in a high optimization environment to increase productivity and ensure product of high quality level. Space optimization in the pharmaceutical industries is critical to ensure productivity and to have the capacity to add new processes or products on the manufacturing areas. At the same time space optimization can contribute to increases the associate's safety in the manufacturing areas. Taking this under consideration, a project on the compression area is required to use the optimal compression machines in order to optimize space, improve production performance on the manufacturing area, and housekeeping in order to have the flexibility of introduce new technology on the available space.

Research Description

As part of the implementation of the Tablet Monitoring Equipment, used to analyze the tablet thickness, hardness and weight on the compression manufacturing area, it was observed that the space is limited on the compression booths to perform the compression activities affecting safety and production performance on the manufacturing floor. Also, it was determined that not all the current compression machines are required to achieve the current production demand.

Research Objectives

The objective of this project is to improve the manufacturing process layout (space optimization) to increase the efficiency of working area, clean-ability, general housekeeping in the workstation increasing the safety on the compression process.

Research Contributions

This space optimization project will help to define a process layout on the compression manufacturing area of this pharmaceutical industry in order to increase the safety during the compression process, production performance. Also, this project will help to optimize the space for introduction of new technology on the manufacturing floor and increase the competitiveness of this Pharmaceutical Industry.

LITERATURE REVIEW

The literature review will include relevant research in the following areas: Pharmaceutical Industries; Compression Process; Space Optimization; and Application of DMAIC. These topics are essential to enrich readers' knowledge of the problem statement and the business area of this design project.

Pharmaceutical Industries

Pharmaceutical industries are organizations involved in the discovery, development, and manufacture of drugs and medications. Historically, medicines were prepared by physicians and later by apothecaries. Today, drug development relies on the collaboration and effort of highly trained scientists at universities and private companies. The modern era of drug discovery and development originated in the 19th century when scientists learned how to isolate and purify medicinal compounds and developed large-scale manufacturing techniques. As understanding of biology and chemistry improved in the 20th century, the occurrence and severity of such diseases as typhoid fever, poliomyelitis, and syphilis were greatly reduced. While many drugs, such as quinine and morphine, are extracted from plant substances, others are discovered and synthesized by techniques including combinatorial chemistry and recombinant DNA technology. The pharmaceutical industry has greatly aided medical progress, and many new drugs have been discovered and produced in industrial laboratories. Identifying new drug targets, attaining regulatory approval, and refining drug discovery processes are among the challenges that the pharmaceutical industry faces in the continual advancement of control and elimination of disease.

The manufacture of oral solid dosage forms such as tablets is one of activities performed in the pharmaceutical manufacturing industries. This is a complex multi-stage process under which the starting materials change their physical characteristics a number of times before the final dosage form is produced. Traditionally, tablets have been made by granulation, a process that imparts two primary requisites to formulate: compactibility and fluidity. Both, wet granulation and dry granulation are used during the process. Regardless of whether tablets are made by direct compression or granulation, the first step, milling and mixing, is the same; subsequent steps differ. Numerous unit processes are involved in making tablets, including particle size reduction and sizing, blending, granulation, drying, compaction and coating. Various factors associated with these processes can seriously affect content uniformity, bioavailability, or stability.

Compression Process

Compression is defined as the formation of solid specimen of defined geometry by powder compression [1]. Because of the increased proximity of particle surfaces accomplished during compression, bonds are formed between particles which provide coherence to the powder (i.e compact is formed). Today, the compression is performed by a multi-station machine known as a rotary press. The tablet or rotary press press is a high-speed mechanical device that squeezes the ingredients into the required tablet shape and can press the name of the manufacturer or the product into the top of the tablet.

The effect of compression process consists on external mechanical forces applied to a powder mass to obtain a reduction in bulk volmues as follow: repacking, particles deformation, brittle facture and microquashing (irrespective of larger particles, smaller particles may deform plastically) [2]. Powders intended for compression into tablets must possess two essential properties: powder fluidity to transport material through the hopper into the die and produce tablets of a consistent weight; and powder compressibility to form a stable and intact compact mass when pressure is applied. The compression takes place in a die by the action of two punches, the lower and the upper which compression force is applied. The compression process consists on the following phases:

- Filling - by gravitational flow of powder from hopper via the die table into die. The die is closed as its lower end by the lower punch.
- Compression - the upper punch descends and enters the die and the powder is compressed until a tablet is formed. During the compression phase, the lower punch can be stationary or can move upwards in the die. After maximum applied force is reached, the upper punch leaves the powder (i.e the decompressed phase).
- Ejection - the lower punch rises until its tip reaches the level of the top of the die. The tablet is subsequently removed from the die and dies table by a pushing device.

As part of the compression process, in-process inspection are performed with a Tablet Monitoring Equipment. The use of the tablet monitoring equipment enables the most important tablet parameters to be automatically measured: weight, thickness, hardness and diameter. With this equipment, measurements are continuously assessed and recorded to ensure high tablet quality is guaranteed before or after the removal of dust from the tablets.

Space Optimization

Strategic process selection and design for space optimization are crucial to maximize productivity and reducing costs in manufacturing operations. Process layouts and product layouts are two popular facilities layout philosophies best suited to different production situations.

A process layout is a type of facility layout in which the floor plan is arranged with similar processes or machines located together [3]. The process layouts are the common layout used for the compression process on the pharmaceutical industries. It consists of compacting machines and tablet monitoring equipment located together and arranged as a process layout. It differs from a product layout in which the equipment is arranged based on sequential steps involved in manufacturing a product, as on an assembly line.

Design of a process layout begins with a needs analysis. This analysis takes into consideration different factors to ensure that the final layout is sufficient for all the necessary functions of the facility. The needs analysis includes how much space each machine or process will require, and how each will be configured. Details regarding the types of the required equipment and the quantity of each are also determined for the design of a process layout for space optimization.

DMAIC

DMAIC methodology is used to improve, optimize and stabilize business process and designs to deliver quantifiable and sustainable results. The DMAIC Methodology consists of five phases of steps that guide us to identify the correct direction of the project [4]. The DMAIC five steps are Define, Measure, Analyze, Improve, and Control.

Define is considered as the most important step of the project, since it determines the customer's requirements or what is more significant for the customer and the objectives that should be evaluated. During, the define phase, the project charter is created to determine the problem, scope, project plan. Moreover, in the Define step, the Project Champion identifies the cross functional team that needs to be working on the project. During the Measure phase, data is collected to evaluate and measure the key characteristics of the process, review the customer requirements and determines the product standards, and establish the current process performance. During this phase, the team uses numerous quality tools to determine the specific parts of the process and verify the accuracy and precision for the measurement system, process capability, stability, and quality. Process Map and Cause and Effect Diagram are developed to identify the critical inputs that need to be evaluated. The Analyze step is considered as one of the critical phases of the DMAIC process. During this phase, data collected in the Measure phase is analyzed by brainstorming, and tools as decision or prioritization matrix to cause of defects. The purpose of this phase is to determine the key

variables during the process that needs to be removed or reduced from to improve the process under evaluation. The improve phase typically designs and performs experiments in order to confirm the best alternative to solve the problem. During this step, the team should have identified suspect variables and developed a plan for improvements. Finally, the Control is performed to implement and monitor the improvements to sustain the outcome.

As a business strategy, DMAIC Methodology was used on this project in order to optimize space in the manufacturing compression area of a pharmaceutical industry.

PROJECT METHODOLOGY

DMAIC Methodology will be used as problem solving tool to optimize the current space at the manufacturing compression area in order to improve the safety, production performance, clean-ability, and general housekeeping in the workstations. With the application of this approach, improvements will be implemented to maximize the process performance at the compression area. This model includes a set of tools outlined in five phases that must be completed in chronological order and which is used to characterize and optimize the process under evaluation. The methodology consists of five phases: Define Measure, Analyze, Improve and Control. Each phase will be described in details to show the methodology to be used for this Design Project.

Define

During this phase, a project charter will be created to define the problem statement, objectives and participants in the project. It will provide a preliminary delineation of roles and responsibilities. The project charter will be created to define the main stakeholders and the authority of the project manager at the time that establishes the business impact.

Measure

Based in the current site product portfolio and volume, the utilization of two (2) out of twelve (12) compression machines are no longer required. During the Measure phase, different factors as the: machine model, flexibility for each machine (product portfolio to be run on each machine) and other factors will be evaluated to determine the machines to be removed from the compression area. Also, the space for each compression booths in where compression tablet machine, tablet monitoring equipment and compression process auxiliary equipment are located, will be measured in order to determine the machines to be removed and the optimal process layout for the compression area.

Analyze

During the Analyze phase, data analysis will be performed to determine which of the compression machines are more suitable for its intended use. Tools to be used during the analyze phase will be brainstorming and a decision matrix. Brainstorming is a group or individual creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its member(s). A decision matrix is a list of values that allows an analyst to systematically identify, analyze, and rate the performance of relationships between sets of values and information. Elements of a decision matrix show decisions based on certain decision criteria. Some of the factors to be analyzed will be the overall equipment efficiency and the model of the machine. The space area of the different compression booths will also be analyzed in order to decide which rooms are more suitable to perform compression activities.

Improve

During this phase, decommissioning of the two machines that result less suitable for use will be performed. Decommissioning is a controlled process used to safely retire the equipment that is no longer needed. As part of the improve phase, the layout of the compression manufacturing area

will be modified. As part of the layout modification, some of the compression machines will be relocated and qualification activities for the tablet compression machines and the tablet monitoring equipment will be performed in order to determine that no issues are created as part of this process layout. Because booths will be empty between decommissioning and relocation, the opportunity will be used to introduce a number of smaller improvements to the compression booths to improve efficiency of working, clean-ability, and general housekeeping in the workstations. The deliverable of this phase will be an improved layout in order to manufacture product that meets customer's requirements.

Control

As part of the DMAIC Methodology, a control plan is required to verify the project results. Drawings, standard operating procedures and manufacturing batch records will be updated to sustain the implementation. Two months of monitoring will be established to verify that the implemented actions are effective in terms of safety. Production performance will be also monitored in terms of non-conformance related to production environment and documentation errors associated to the re-layout conducted on the compression manufacturing area.

As part of the project methodology, a research schedule was created to shows the due dates for each phase.

RESEARCH RESULTS AND DISCUSSION

The results obtained in this design project will be discussed following the problem solving tool DMAIC. As mention on the methodology, the DMAIC problem solving tool consists of five phases: Define, Measure, Analyze, Improve and Control. Each phase was completed using different tools that help to determine solutions to solve the problem. The deliverables for each phase will be presented and discussed on this chapter.

Define

The scope of the design project is to optimize the process layout of the Compression Manufacturing Area in a Pharmaceutical Industry to improve the production performance, housekeeping and safety on the area. Figure #1 shows the project charter created to define the problem statement, objective, project scope and team for this project.

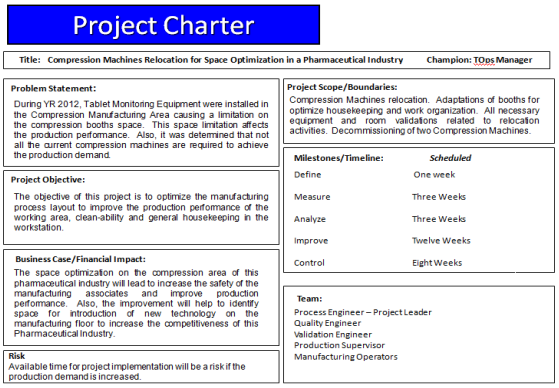

Figure 1
Project Charter

Measure

During the measure phase, data of some important factors related to the compression machines were collected to define a suitable process layout of the compression manufacturing area. The factors taken under consideration were the following: overall equipment efficiency (OEE); machine model; flexibility of the machines; and operator's feedback.

The OEE calculation (availability x performance x quality) is a metric to indicate how effectively the machine is running taking in consideration availability (downtime loss), performance (speed loss) and quality (quality loss). Availability measures any events that stop planned production for a period of time as equipment failure, material shortage and changeover. Performance includes any factors that cause the process to operate at less than the maximum possible speed, as machine wear, substandard materials, mis-feeds, and operator inefficiency. Quality takes into accounts the produced pieces that

do not meet quality standards. As part of this project, OEE for each machine was evaluate to determine what machines have the best OEE and the worst OEE results. Machine model takes into consideration all the versions available for each machine at the compression area considering the most updated and the old machine model versions. From the twelve (12) machines, there are two (2) different models, the "X" model which is an advance model and the "Y" model is a good model but can be considered outdated. Flexibility takes into consideration the availability for each machine to manufacture different products. It measures if the machine is validated to produce the different types of products manufactured in the site. Finally, the operator's feedback was obtained to determine what machine are the top machines to operate and the most difficult machines to operate in terms of machine functionality. Table 1 shows the collected data during the measure phase.

Table 1
Decision Factors

Machine	Avg. OEE (%)	Model	Flexibility	Feedback
1	73	X	Yes	Excellent
2	75	X	Yes	Excellent
3	50	Y	No	Bad
4	48	Y	No	Fair
5	69	X	Yes	Good
6	70	X	Yes	Good
7	72	X	Yes	Very Good
8	70	X	Yes	Very Good
9	71	X	Yes	Very Good
10	76	X	Yes	Excellent
11	78	X	Yes	Excellent
12	60	Y	No	Good

Also, the booth area (ft^2) of the different compression booths was measure in order to identify which booths are more comfortable to perform compression activities. Table 2 summarizes the current location of the compression machines and the area of the different booths.

Table 2
Machines Current Location

Compression Machine	Location (Booth)	Booth Area (ft^2)
1	A	340
2	B	340
3	C	400
4	D	400
5	E	400
6	F	400
7	G	400
8	H	300
9	I	300
10	J	300
11	K	300
12	L	300

Analyze

As part of the problem solving process, a brainstorming session was performed with the team members and manufacturing operators to evaluate the appropriate criteria for each Compression Machines (1 to 12) in order to determine the two machines to be removed from the compression manufacturing area. As part of the brainstorming, it was decided to evaluate the following factors: 1) overall equipment efficiency (OEE), 2) machine model, 3) flexibility and 4) operator's feedback. Based on the decision matrix, the most important factors for this evaluation were overall equipment efficiency and flexibility. According to the decision matrix results detailed on Table 4 "Decision Matrix for Machine Retirement", Machine "3" and Machine "4" were identified and selected with a score of less than 30 as the machines to be removed from the Compression Manufacturing Area. Both machines ("3" and "4") are considered as the worst in terms of lack of flexibility to run different products, machine inefficiencies due to downtime loss, speed loss and quality loss (OEE), these machines are old machine models and receive bad operator's feedback. Table 3 shows the decision matrix related to the retirement of the compression machines.

Table 3
Decision Matrix for Machine Retirement

Machine	*Factor*	OEE	Model	Flexibility	Feedback	Score
	Weight	5	3	4	3	
1		4	3	5	5	**64**
2		4	3	5	5	**64**
3		2	1	1	1	**20**
4		2	1	1	2	**23**
5		4	3	5	3	**58**
6		3	3	5	3	**53**
7		4	3	5	4	**61**
8		4	3	5	4	**61**
9		4	3	5	4	**61**
10		3	3	5	5	**59**
11		4	3	5	5	**64**
12		3	3	1	3	**37**

1 - Poor, 2-Fair, 3- Good, 4-Very Good, 5-Excellent

After analyze the space area of the compression booths, it was found that booths "H", "I", "J", "K" and "L" are small and uncomfortable to perform compression activities.

Improve

Based on the results of the analyze phase, it was decide to remove Compression Machines "3" and "4" since both are considered the less suitable machines for is intended use. Since machines "3" and "4" will be retired and booths "C" and "D" will be empty (available), it was decided to relocate Machines "10" and "11" which are considered as good machines, from booths "J" and "K" to booths "C" and "D" respectively, since booths "C" and "D" (400 ft^2) are more suitable booths to perform compression activities than booths "J" and "K" (300 ft^2). Table 4 summarizes the proposed Compression Machines configuration as part of this improve phase.

Table 4
Expected Compression Machines Configuration

Compression Machine	Location (Booth)	Booth Area (ft^2)
1	A	340
2	B	340
10	C	400
11	D	400
5	E	400
6	F	400
7	G	400
8	H	300
9	I	300
Empty	J	300
Empty	K	300
12	L	300

Since booths "C" and "D" will be empty between the decommissioning of machines 3 and 4 and the relocation of machines "10" and "11" the opportunity will be used to introduce a number of smaller improvements to the booths lay-out to improve efficiency of working, cleanability, and general housekeeping in the workstations. Some of the improvement will be replace the two outlet air grids with a roster to decrease noise generation; create a cabinet through the wall to place the tablet monitoring equipment in order to have more space on the booths; enlarge the documentation table in order to have a more comfortable space to document the compression activities. Figure 2 shows the cabinet that will be created for to place the tablet monitoring equipment.

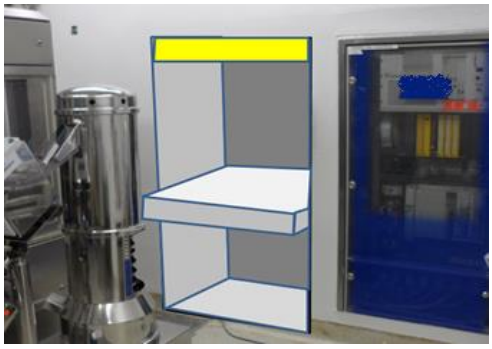

Figure 2
Cabinet for the Tablet Monitoring Equipment

Control

In the control phase, safety in the workplace will be monitored. Production performance will be monitored in terms of none non-conformance

related to the process layout change during eight weeks period. Since the air outlet grids will be changed, noise generation in the booth will be monitored to ensure continuous improvement on the manufacturing area. Drawings, standard operating procedures and manufacturing batch records will be updated to sustain the implementation changes.

CONCLUSION

The space optimization leads to more organized manufacturing areas, cost reductions, improve productivity, reduced travel times and labor costs and open a door to identify available space for introduction of new technology, process or products. Based on this space optimization is fundamental for continuous improvement and competitiveness of the Pharmaceutical Industries. This design project used the DMAIC methodology to determine the best alternative for space optimization of the compression manufacturing area. According to the project, a process re-layout to remove Machines "3" and "4" and relocate machines "10" and "11" to the booths of the machines removed was considered as the strategy for space optimization on the compression manufacturing area.

As part of the control phase for this project it will be required to update the engineering drawings, manufacturing batch records and standard operating procedures in order to sustain the changes. Also, a 6S program will be evaluated to demonstrate the sustainability of the organized manufacturing area.

The results of this design project will represent a more organized area, available space for new introduction, free of safety issues since a more comfortable room will be provided to operators.

As part of a future research, the removal of Machine "12" can be evaluated since it is considered as the next alternative due to the lower score on the decision matrix by low OEE, old machine model, flexibility issues due to not all products are validated on this machine. Also, booths "I" and "J" which are considered as small booths (300 ft^2) can be merged into one bigger and comfortable room. This recommendation can be applicable to booths "K" and "L".

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