UNIVERSIDADE FEDERAL DO VALE DO SÃO FRANCISCO
CURSO DE GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO

DENILTON DE CASTRO SANTANA

REDUCING WASTE IN A PACKAGING PROCESS BY USING VALUE STREAM MAPPING AND DISCRETE EVENT SIMULATION: A Case Study

Juazeiro – BA

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Trabalho apresentado à Universidade Federal do Vale do São Francisco – UNIVASF, Campus Tecnológico, como requisito para obtenção de nota na disciplina de TFC - Monografia. Orientador: Prof. Dr. Thiago Magalhães Amaral

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FOLHA DE APROVAÇÃO

DENILTON DE CASTRO SANTANA

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Trabalho Final de Curso apresentado como requisito parcial para obtenção de nota na disciplina de TFC - Monografia da Universidade Federal do Vale do São Francisco.

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Dedico este trabalho a Deus, a meus pais e à Fernanda Maria, minha namorada, que sempre esteve ao meu lado nesta longa caminhada.

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“Faça as coisas o mais simples que você puder,
porém nunca as mais simples. ”

(Albert Einstein)

SANTANA, Denilton de Castro. **Reduzindo desperdícios em um processo de empacotamento através do uso de mapeamento do fluxo de valor e simulação de eventos discretos: um estudo de caso.** Juazeiro (BA). Trabalho Final de Curso. Universidade Federal do Vale do São Francisco, 2016.

RESUMO

Desperdícios em um processo de manufatura podem implicar em custos adicionais e uso desnecessário de alguns recursos. Este estudo tem como objetivo analisar o uso de Mapeamento do Fluxo de Valor (MFV) e Simulação de Eventos Discretos (SED) para reduzir os desperdícios e melhorar a performance de um processo de manufatura. Este estudo de caso foi aplicado a um processo real de embalar produtos químicos em uma empresa anônima no estado de Wisconsin, EUA. A aplicação começa com o uso de MFV para mapear o processo atual, em seguida, um modelo de simulação é desenvolvido para melhor analisar o processo. Além disso, um mapa do estado futuro é feito para descrever as alterações sugeridas e uma nova simulação é desenvolvida para analisar os resultados e verificar a viabilidade das mudanças. A aplicação de ambas as ferramentas conduziu à redução do *lead-time* do processo em cerca de 67% e aumentou de 21% para 55% as atividades que agregam valor ao produto. Além disso, as necessidades de mão-de-obra foram reduzidas em 33%. A partir deste estudo de caso, é possível concluir que, para esta situação prática, o MFV e o SED são ferramentas muito úteis para analisar desperdícios de um processo e implementar a manufatura enxuta. De fato, é possível melhor organizar um *layout* usando essas ferramentas e melhorar o desempenho global de um processo sem investir em novos recursos. Sugere-se também um novo estudo para otimizar o *layout* considerando a possibilidade de compra de novos equipamentos.

Palavras-chaves: Mapeamento do Fluxo de Valor; Simulação de Eventos Discretos; Manufatura Enxuta; Sistemas de Manufatura.

SANTANA, Denilton de Castro. **Reducing waste in a packaging process by using value stream mapping and discrete event simulation: a case study.** Juazeiro (BA). Final Project. Federal University of São Francisco Valley, 2016.

ABSTRACT

Waste in a manufacturing process may imply extra costs and the unnecessary use of resources. This study aims to analyze the use of Value Stream Mapping (VSM) and Discrete Event Simulation (DES) to reduce waste and improve the overall performance of a manufacturing process. This case study was applied to a real process of packaging chemical products in an anonymous company in Wisconsin, USA. The application starts with VSM to map the current process, then a simulation model is developed to better analyze it. Furthermore, a future-state map is made to describe the changes suggested and a new simulation model is also developed to analyze the results and check viability. The application of these tools led to a reduction in lead-time of about 67% and enhanced the percentage of value added activities from 21% to 55%. In addition, labor requirements were reduced by 33%. From this case study, it is possible to conclude that, for this practical situation, VSM and DES are very useful tools to analyze process waste and implement the lean manufacturing approach. Indeed, it is possible to better organize a layout by using these tools and improve the overall performance of a process without investing in new resources. It is also suggested to perform a new study to optimize the layout with the possibility of buying new equipment.

Keywords: Value Stream Mapping; Discrete Event Simulation; Lean Manufacturing; Manufacturing Systems

LISTA DE FIGURAS

LISTA DE ABREVIATURAS E SIGLAS

DES – *Discrete Event Simulation*

KPI – *Key Performance Indicator*

SIMAN – *Simulation Management*

SMED – *Single Minute Exchange of Dies*

TPS – *Toyota Production System*

VSM – *Value Stream Mapping*

SUMÁRIO

REDUCING WASTE IN A PACKAGING PROCESS BY USING VALUE STREAM MAPPING AND DISCRETE EVENT SIMULATION: A Case Study.

D. C. Santana[1] • T. M. Amaral[1]

Abstract Waste in a manufacturing process may imply extra costs and the unnecessary use of resources. This study aims to analyze the use of Value Stream Mapping (VSM) and Discrete Event Simulation (DES) to reduce waste and improve the overall performance of a manufacturing process. This case study was applied to a real process of packaging chemical products in an anonymous company in Wisconsin, USA. The application starts with VSM to map the current process, then a simulation model is developed to better analyze it. Furthermore, a future-state map is made to describe the changes suggested and a new simulation model is also developed to analyze the results and check viability. The application of these tools led to a reduction in lead-time of about 67% and enhanced the percentage of value added activities from 21% to 55%. In addition, labor requirements were reduced by 33%. From this case study, it is possible to conclude that, for this practical situation, VSM and DES are very useful tools to analyze process waste and implement the lean manufacturing approach. Indeed, it is possible to better organize a layout by using these tools and improve the overall performance of a process without investing in new resources. It is also suggested to perform a new study to optimize the layout with the possibility of buying new equipment.

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Keywords Value Stream Mapping • Discrete Event Simulation • Lean Manufacturing • Manufacturing Systems

1 Introduction

Several methodologies have been developed to look for ways to improve manufacturing processes. Moreover, depending on the problem and the objectives, the best solution may be found by creating possible courses of action and testing them. In this way, simulation is a tool that allows us to create and test experiments that do not interfere with the real-world systems. Simulation provides the opportunity to perform tests and experiments with a model that does not affect the manufacturing process that it represents [1].

According to Vasudevan et al [2], DES becomes more powerful when combined with other industrial engineering techniques, such as bottleneck analysis, work measurement, floor space requirements, facility layout analysis and value-stream mapping. Stamatis [3] further emphasizes that to optimize a process, it is necessary first and foremost to know the current process, and afterwards project a future scenario for a new process with all improvements. In this way, VSM is a useful technique to understand the current process and model a new process. Also, VSM helps to find waste and plan to eliminate it [3].

A study made by The Lean Enterprise Research Centre showed that in most manufacturing processes, 5% of the activities add value to the product, 35% add no value but are necessary activities, and the other

60% of the activities do not add any value [4]. Therefore, at least 60% of the activities in a manufacturing process can be eliminated by improving it. Negahban and Smith [5] point out that a facility's design is an important factor to consider when looking for ways to optimize a manufacturing system. Indeed, the location of machines/departments can affect the efficiency and effectiveness of manufacturing operations and reduce their costs. Based on these aspects, how can DES and lean techniques support decision making to reduce waste in a packaging process of chemical products?

This study aims to analyze the use of simulation and lean techniques to reduce waste by using a practical case study to improve the design of a real manufacturing process. In this way, lean manufacturing concepts will be used to analyze waste reduction in the process of packaging chemical products. More specifically, VSM will help to identify waste. In addition, a simulation model will support the decision making process and evaluate the feasibility of changes and improvements. This study is divided into five chapters: the first chapter has the introduction and the objectives; the second chapter approaches a brief review of the literature showing concepts of lean manufacturing, VSM, DES and Arena Software; the third chapter shows the methods used in this research; the fourth chapter approaches the application of those concepts in a real case study; and the last one has the conclusions and suggestions for future studies.

2 Literature Review

2.1 Lean Manufacturing

Lean manufacturing is a philosophy based on eliminating waste. This waste usually falls into seven categories, as shown in Figure 1 [6]. Waste can be eliminated by analyzing the activities in a process and then reducing or totally eliminating those activities that do not add value to the product or service. The tool used to analyze value added and non-value added activities is VSM [7]. When non-value added activities are reduced or eliminated, the overall performance of the process increases. In fact, lean manufacturing has helped companies to produce their goods with efficient cost, excellent quality and just in time delivery [8].

Lean manufacturing was created in the Toyota Production System (TPS), which is a pure manufacturing system. However, lean manufacturing concepts and tools may be

Fig. 1 The seven categories of waste. Source: Adapted from Asefeso [6].

applied beyond manufacturing processes to reduce waste and improve performance. Indeed, the concept of value works to improve process industries, technical-professional work, healthcare services, and many other service industries [9]. In fact, there are several applications of lean concepts and tools in the literature that led companies to improve their production systems. Paneru et al [10] show how lean manufacturing tools can be applied to the clothing industry to reduce lead time and rework, and improve overall performance. Erfan [11] describes how lean manufacturing was applied to a healthcare system to reduce waste and decrease the lead time, which increased the capacity to serve patients in an emergency department. In addition, Indrawati and Ridwansyah [12] applied concepts of lean manufacturing to reduce waste in the iron ores industry and improve manufacturing process capability.

A lean management system consists of three main aspects: discipline, daily practices, and tools [9]. In fact, there are many lean tools and methods. In addition, lean can be applied from top management to the plant floor. These tools and methods are used to eliminate waste and improve performance. This is not only done by reducing inventory, however, but by reducing all kinds of waste. Among the lean tools and methods, it is possible to cite VSM, Spaghetti Diagrams, Visual Management, 5S, Total Productive Maintenance, Andons, Kaizen, Poka-Yoke, Single Minute Exchange of Dies (SMED), Just-in-Time Production and Kanban [13].

Companies have used Lean to improve their processes because it is easy to understand and relatively cheap. In fact, the concepts of lean, such as customer focus, value stream organization, standardized work, flow, pull system, and continuous improvement, can be easily understood. Also, lean is suitable for simple equipment with minimal automation, and lean schedule systems are cheap, requiring little, if any, IT investment [9].

2.2 Value Stream Mapping (VSM)

VSM helps companies to avoid making random improvements without analyzing their system. In fact, it helps to find points of improvement and define numerical targets to be achieved. Furthermore, despite it being impossible to eliminate all kinds of waste, VSM helps to find a plan to eliminate some of it [3].

According to Rother and Shook [14], there are four steps to build a VSM as shown in Figure 2:

– Defining a family of products. A family of products is a group of products that share the same processes to be produced. In this

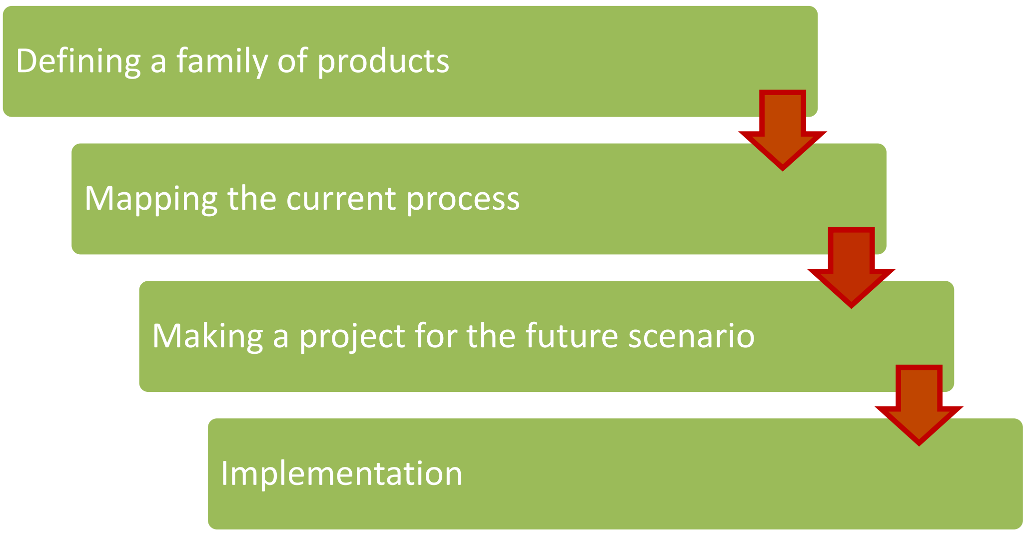

Fig. 2 Steps to build a VSM. Source: Adapted from Rother and Shook [14].

way, there is no need to build a VSM for every single product.

- Mapping the current process. Mapping the current process helps to find waste, and see bottlenecks and problems.
- Making a project for the future scenario. Based on current problems, it is possible to make a future scenario with a balanced process and without the problems identified in the second step. When this new scenario is implemented, it becomes the current scenario and a new future scenario needs to be made, so it is a continuous improvement cycle.
- Implementation. All the elements identified on previous steps need to be drawn according to the model proposed by the TPS.

After making the current process state map, it is possible to identify wastes. These wastes may come from different sources. Stamatis [3] points out that the following factors are the main sources of waste: layout (distance), long setup time, incapable processes, poor maintenance, poor work methods, inadequate training, product design, performance measures, ineffective production planning and scheduling, equipment design and selection, poor workplace organization, and supplier quality/reliability.

In order to justify the changes suggested after building a VSM, simulation is an excellent tool. Furthermore, simulation supports the decision of implementing lean manufacturing concepts by quantifying changes and benefits from applying VSM [15].

2.3 Simulation and Arena Software

According to Vasudevan et al [2], "simulation is one of the most valuable and powerful analytical tools for process improvement […]." Render [1] notes that simulation is used to duplicate the features, appearance, and characteristics of a real system. In addition, a system is defined by Kelton, Smith and Sturrock [16] as a group of components that work together toward a purpose.

Kelton, Smith and Sturrock [16] point out that there are two main kinds of simulation, Discrete Event Simulation (DES) and continuous simulation. This classification refers to how the state change over the time. When the state changes at discrete points in time, it is a discrete system, while when the state changes continuously, it is a continuous system. In this study, DES will be used to model the system.

According to Babulak and Wang [17], DES is a good tool to analyze systems and draw conclusions from an output that assists in the decision making process. The authors emphasize that DES is one of the most effective decision support tools. In addition, Fishman [18] highlights several examples of environments that can use DES to model their systems. These environments are manufacturing plants, inventory systems, distribution systems, communications networks, transportation networks, and health-care delivery systems.

Paju et al [20] emphasize that several tools support the creation of simulation models directly from the digital VSM model. The authors cite examples such as Process Simulator, Simul8, and VisioSim that can automate this process directly from a process map created with Microsoft Visio. In addition, the authors describe other tools, such as Arena, SimCad, and Extend, that offer specific VSM templates. However, although Arena software was used in this study, these VSM templates were not used. In fact, there are several ways to conduct a simulation, such as by hand, programming in general-purpose languages, using simulation languages, or modeling with high-level simulators. Furthermore, Arena combines the ease of use found in high-level simulators with the flexibility of simulation languages. Indeed, Arena can even use general-purpose languages like Microsoft® Visual Basic® [19].

Fishman [18] defines Arena as a simulation system that is used as the means to program a discrete-event simulation.

According to Altiok and Melamed [21], Arena is a simulating environment consisting of module templates. These module templates are built with SIMAN (Simulation Management) language. Indeed, this environment allows us to model any scenario involving the flow of transactions through a set of processes.

In the literature, it is possible to find several papers that show how DES has been used to evaluate changes and design lean manufacturing systems. Xia and Sun [15] show how DES can enhance the application of VSM to improve a process in a tubular machining facility. Gururmurthy and Kodali [22] describe the implementation of lean manufacturing concepts supported by the use of DES and VSM to improve the process of producing doors and windows in a job shop. Vasudevan et al [2] show how DES and some lean manufacturing tools were used to plan and design a fabrication plant to make line pipes. Other studies that used simulation and lean manufacturing concepts are found in Ali, Petterson, and De França [23], Helleno et al [24], and Atieh et al [25].

3 Methods

This work uses a case study as a method to describe the use of VSM and DES to improve a manufacturing process. Case study research is an exploratory research strategy that uses a case from the real life to be analyzed [26]. In this work, the real life case is the packaging process of a manufacturing company. In addition, this is a practice-oriented research because it aims to contribute to the knowledge of specific practitioners [26]. In this case, the practitioners are the company's managers and the business community. In order to elaborate on this case study, it is important to define some steps that need to be followed to achieve the objectives previously defined: variables that are going to be used, and Key Performance Indicators (KPI) to compare the results. The steps of this case

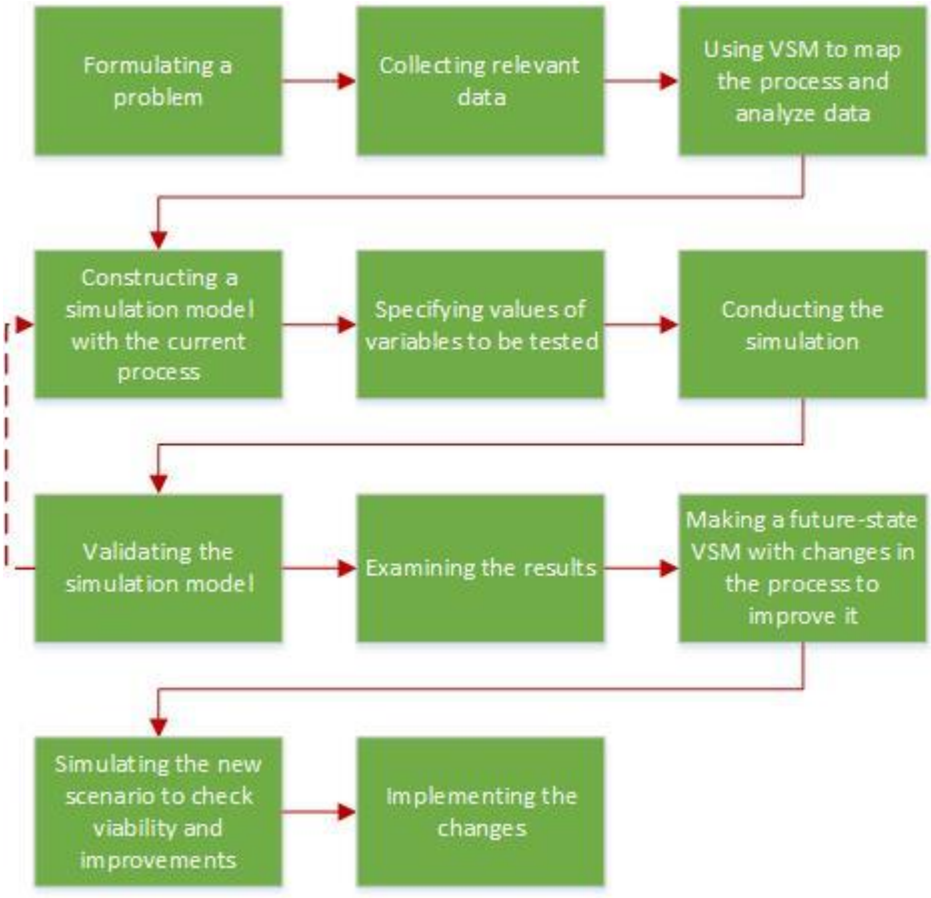

Fig. 3 Steps to construct this study. Source: Adapted from Gil [27] and Render [1].

study were adapted to this research as shown in Figure 3:

- Formulating a problem: The packaging process of this company is divided into three different steps: labelling, which has its own room in the facility, transferring to the filling process, and filling, which also has its own room. In this way, this process takes a large space in the facility of the company and requires most of the operators that directly work with manufacturing processes in the company. In addition, the process seems to take too long to make a product unit.
- Collecting relevant data: The data needed to make the current-state VSM includes cycle times, batch sizes, transportation times, number of operators, flow of information, frequency of flow of information, and flow of materials. This data was also used to analyze the changes proposed in this study.
- Using VSM to make the current-state map and analyze data: a VSM was made to analyze the current process.
- Constructing a simulation model with the current process: a simulation model was constructed using Arena Software to represent the current scenario. In fact, modeling and simulation is a common research method used in the industrial engineering and operations management field [28].
- Specifying values of variables to be tested: the data used to construct the current-state map was used to define the values of cycle times of each operation in the simulation model. Input Analyzer was used to fit the distributions that generate the values for each operation.
- Conducting the simulation: the simulation was run.
- Validating the simulation model: the data that was used to validate the model is the throughput of the real process. The throughput of each machine was compared to the simulation model. If they were not similar to the results in the simulation model, the model would need to be revised.
- Examining the results: the results were analyzed by considering the following KPIs: Lead-time, value added time, percentage of value added activities, labor requirements and labor utilization.
- Using VSM to make a future-state map with changes in the process to improve it: the new scenario with waste reduced was described using a VSM.
- Simulating the new scenario to check viability and improvements: the new scenario was checked and the improvements were analyzed. The KPIs were compared to the results on the current scenario simulation model.
- Implementing the changes: after analyzing the changes and making the simulation model, the changes were proposed to the company.

4 Numerical Application

4.1 The packaging process and the current-state map

The anonymous company that is being analyzed in this study is a full-service provider of maintenance solutions. In fact, the company produces chemical products for several different applications, from machine cleaners to floor coatings. The facility where this study was made is located in Wisconsin, USA. The company has a mix of products that are made with its brand and also products that are customized based on customer needs. These customized products may vary from a simple customized label to a completely new product that the company can develop in its research and development center.

Many processes are performed in order to deliver the company's products. However, this study focuses only on the packaging processes. After making the liquid that is the main material, the operators label packages and fill them with liquid in a process that is divided into three steps as shown in Figure 4.

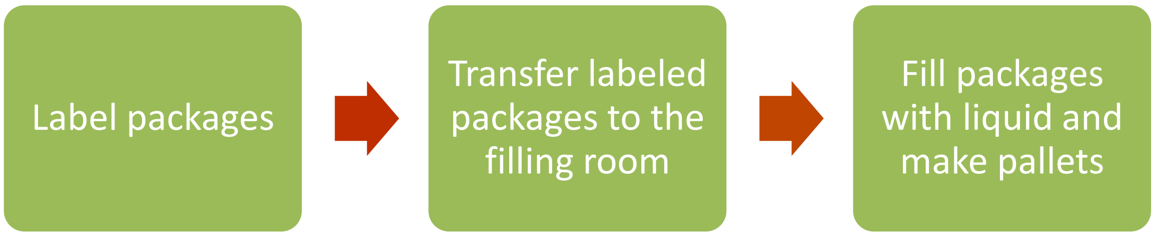

Fig. 4 Packaging process steps

Reasons for setting this process as shown in Figure 4 include the fact that the label's material needs a controlled atmosphere to work properly, so the labeling operation happens in a different room. However, there were no previous studies to show whether this is the best configuration to perform this activity.

The current scenario was mapped as shown in Figure 5. It was used the family of products that use pails as the package, which all share the same operations. The data for this current-state map was collected by watching the operators performing those activities. In order to get the cycle times of each operation as well as the data used to make the distributions for the simulation model, a starting sample of 31 values was collected, then the sample size was calculated based on the variance of this starting sample [29].

It is important to point out that three operators work on this process. One is responsible for the labeling activities, which include loading pails in a labelling machine and making pallets of labeled pails. In addition, two others work on the filling activities, which include one person loading pails on the filling machine and making pallets of filled pails, and the other one lidding pails and also palletizing them. In addition, it is also important to note that activities that add value to the product represent approximately 21% of the total lead-time.

In order to better analyze this process, a simulation model was developed. The simulation model can be seen in Figure 6. Arena Software was used to run this model. In addition, Input Analyzer was used to fit the distributions for each operation and arrivals. The conveyors shown in the model were modelled based on machine specifications,

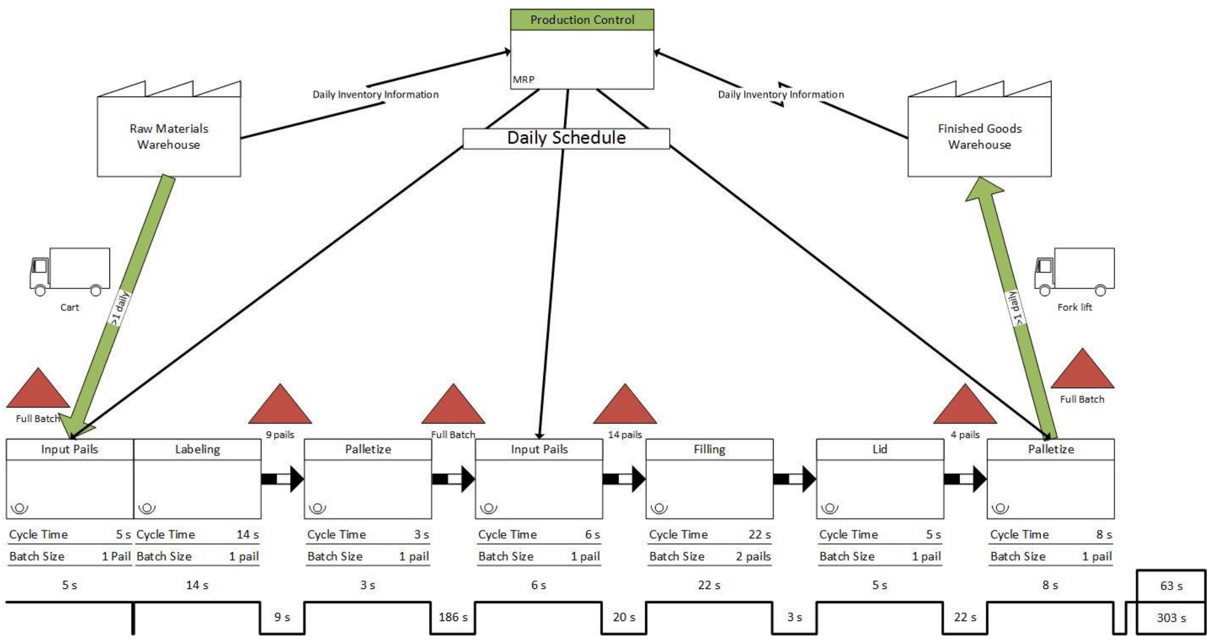

Fig. 5 Current-state map

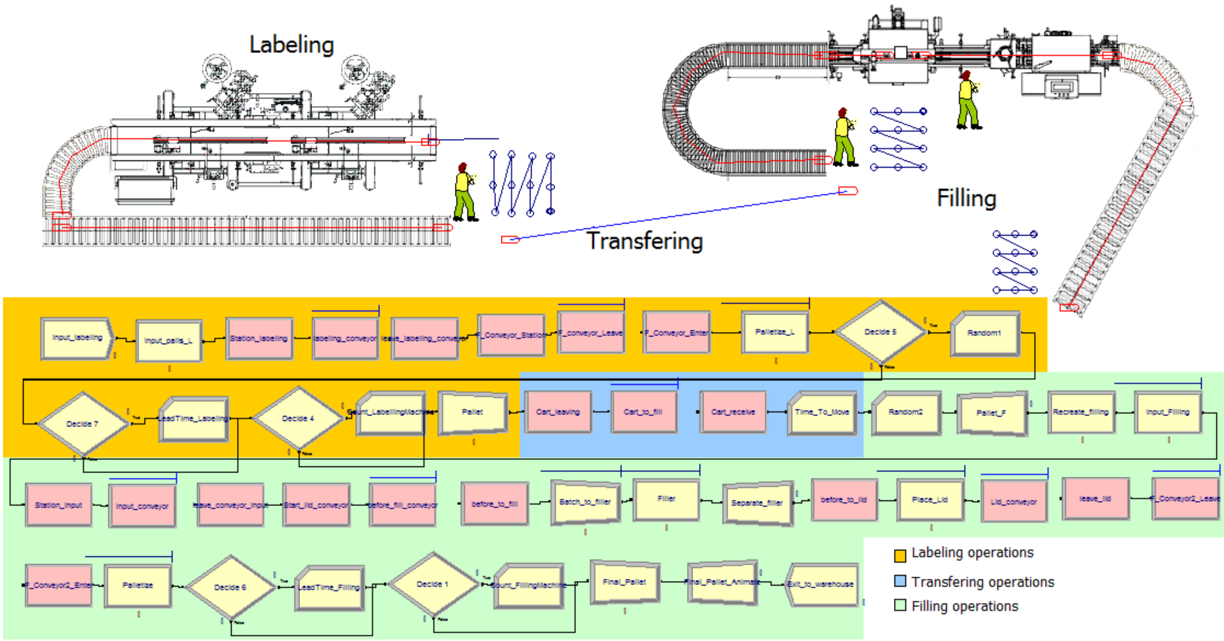

Fig. 6 Current scenario simulation model

so it has both speed and length similar to the real conveyors. Furthermore, it is important to point out that the animation piece of it is not drawn to scale. In fact, in the real process, the labeling machine and the filling machine are about 50 m distant from each other.

The logic behind the simulation model was checked several times in order to verify it. Several comparisons to the VSM and the real process were made to ensure that it follows the same rules – entity flows, queue lengths, and operator priorities – as the real system. In addition, to validate this model, Table 1 shows results from both the real system and the simulation model.

The data in Table 1 was collected in samples of 10 minutes. First, the number of units produced by each machine during periods of 10 minutes was recorded by watching the real process. Afterwards, the same process was replicated on the model by generating random numbers to collect the data during periods of 10 minutes. This automatized process on the simulation model reduces the chances of errors.

From Table 1, it is clear that the averages are similar for both the labeling process and the filling process. In addition, the standard deviations for both processes are lower on the simulation model. This can be explained by two facts. First, the simulation model automatically collects the data, which decreases the possibility of errors, such as delay in stopping the stopwatch, or counting extra entities. Second, there are aspects which can impact the results in the real process that are not present on the simulation model, so this makes the real process more variable than the simulation model. For example, operators may work faster because there is someone watching them.

To check the validity of the simulation model, a T-test was also performed. The T-test compared the means of the population of the real system with the simulation model for both the labeling and the filling processes. The null hypothesis was that, with a significance level of 5%, the means of both the real process and the simulation model are the same. The results showed a p-value of 0.1164 for the labeling process compared to the simulation model and a p-value of 0.5157 for the filling process. Because both p-values are higher than the significance level (0.05), we cannot reject the null hypothesis. Therefore, there is no significant difference between the means for both the labeling process and filling process compared to the simulation model, so the model is valid.

Table 1 Results from samples of 10 minutes on both the real process and the simulation model

Labeling Process				Filling Process			
Real process data		Simulation data		Real process data		Simulation data	
ID	Count	Replication	Count	ID	Count	Replication	Count
1	59	1	60	1	41	1	41
2	56	2	61	2	40	2	40
3	55	3	59	3	41	3	42
4	62	4	60	4	43	4	41
5	60	5	61	5	42	5	41
6	60	6	60	6	40	6	41
7	55	7	57	7	39	7	42
8	59	8	59	8	41	8	41
9	66	9	60	9	43	9	41
10	65	10	61	10	40	10	40
11	59	11	58	11	41	11	40
12	63	12	59	12	41	12	42
13	60	13	60	13	42	13	41
14	58	14	59	14	43	14	40
15	63	15	61	15	40	15	40
16	58	16	59	16	40	16	41
17	58	17	61	17	42	17	41
18	63	18	60	18	43	18	43
19	64	19	57	19	38	19	42
20	64	20	58	20	36	20	40
21	58	21	57	21	39	21	40
22	59	22	60	22	40	22	40
23	58	23	60	23	37	23	42
24	62	24	59	24	43	24	42
25	62	25	59	25	42	25	40
26	59	26	59	26	40	26	42
27	60	27	59	27	42	27	42
28	63	28	59	28	41	28	42
29	59	29	60	29	43	29	40
30	60	30	59	30	40	30	40
Average	60.23	Average	59.37	Average	40.77	Average	41.00
Stand. Dev.	2.82	Stand. Dev.	1.16	Stand. Dev.	1.79	Stand. Dev.	0.91

After running the simulation with 30 replications, the report showed results that can be compared to the current-state map. Table 2 shows the cycle times of each operation in the simulation model. Some of these results are automatically collected by Arena; however, some of them need the use of the Record block to collect the cycle times. These results show that the cycle times in the simulation model are consistent with the current state map in Figure 5. In addition, similar to the current-state map, the value added time represents 21% of the total time.

Another important analysis on these results is resource utilization. For this case, only the operator utilization is important. The operator utilization was calculated by relating the operators' usage with the process that they are part of. This was done because, when the labeling activities are performed, the operators on the filling activities are idle. Also, when the filling activities are performed, the labeling operator is idle. Therefore, the labeling operator utilization was calculated based on the lead-time of the labeling process isolated and the filling operators utilization was calculated based on the lead-time of the filling process. The results showed that the labeling operator has a utilization of 83% and the two operators on the filling process have 70% and 62% utilization.

Table 2 Cycle times from current-state simulation model

Activity	Time per entity (s)
Input Pails on labeling machine	5.3
Labeling	14.0
Moving to palletize	9.0
Palletize	3.1
Transferring to filling room	185.9
Input Pails on filling machine	6.2
Moving to fill	20.0
Filling	22.2
Moving to lid	3.0
Lid	4.9
Moving to palletize	22.0
Palletize	8.2
Value added time	63.9
Total time	303.8

4.2 Future-state map optimization

The new layout suggested in this study intends to eliminate the activity of transferring pails from one room to another by connecting the machines in the same room. In order to use this new layout, the labels need to be switched to new ones made of a different material that do not need a controlled atmosphere to work properly. This need to be done because the labeling machine will need to move to the filling room. Therefore, the packaging process will be performed in one single step, instead of three.

The future-state map for the new scenario can be seen in Figure 7. This new state map shows that, by connecting the labeling machine directly to the filling machine, activities that add value to the product now represent approximately 55% of all activities, which is a much better scenario than the 21% from the previous one. In addition, it can be noted that the lead-time was reduced from 303 s to 99 s, which represents a 67% reduction on lead-time. In fact, this new scenario eliminated the activities of pails moving on one conveyor, palletizing pails after labeling, moving them to the filling room, and loading them on the filling machine. These activities take 204 s per entity on the current-state map, or those 67% of the lead-time.

From this new layout, a new simulation model was developed. The future-state simulation model has the same rules as the future-state map. Table 3 shows the cycle times from this simulation model. The results showed that the cycle times are similar for both the future-state map and the simulation model.

Table 3 Cycle times from the future-state simulation model.

Activity	Time per entity (s)
Input Pails on labeling machine	5.3
Labeling	14.0
Moving to fill	20.0
Filling	22.2
Moving to lid	3.0
Lid	4.9
Moving to palletize	22.0
Palletize	8.2
Value added time	54.6
Total time	99.6

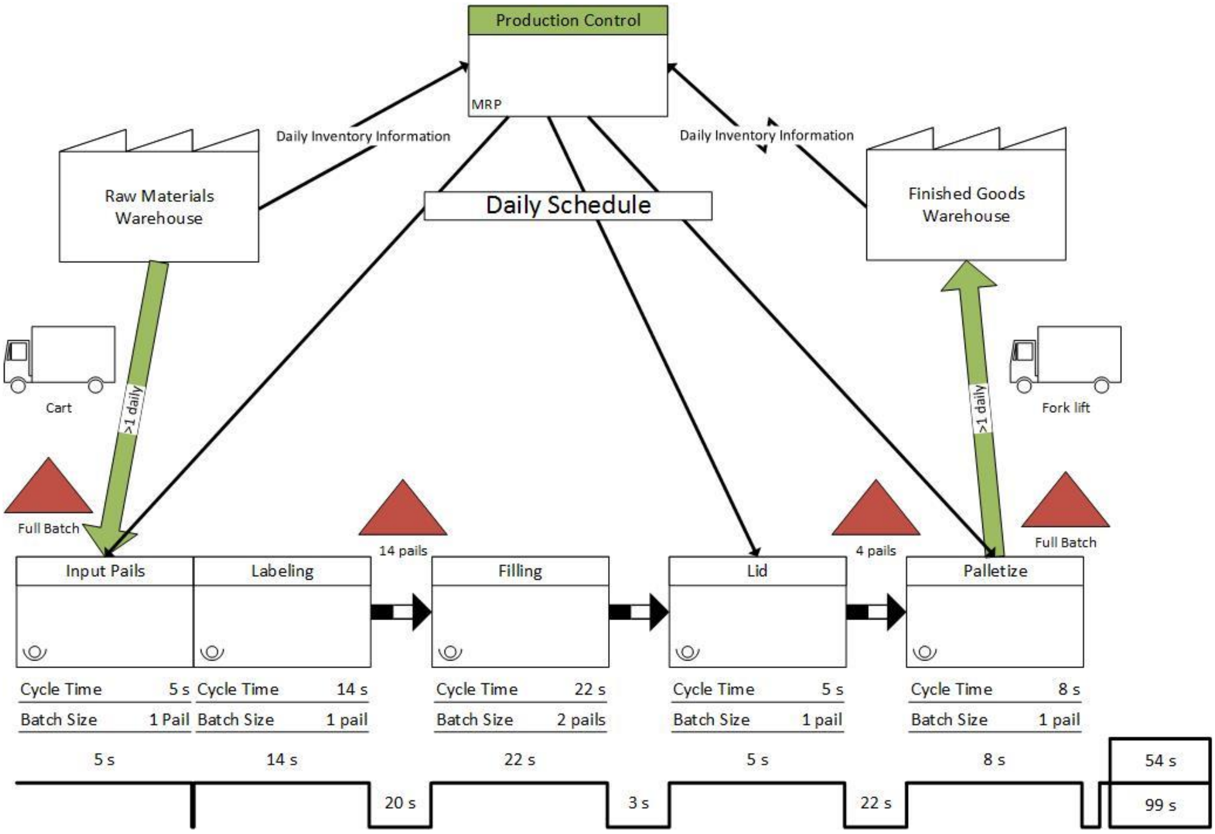

Fig. 7 Future-state map

The new layout shown in the simulation model in Figure 8 is the best that can be made without buying new conveyors. In fact, the labeling and the filling machines could be set in parallel, but they are too large to do so. Therefore, if the company buys new conveyors, a new layout, such as a U-shaped layout, can be tested.

This new scenario can be implemented without spending money. In fact, the company does not need to buy new machines or conveyors, or even hire new operators. The only concern about this is the label's material that needs to be tested on a different environment. In addition, with this new layout, the company is going to save time by reducing the lead-time and also reducing labor requirements by one operator, which can be moved to a different activity.

4.3 Discussion

By comparing both scenarios previously described, it is possible to notice the improvements of changing to this new scenario. Table 4 shows a summary of the KPIs used in this study and compares them for both simulation models.

Table 4 shows that the labor requirements were reduced by one operator. This is similar to the study made by Helleno et al [25], which showed that by applying VSM and DES it is possible to analyze several scenarios that could imply a reduction in labor needs. However, in their study, the authors changed process technology in one scenario in order to reduce labor requirements, which was not necessary in this study. In addition, as shown on Table 4, lead-time was reduced by 67%. The study made by Atieh et al [26], in which they applied VSM and DES to improve a glass manufacturing process, reduced the average lead-time by 20%; however, they increased the resources used in order to decrease the lead-time. In this study, there is no need to spend money on new resources.

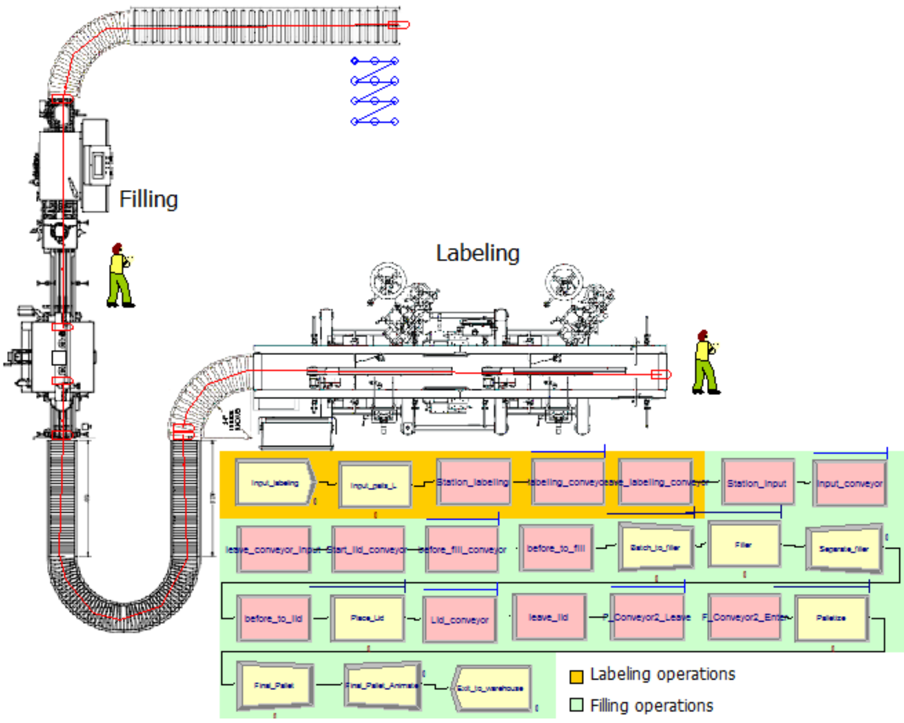

Fig. 8 Future scenario simulation model

Table 4 Key Performance Indicators

KPI	Current scenario	Future scenario
Value added time	63.9 s	54.6 s
Lead-time	303.8 s	99.6 s
Value added activities	21%	55%
Labor requirements	3 operators	2 operators
Operator 1 utilization	83%	82%
Operator 2 utilization	70%	79%
Operator 3 utilization	62%	-

5 Conclusions

This work showed how to find a better layout for a packaging process in a company that produces chemical products. By using VSM and DES, it was possible to analyze different scenarios that could create savings in the process. The new scenario proposed eliminated some activities that do not add value to the product. The packaging process changed from a three-step process to a single-step process which synchronizes activities and allows for a better flow of materials. In this new scenario, there was a reduction in lead-time of 67% and a reduction in labor requirements of 33%. In addition, it eliminated the need for space to store some work-in-process inventory after labeling the packages. The trade-off of this change, however, is that the company will need to test new labels because the ones they current use may not work properly in the new environment. Indeed, this reduction on lead-time will allow the company to better respond to its demand and improve the efficiency of some resources.

As a limitation for this study, there was a lack of data to validate the activity of transferring the packages from the labeling process to the filling process. In addition, the transferring activity has a high variability, which impacted the sample size that should be collected to create the simulation. Indeed, the sample size calculated was too large to be collected, so it was assumed to be the largest sample size of the other activities. On the other hand, as a benefit of using DES, there is the possibility of easily creating several scenarios and comparing them to each other to find the best one. In fact, the best scenario improved the percentage of value added activities and improved labor requirements.

For future work, different layouts can be tested with new conveyors to reduce the space required for the activity. In fact, a U-shaped layout may be more effective than the proposed one because it would require less space. In addition, the bottleneck changed from the transferring operation to the filling operation, so new scenarios can be tested with more resources applied to this activity, to decrease the impact of this operation on the overall performance.

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ANEXO A – Regras de formatação da revista International Journal of Advanced Manufacturing Technology

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Footnotes to the text are numbered consecutively; those to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data).

Footnotes to the title or the authors of the article are not given reference symbols.

Always use footnotes instead of endnotes.

Acknowledgments

Acknowledgments of people, grants, funds, etc. should be placed in a separate section on the title page. The names of funding organizations should be written in full.

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Please always use internationally accepted signs and symbols for units (SI units).

Please use the standard mathematical notation for formulae, symbols etc.:

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Roman/upright for numerals, operators, and punctuation, and commonly defined functions or abbreviations, e.g., cos, det, e or exp, lim, log, max, min, sin, tan, d (for derivative)

Bold for vectors, tensors, and matrices.

References

Citation

Reference citations in the text should be identified by numbers in square brackets. Some examples:

1. Negotiation research spans many disciplines [3].
2. This result was later contradicted by Becker and Seligman [5].
3. This effect has been widely studied [1-3, 7].

Reference list

The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. Do not use footnotes or endnotes as a substitute for a reference list.

The entries in the list should be numbered consecutively.

Journal article

Gamelin FX, Baquet G, Berthoin S, Thevenet D, Nourry C, Nottin S, Bosquet L (2009) Effect of high intensity intermittent training on heart rate variability in prepubescent children. Eur J Appl Physiol 105:731-738. doi: 10.1007/s00421-008-0955-8

Ideally, the names of all authors should be provided, but the usage of "et al" in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al (1999) Future of health insurance. N Engl J Med 965:325–329

Article by DOI

Slifka MK, Whitton JL (2000) Clinical implications of dysregulated cytokine production. J Mol Med. doi:10.1007/s001090000086

Book

South J, Blass B (2001) The future of modern genomics. Blackwell, London

Book chapter

Brown B, Aaron M (2001) The politics of nature. In: Smith J (ed) The rise of modern genomics, 3rd edn. Wiley, New York, pp 230-257

Online document

Cartwright J (2007) Big stars have weather too. IOP Publishing PhysicsWeb. http://physicsweb.org/articles/news/11/6/16/1. Accessed 26 June 2007

Dissertation

Trent JW (1975) Experimental acute renal failure. Dissertation, University of California

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Supply all figures electronically.

Indicate what graphics program was used to create the artwork.

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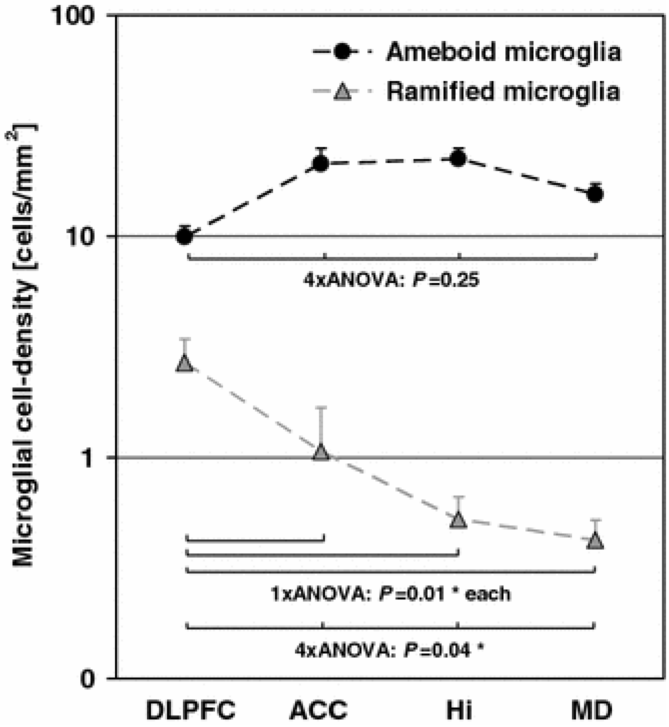
MSOffice files are also acceptable.

Vector graphics containing fonts must have the fonts embedded in the files.

Name your figure files with "Fig" and the figure number, e.g., Fig1.eps.

Line Art



Definition: Black and white graphic with no shading.

Do not use faint lines and/or lettering and check that all lines and lettering within the figures are legible at final size.

All lines should be at least 0.1 mm (0.3 pt) wide.

Scanned line drawings and line drawings in bitmap format should have a minimum resolution of 1200 dpi.

Vector graphics containing fonts must have the fonts embedded in the files.

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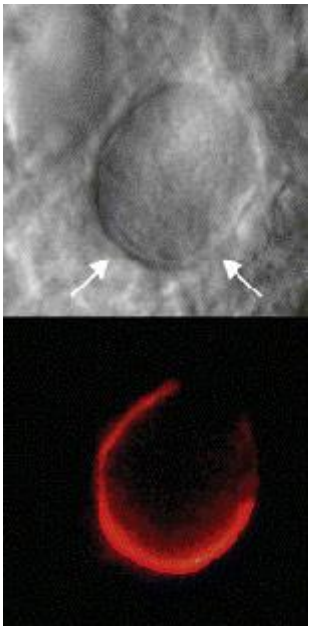

Definition: Photographs, drawings, or paintings with fine shading, etc.

If any magnification is used in the photographs, indicate this by using scale bars within the figures themselves.

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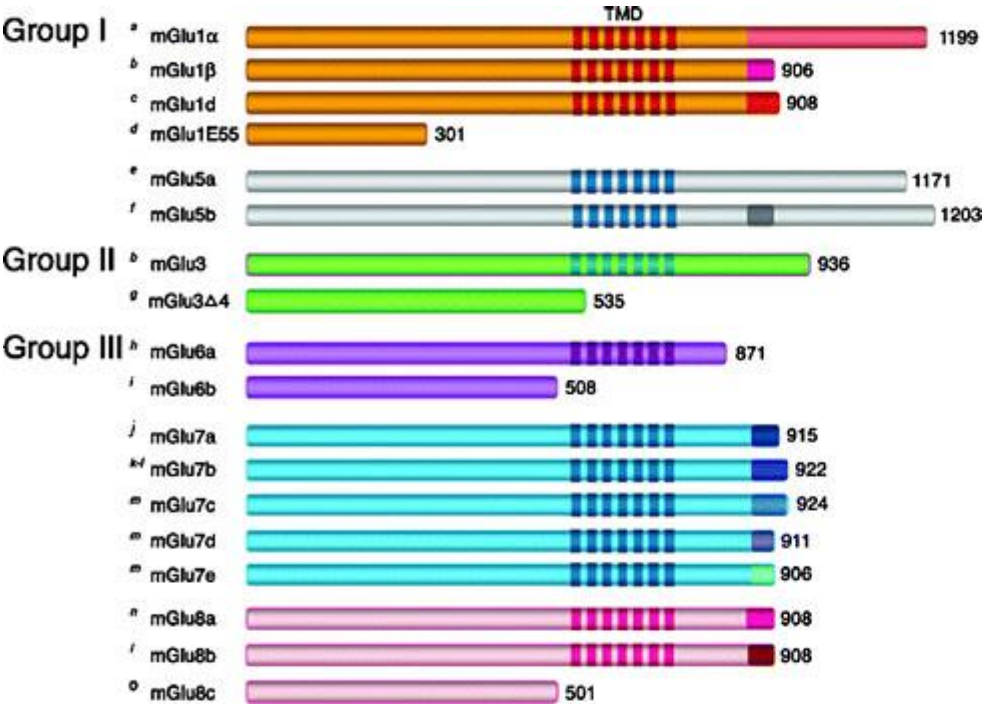

Definition: a combination of halftone and line art, e.g., halftones containing line drawing, extensive lettering, color diagrams, etc.

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If the figures will be printed in black and white, do not refer to color in the captions.

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Each figure should have a concise caption describing accurately what the figure depicts.

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Figure captions begin with the term Fig. in bold type, followed by the figure number, also in bold type.

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Identify all elements found in the figure in the figure caption; and use boxes, circles, etc., as coordinate points in graphs.

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Refer to the supplementary files as “Online Resource”, e.g., "... as shown in the animation (Online Resource 3)", “... additional data are given in Online Resource 4”.

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