Implementation of DMADV in a Body Armor Manufacturing Company

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Abstract *— The incoming inspection area of a Body Armor Manufacturing Company is responsible for ensuring all finished products from subcontractors meet all customer and internal requirements. This area has been identified as a bottleneck for the complete manufacturing facility and as ineffective in capturing non-conformance to requirements. After analyzing and implementing the DMADV methodology the incoming inspection area improved effectiveness and efficiency clearing all accumulated material and enhancing internal and external customer satisfaction. This was achieved by dividing the effort in four major groups: requirement flow down, material flow, staffing and non-conforming material management. After one year and four months the design proved adequate and the results reflected a methodical system that provides an effective barrier for material entering the manufacturing process and a mechanism to process non-conforming material minimizing financial impact.*

Key Terms *— First in First Out (FIFO), Material Review Board (MRB), Standard Work Instructions (SWI), Technical Data Package (TDP).*

INTRODUCTION

The incoming inspection is the process that products undergo to ensure that all goods purchased from subcontractors meet all the customer and company requirements. This process is very critical for the manufacturing of good quality products. The main problem that this project pretends to solve is the material flow, material identification, inspection accuracy, inspection efficiency and product traceability in the finished goods incoming inspection area. At the moment the factory is receiving material from several suppliers at once. Priorities are being set at the moment and no planning is being performed.

Within the process of improving the area this project will be performed in phases. These phases will take place in a one yearlong study and implementation.

SUPPORTING THEORY

The company involved in this project is a leader in the industry of body armor. Producing commercial and military products for customers including law enforcement agencies, different branches of the military and foreign governments are amongst the end item users. The company is composed of several departments that work driven by the goal of delivering a top quality product with on time delivery while exceeding customer expectations. Within these departments the Quality Department ensures the product meets customer requirements and specifications and this will be the main department of focus. The process of incoming inspection can be defined as the first inspection point once the product built by subcontractors is delivered to the Company for processing. It is critical that all products get inspected accurately and efficiently so that the manufacturing and subsequent inspection points can run efficiently and effectively. The output of this area can be considered the input of every other area in manufacturing. At this point in the process is where all material is compared to the standards and requirements and is accepted to enter the manufacturing process.

The process begins with the finished goods being received in the factory. In this stage the inventory department verifies the material count with the packing slips, the PO and the receiving schedule. After this part is completed all the

documentation is handed to the receiving inspector that verifies all the paperwork of the items received. This paperwork includes the Certificate of Conformance, PO and packing slip. After the paperwork is verified it is uploaded to the system and the material is set on quality hold in the system until the physical material is inspected and approved by the incoming inspection team.

There are two main materials that pass through the incoming inspection area. Those are the following:

- Ripstop – the cover for the ballistic material. This is a very simple product composed of only one or two plies of fabric sewn together and one label.
- Carrier – Carrier are the more complex garments that are composed of several items including fabrics, tapes, webbings and hardware. These items are integrated together to create systems and interconnect with other systems. These are the most critical items that go through the incoming inspection area.

The material comes in sets or kits. The sets and kits are defined by the customer order and contract requirements. The main lot size that is evaluated is 1,200 for kits and 2,400 for components. Kits in terms contains between 2 and 15 individual components.

Each part goes through the process in bundles of 10 units since that is the final packing requirement. At this time QC inspector takes the 10-part bundle and inspects it against the requirements. For every bundle the QC operator generates one line in a paper report to capture any defects found. In that form the Quality inspector records the amount inspected, amount accepted and amount rejected. For each rejected part the inspector needs to specify the defect by code. At the end of the day the forms are handed to the team leader and then sent to the Documentation Department for data entry and analysis.

The variation between individual components is very significant and the testing performed to each of them varies greatly. The inspection time varies from 15 seconds to 5 minutes per part depending on the issues found and the subcontractor that manufactured the parts. After the contractor has been evaluated and the defect rate is below the established amount the 100% inspection is removed. Once removed an audit process is started for the specific configuration, component, contract and subcontractor. In this audit process an AQL level inspection is performed in tightened levels. If any part fails 100% inspection is done on the specific component that fails and if two or more components fails the complete lot is inspected 100%.

Once the lot passes the inspection process the items deemed acceptable are sent to the inventory department to finalize the receiving and payment processes. All the rejected parts are stored and then the management team evaluates them and then final disposition is taken on the items.

While this process is occurring, the Operations team is pressuring the area since the materials are required immediately to continue production. This causes the area to shift between priorities and if something is detected go to the next lot to try and feed the line with the best material in the fastest way possible. The main problem this causes is the loss of visibility on what has been verified, what is still pending and all the non-conforming product gets stored in the quarantine cage and disposition is delayed.

The second part of the incoming inspection process is the disposition on the product. Good product is sent to the production floor and defective product is sent to the cage. The biggest issue is the aging of the non-conforming product. At this moment the cage contains rejected material dating back to November 2012. This material needs to be disposed according to the procedure and this is as follows: Material that is deemed acceptable with minor defects gets disposed as “use as is”, material that is repairable internally will be disposed as “rework”, and material that is deemed not acceptable and not repairable internally is disposed as “return to vendor” is set to return to vendor and

the RMA process is started to be able to return the product for replacement.

The incoming area has been shifting from two employees to 26 people and two team leaders in a matter of three months. This area processes over 200,000 units per month with little structure. In the next chapter the phases and stages of this growth will be discussed as part of the progress of the project. Material movement and traceability for this type of operation is a big challenge. This area a very critical part of the process but due to schedule crunches the area has been neglected.

METHODOLOGY DMADV

For this project the methodology that will be implemented to develop and improve the incoming inspection process will be DMADV. Initially the project was being focused in the DMAIC methodology but as part of the extensive investigation and improvement initiatives it was determined that the process was not defined in a way that this methodology could be implemented. Instead, DMADV methodology was selected because the project shifted to the development of the process in the area from scratch. There was no defined process to either measure against or improve [1]. In the past, the incoming inspection area was just a verification of product quantity, delivery and occasional product verification. The process was not defined and as part of this project that consists of several phases, a process will be defined, designed and implemented at the same time that product will be flowing and inspected.

DMADV is a 5 step method that will incorporate continuous improvement visibility and traceability to the project progress and development. The 5 steps for this methodology are:

- Define – goals of project
- Measure – critical indicators to the project
- Analyze – options to achieve the project goal
- Design – the process with options analyzed
- Verify – the design meets the project goals [2,3]

In this section we will go through each of these steps and apply them to the area in question.

Define

The main goal of this project is to design a process to insure all material that is received in the manufacturing plant complies with all customer requirements and company specifications. In order to meet the customer expectation of quality excellence and adherence to design and contractual requirements, it is critical for the incoming inspection area to be efficient and accurate when inspecting and determining disposition of incoming product.

The main complaint received from different internal and external customers is that the quality of the outer carriers is below expectations. The items manufactured by the company are mostly the ballistic inserts that go into the carriers. These items have very minimal quality issues reported by internal and external customers. Around 80% of all issues reported by customers are related to carrier problems. The carriers are produced in the majority, around ninety percent, by subcontractors that manufacture the goods and ship them for assembly, stuffing and shipping in the company. For this reason it is critical to have a clearly defined process than can ensure that all material received complies with all customer expectations and requirements before it enters the assembly process.

Measure

In order to measure the incoming inspection process it is important to first define the process inputs, outputs and any feedback that is provided to the area. The baseline inputs in the area are: Product to be inspected (Carriers and Ripstops); Customer requirements (Purchase description and contract requirements); Staffing (resources that perform the inspection); Master Sample (sample provided by the Engineering department); Fit testing equipment (ballistic fillers and hard plates for testing) and Documentation (physical copies of the purchase description, photos of the items, forms that need to be completed to record the results of

audit and any additional documents available per contract). The outputs of the process are as follows: Accepted product (the material that meets the requirements); Non-conforming product (material that does not meet the requirements) and Records (the forms with all the results of inspections). There is no feedback to the process except the occasional training when a major defect is found by an external customer.

In this section we will measure the items that are needed for the incoming inspection area to improve. This will be performed in several phases. The phases are as follows:

1. Measure the effectiveness of the flow down of requirements to the incoming inspection area. This will ensure the incoming inspection area has clear understanding of customer requirements and contractual requirements for all products that are processed. The main complaint is that inspection point are not consistent in the area and material is rejected and then passed and vice versa because of confusion. At this time the only measurable item on flow down of requirements is informal training that is not aided with any visual, clear or easy to understand document. It has been left to the interpretation of the trainer.
2. Measure the material flow, identification and traceability in the area. This will measure the way material is handled in the incoming inspection area. The main complaint from manufacturing is missing materials after incoming. The metric is measured by the amount of material that goes to incoming versus the amount of material that goes out of incoming and it is documented by the data reported by the inspectors. At the start of this project the data is unreliable and had to be excluded from any analysis. One of the focuses of the project is to develop metrics for this area.
3. Measure if the area has all the staff required for the functions that are expected in the area. At this stage, since requirements of inspection are not clearly defined, it makes the measuring of the time needed to inspect impossible. Staffing is critical and with the existing volume, staffing criteria needs to be measured to ensure adequate ramp up and line stability.
4. Measure the material handling of non-conforming product in the incoming inspection area. This is measured with the aging time of the material in the non-conforming cage. At this time material age average is 2 months and material is going in to the cage daily. The goal of this design is to have the non-conforming material repaired in house or returned to the subcontractors the same day that it is found without ever getting to the cage.

Analyze

In this stage of the process we will analyze all the possible options that can be implemented in the incoming inspection area to then develop a design that will meet the goals and objectives of this area.

Analysis of Flow Down of Requirements

The first problem that will be analyzed is the lack of clear requirements for the items inspected at incoming inspection.

The main complaint by the customer and inspectors is the lack of clear, understandable and transferable way to communicate all the requirements to the different processes. The company has not been able to define a way to translate those requirements to all contractors and incoming inspector areas creating great confusion and in some cases two different products built to the same specification. The problem is caused by the vague requirements established by the customer.

To solve this there are several options that can be implemented. These are as follows:

1. Implement a TDP for all the items that will be inspected in the area. A version of the TDP was in process in the past but it was decided that it was a very complex and long process. For this idea to be implemented the TDP will have to be shorter, clearer and more visual than the previous version. The suggestion is to make

one document with all the information any inspector, subcontractor, customer or any other entity would need in a very simple format that could be understood at all levels. This document should contain at minimal: the materials needed, the critical dimensions or characteristics, visual sketches or pictures to show all the component interactions within the product.

2. Implement SWI to guide the inspectors at incoming inspection on how to inspect items. This will achieve a consistent inspection method and remove most of the interpretation at time of inspection.

Analysis of Material Flow, Identification and Traceability

The second problem that will be analyzed is the material flow, identification and traceability of all material process at incoming inspection. This problem affects the complete operation. The main focus of this area will be divided in two: the definition and management of good material and the processing and identification of non-conforming material. To define this problem we will take into consideration complaints from manufacturing department and inventory department.

The main complaints are that material sits for a long time before it gets inspected by the incoming area and that once the material is inspected good material and bad material are not clearly identified and they have to wait to get clarification before moving the material out of the incoming area. Initially there was a staging area for this process but because of manufacturing plant re-layouts, this was eliminated and material segregated but not identified.

To solve this there are several options that can be implemented. These are as follows:

1. Implement a labeling system for clear identification of good and non-conforming parts. At the moment non-conforming parts are placed in bins but no identification is set on the parts. Another problem is there is nothing to identify accepted product. The proposal is to have an accepted label placed in all accepted boxes. This will clearly have identified the material for future reference.
2. Implement a new non-conforming red tag that will be placed in the item that will provide all the defect information, inspector name and inspection date for future reference. With this tag there is no reason to have a good item tag.
3. Hire a new resource to manage all the material that goes in and out of the incoming inspection area. This person will be responsible of all inventories of parts, material movement, material identification and material distribution. This will ensure that all material is being tracked at all times and that the material wait times are controlled.
4. Implement FIFO for the material received for incoming inspection. The complaint is that the incoming team works on the priorities of the day and material that is not priority sits in receiving until incoming is out of rush priorities. Implementing FIFO will provide a way to always keep track of all the material that enters the plant.
5. Re-integrate the staging area for clear visual identification of material status. A simple three stage area will be implemented. An area for all material that needs to be inspected at incoming, an area for all good material that passed through incoming inspection and a non-conforming material area.

Analysis of Staffing

The third problem that will be analyzed is the staffing needs. The incoming inspection area is being managed by the Quality Supervisor. The way this area works is, every time a shipment comes from a subcontractor the Supervisor will get staff from the line inspectors and get the items evaluated. The main concern is managing expected increased volumes with limited resources.

To solve this there are several options that can be implemented. These are as follows:

1. Implement an incoming inspection team of 3 people initially, to gather information on the

incoming inspection cycle times and implement a staffing plan for changes in area volume and inspection capacity.

2. Have one team leader assigned to incoming inspection area to ensure that all work is being performed to the requirements and that all forms are filled out accurately.
3. Implement ramp up plans using the set production and delivery schedule as basis for staffing ramp up planning and training.

Analyze the Non-Conforming Product Management and Non-Conforming Cage

The fourth problem that will be analyzed is non-conforming product cage management and material returns. Non-conforming items are sent to a non-conforming cage located in the material warehouse so that final disposition can be taken by management.

The main complaint is the aging of non-conforming material that is sent to the non-conforming cage. There is no established system to get the defective items repaired, returned or destroyed. This caused the inventory levels to keep growing and the dollar value of finished goods material that could not be used kept growing.

To solve this there are several options that can be implemented. These are as follows:

1. Create a cage team that will go through all the rejected material in the cage, will re-inspect all items, tag them with the defects and do a final inventory of all the items. Then return to the subcontractors for repair or replacements.
2. Implement a system that when any rejection is found, the defects are kept at the new staging area and daily dispositions will be taken. These materials will be tagged and organized by lots to, at the end of every day, send the shipment back to the subcontractor.
3. Implement a system for tracking all returns for adequate deductions and payments. Since non-conforming product is not usable, the company will have to develop a system to charge back the units to the contractor and take them out of inventory. One of the new outputs of the area will be to fill out a non-conforming report for all the rejected units by lot and by vendor. This will be the input for the inventory and finance debit process.
4. Once the Cage is cleared it will only be used for material that require RMA and cannot be shipped back daily and for material returned from customer for evaluation and disposition. This will minimize cage inventory and improve non-conforming material control.

Design

In this section the design of a new system for the incoming area will be developed. The design will be done in phases that will follow the same order as the Analyze section.

Design of Flow Down of Requirements System

First part of the Design will be to design a system to flow down the requirements to the incoming area. From the options analyzed the items that are going to be used for the design are the creation of a TDP and the creation of SWI.

In order to adequately design the TDP the most critical items to flow down have to be defined. To accomplish this, the TDP will be designed following these sections:

1. Cover page with name, lower level model numbers and revision levels. This will allow the user to easily identify the item being made, using the same codes as the cutter and Engineering use.
2. Table of contents.
3. General Requirements page – will contain all the general guidelines on all critical requirements that need to be met. This will ensure that any user has a clear understanding on specific customer requirements as stated in contractual and build documents.
4. Revision Log – This section is intended to keep a record of all the revisions, changes, updates that the TDP goes through.
5. Pieces-materials guide – This section will contain all materials the design product would need. This area will also have the type of

material and characteristics as specified by the customer documents.

6. Measurement Guide – This section will include all the finished dimensions of the component as specified by the customer.
7. Schematics section – This section will contain a step by step visual aid that clearly states were all the trims go and specifically what trim goes where.

The second will be the creation of SWI. These will provide a guide on how to inspect the products step by step. This work instruction will reference all inspection tools required, how to use them and all critical to quality items that are present in the product. It will provide clear guidance for all fitment and performance tests that need to be performed on the products. The SWI will also reference the TDP and customer documents.

Design of Material Flow, Identification and Traceability

The second part of design will be to design a method to improve the material flow, identification and traceability of all products processed at incoming inspection. From the options analyzed, the items that are going to be used for the design are the labeling or tagging of non-conforming material and good to use boxes, hire a new resource to manage the material movement, implement FIFO that will be managed with the plant priorities by the new area manager and create a staging area for all materials.

For Labeling and tagging two new label tagging systems will be purchased. The first is a red non-conforming tag that will be placed on every defective part and will include all the information on non-conformity, date, inspector and item. The second will be a green quality control pass sticker that will be placed on all passed boxes. The red tag will travel with the parts till the completion of the disposition process.

Hire a resource to manage all the material flow in and out of the incoming area. This resource will be placed to coordinate material movement between all departments and serve as communicator between management priorities and the incoming area. In addition this resource will coordinate the return of material to subcontractors, send material for internal repair and scrap any scrap material.

FIFO and staging area will be incorporated to the area. The material manager will set priorities for the incoming area by placing the material to be inspected in a staging area identified as to be inspected. The material will be processed through the area in the same ordered received. To achieve this, the layout of the incoming inspection line will have only one input and one output and the staging area will follow a single row form and the material will be evaluated in the row order. A second staging area will be created at the end of the line to place all the good material that will be sent to inventory and a third are will be created for all non-conforming product. This third area will also include an evaluation table to perform a daily disposition of the material in that area.

Design on Staffing

The third part of the design is the staffing requirement and plan system. The first stage was to set a team in place to process the increasing volume. Instead of 3 people as in the analysis page, 12 people were placed in the incoming inspection area and cycle times determined for the items inspected. A ramp up plan was established and a team leader assigned to the area. The Staffing plan is generated with the cycle times and the expected volumes per month. Since volume is expected to duplicate, the plan is to establish two mirror shifts. For this design, the plan is to ramp up to 12 people per shift and two team-leads. This will mitigate the learning curve and increase efficiency. The expected ramp up time to 80% efficiency is two months. The new staffing plan allows adjustment in staffing levels and ramp up phases. This will incorporate a methodical evaluation of staffing never before implemented in the Quality department.

Design of Non-Conforming Product Management

The Fourth stage of the design is to create a system to manage non-conforming product and the non-conforming product cage in the warehouse. A team was placed to evaluate all material in the cage with the tools developed.

The second part of the design is to implement a system to process non-conforming product quickly. In the material management design section a staging area for non-conforming material was incorporated. In this area daily meetings of the MRB will be held. All material will be processed and disposition on a daily basis to ensure no accumulation takes place. This will ensure little to no additional material is send to the non-conforming cage.

The third part of the design is to create a tracking system for all returns and repairs for adequate deductions and payments based on current non-conforming procedure. This system design will include finance, inventory, manufacturing and QA departments. A debit memo program will be started with the input being the non-conforming report that will provide all information finance will need to issue a memo for all returns. This will allow an accurate tracking of all items and the financial impact of poor supplier quality.

The fourth and last part of this design is to determine the material that is allowed to go in the cage. The material that is the returns from vendor, quarantine lots due to any testing failure and rejected material from incoming that requires additional RMA. The incoming non-conforming material will have a designated area with high visibility tools that allow fast and clear identification of product aging.

CONCLUSION AND RESULTS

The results of the implementation will be evaluated to ensure the complete project was effective as part of the Verify step and is being performed after one year and four months after implementation. This section will go through the results and current status of the incoming inspection area.

Flow Down of Requirements System

After implementation of flow downs as designed in this project, the requirements have been flowed not only to the incoming inspection area but to all the subcontracted plants and internal manufacturing facilities and has made the task of building one standardized product a simple one. The project scope initially was focused on one product line but has expanded to all new and existing products manufactured after the initial implementation.

The feedback received at all levels is that with the TDP system has been extremely positive because of the clarity and standardization.

The SWI created for Incoming inspection have provided a standard final inspection tool at all manufacturing facilities. The SWI have also incorporated additional methodology and requirements and have evolved to be the standard of evaluation of all finished carriers.

In conclusion the design and implementation has been rated to a major improvement in the company project score card.

Material Flow, Identification and Traceability

The implementation of material flow and traceability management in the incoming inspection has reduced the inspection lead time and receiving lot aging from average 2 weeks to average 2.5 days. The integration of the priority management, FIFO and staging area proved to push the complete system at incoming to have high visibility and provide a very clear perspective of the effects of poor tracking. With the addition of the three tools designed in the system the surrounding departments had to improve their systems as well. To do this a multi department team from inventory and quality implemented 5S principles and the integration of a kanban system for incoming inspection scheduling. With the addition of these new strategies the incoming inspection area maintains the material flow with consistency and a buffer inventory has

been achieved between manufacturing and incoming removing incoming as the initial bottle neck for the assembly area.

Staffing

The Staffing plan established in the project initially yielded significant improvements. It provided a good baseline on the evaluation of personnel needs. The modifications that had to be made to the system are the addition of individual component and contract requirements and methods that concluded in a more schedule base approach to the staffing plan. The improved staffing plan takes into consideration contract specific sampling plans and procedure requirements that were not considered originally. With the new implementation the incoming area staffing was able to be reduced and three floaters or "utility inspectors" added to the factory headcount to account for any special needs of the incoming and assembly areas. The scope of the staffing plan was expanded to other inspection areas concluding in a savings of more than $500,000 in inefficient and unnecessary resources in the QA organization.

Non-Conforming Product Management and Non-Conforming Cage

Of all the areas this project improved this is the area that most positive financial impact was produced. The complete implementation concluded with over $1.4M of inventory being recovered. This was able to be accomplished by understanding and controlling the inventory in the cage and implementing the new management of non-conforming product at incoming. The complete inventory of the non-conforming cage has been disposed with the different classifications described in the section of the methodology and now the cage only contains product returned from vendor since all RMAs are handles with a 3-5 day period. The daily meetings in the area have been expanded to include members of different organizations like finance and accounting since the debit memo program incorporated is now part of the corporate KPI and discussion point in all staff meetings.

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