Mapping and Modeling Tools and Techniques for Metal Finishing Process Improvement

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Abstract

Process mapping and modeling tools provide for improved process visualization and understanding that facilitates identification of opportunities for process improvement. Systematic techniques and tools for process improvement also facilitate decision-making and expedite process improvement implementation resulting in lean manufacturing improvement, improved quality and performance and reduced life cycle costs. These tools and techniques can be used over a project life cycle to pursue continuous process improvement.

1.0 Introduction

Product quality, manufacturing efficiency or waste minimization: how does your company manage improvement? Today's business environment demands that companies of all sizes effectively improve in order to remain competitive and profitable in the global marketplace. Improvement can mean doing more with less, understanding what you do better or it can mean doing better with what you have. Improvement can help the bottom line. However, improvement takes planning and commitment. Companies must focus on improvement as they go about every business activity because of the fast pace of today's business and must be flexible to take advantage of opportunities as they appear. To be effective, improvement typically must be embraced by the entire company community from top to bottom, and, when done properly, leads to significant savings (1-3).

The focus on continuous improvement has been in the forefront of the manufacturing world for over twenty years (4). During that time many approaches have been developed as various companies have gained experience and the approaches were refined. Some of the popular approaches include Six Sigma pioneered by Motorola and refined by General Electric; the Lean/Kaizen and Value Stream Mapping techniques developed by Toyota; and the recent Lean/Sigma combined approaches (5-7). Finding the best approach for your company and identifying the suite of tools that will effectively work within your company culture are keys to success. There are several general principles that are true regardless of the approach used.

1) Champions are critical and everyone in the company should do their part to move the company forward.
2) Improvement should be a never ending cycle.
3) The tools available have improved dramatically, particularly for identifying improvement opportunities and for modeling the effect of those changes.

These tools provide reliable data so changes can be better understood before they are implemented and have a higher rate of success (7-14).

Metal finishers face some unique challenges as they pursue improvement. Metal finishing operations are composed of many separate but interrelated processes. The individual process steps use chemistries that can be composed of many ingredients whose operation is only *approximately* known. Approximate is used to describe the control of these solutions because their function is known but it is impractical to control all of the process variables dictated by the chemistry. This leads to the well known “art” in plating that traditionally has resulted in a high level of operator interaction with the processes. These processes use a variety of different materials, most of which are quite hazardous, to produce the desired coatings. Limiting exposure to the hazardous materials to continually increasing range of materials requires high levels of engineering or administrative controls to insure safety to the workers. The pressures exerted by exposure and product quality directives have resulted in greater understanding of processes and variable controls. Technical advances in process control have resulted in greater availability of sophisticated analysis tools. Therefore, managing improvements must consider a spectrum of variables.

The particular focus of improvement can change from year to year or even month to month. The change in focus continually illuminates areas to work on but exerts pressure on the organization because all this must be managed while maintaining competitiveness and profitability, often with limited staff. This paper presents some of the tools that can be useful within systematic overall process improvement frameworks to help facilities identify and evaluate improvement opportunities quickly and cost effectively.

2.0 Role of Mapping and Modeling for Process Improvement

Identifying opportunities, evaluating the relevance of each opportunity and designing and implementing the processes changes required can be challenging for metal finishers. One of the key challenges for metal finishers is being able to visualize the interdependencies of the various processes and process steps. These interdependencies must be kept in mind when contemplating changes. For example, considering eliminating chromium plating because of the new lower OSHA PEL may seem a good idea compared to the cost of implementing more stringent exposure controls. However, when one reviews the alternative processes one may find that two or three processes must be employed to cover the full spectrum of applications. The facility must either implement the necessary alternatives to cover the process ranges for their current products or limit the workload to applications where processes and ranges of parameters stay within acceptable levels. If they choose to incorporate the full range of alternatives they will likely increase waste produced, energy and or water usage so the choice is not simple.

Process mapping and modeling tools can help wade through the possibilities. These tools help establish a baseline view of the facility and can be used to track changes and can document why particular choices were made and what is needed to prevent old problems from reappearing.

3.0 Value Stream Mapping

Value stream mapping (VSM) makes use of visual techniques to identify and quantify waste through the production process (5, 6). Waste is defined as any activity that does not add value to the product. Toyota make benchmark use of and popularized value stream mapping VSM and lean manufacturing techniques for improving overall manufacturing through improving flow of materials and information. Mapping can be facility-wide, starting with raw material in the door and completing through with shipment of finished goods. Mapping can also be focused down to the individual process level by looking at material inputs to the process, quantifying the process steps and cycle times and finishing with product out of the process. Value stream mapping communicates details about the processes mapped can be used to strategically model facility improvements or individual process improvements. Seven general kinds of waste are identified to focus on for process improvement:

1. Overproduction- producing at a faster pace than required
2. Waiting- bottlenecks or over production from previous process
3. Transport- distance between process steps, non optimized flow
4. Inappropriate Processing- extraneous or duplicate steps
5. Unnecessary Inventory- either of raw materials, parts or finished goods
6. Unnecessary Motion- relocation after transport
7. Defects

A number of tools can be used to map key aspects of the facility operation (6). The format of each model can be flexibly defined to illustrate the current and future (improved) state of the facility. For example, production time can be used with individual cycle times to identify pauses in production. Time between process cycles may represent transport or idle times where in-process parts are stored. The additional production time over the process cycles represents waste and can be minimized. Flow charts represent one of the most commonly used and powerful visualization tools.

3.1 Process Flow Diagrams

Figure 1 shows the process flow for the overhaul of a complex part aerospace part requiring multiple metal finishing operations. Process flow diagrams are logic diagrams where each step is completed sequentially. There are decision points that can allow the skipping of certain steps or cause the redo of steps. This process begins with cleaning and inspection then continues with surface preparation and masking. Then there are several plating steps and it finishes with post treatments. Each rectangle in the diagram represents an activity and the diamonds represent decisions. The flow chart is a very powerful tool for visualizing a process using different colors and shapes to represent different process steps, decisions and other information. Creating flow charts forces the developer to formalize the steps of the process. Initially it is easy to omit operations but as you review the flow chart reading the steps it helps the developer capture all the steps of the process. Observation of the process as it actually operates while reviewing the flowchart of how the process is intended to operate is an easy way to identify discrepancies and likely areas to improve.

Although the flow chart in Figure 1 is lengthy, it allows relatively quick evaluation of the processing cycle. Additional information about each process step can be added -- some facilities use flow charts for work instructions. The flow chart can be used to map an existing process or to design a new one. Once the flow chart is completed it can provide a great deal of information relating to the adjacency of related processes. Clearly processes required for the sequential processing of a part should be located closely. The flow chart then supplies information on how to organize process lines and the shop as a whole. Flow charts can be hand written but are easier to manipulate on a computer. Special software packages are available that speed the process but a flowchart can easily be created by any drawing program.

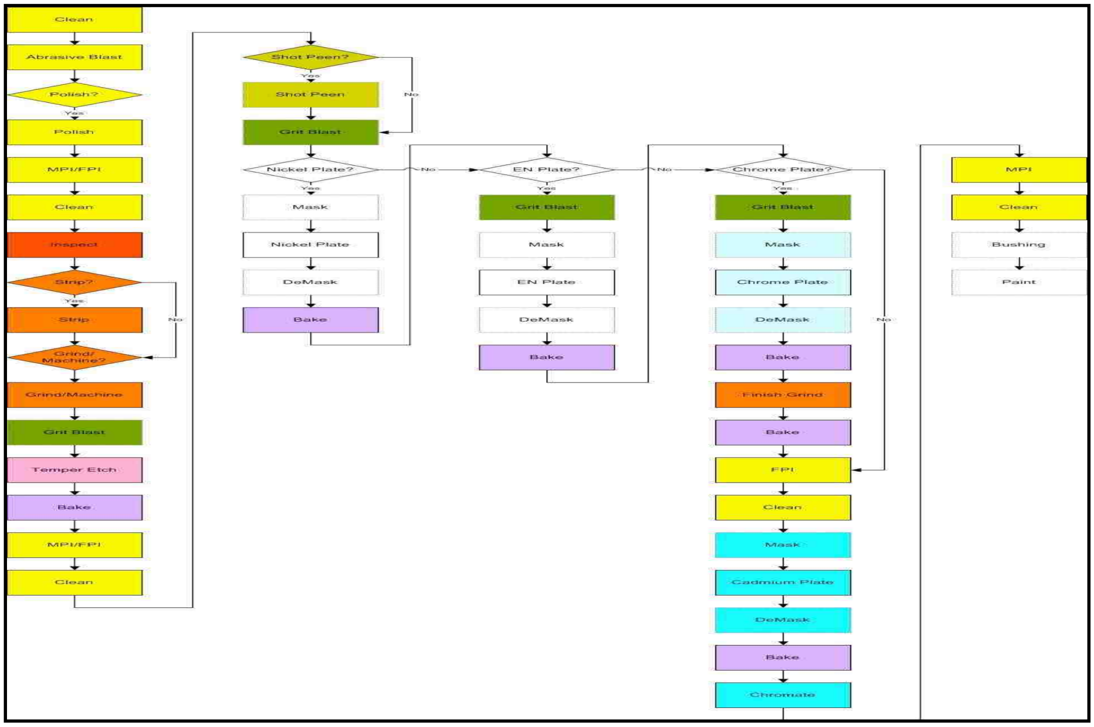


Figure 1 Process Flow Diagram

3.2 Process Adjacency/General Arrangement Diagrams

Figure 2 shows two-dimensional diagram to examine more closely the adjacencies important to a particular shop. In this diagram each of the shop processes are represented by a block. Numbered arrows are used to indicate the process steps for a specific type of part, in this case a part requiring chromium plating. It is easy to see that the process backtracks on itself primarily because the same area is used for racking and unracking parts. In addition, the same processes are used to mask and unmask the part. Depending on the facility production quantities, the facility may benefit from separate rack/unrack and mask damask processes as these point are potential bottlenecks for production.

Each different process in the shop is diagrammed separately. This type of flow diagram can quite simply point key relationships between processes in the shop. If different color arrows are used and the separate process sheets are combined or superimposed, inter-process relationships can be examined with this tool. It will become clear, in combination with the process flow charts, which processes should be located close together. This information must be considered along with production quantities and space limitations. It may not practical to create a single long line for all process steps. A process that is used infrequently may need to be located off the process line it is related to if that means a building extension is required.

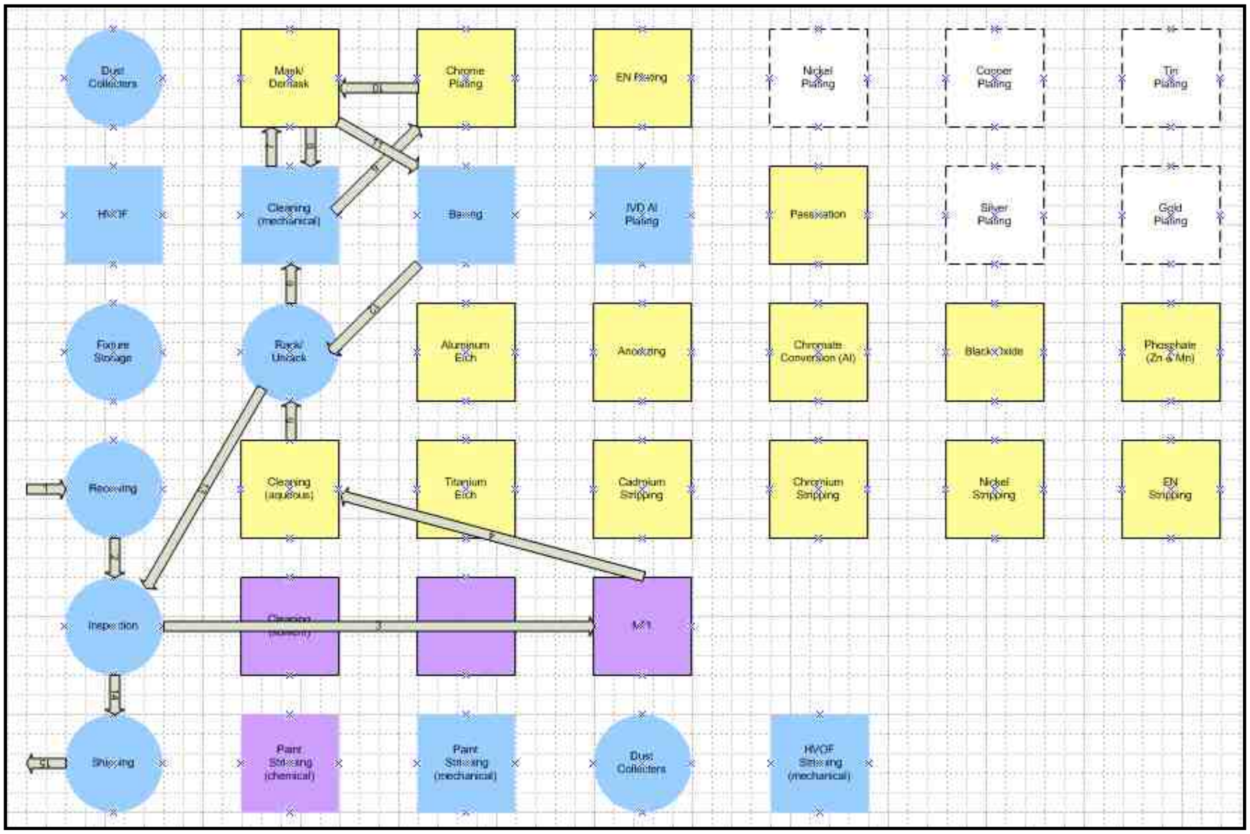


Figure 2: Process Adjacency Flow Diagram

3.3 Process Relationship Diagrams

Figure 3 shows a schematic diagram methodology that looks at adjacency for optimizing process solution maintenance and recovery. The color coding in the diagram is for different kinds of recovery methods. It also locates mist eliminators on particular tanks. These adjacencies can be used to determine if common treatment of compatible process and or rinse tanks can be accomplished with a centralized unit. This type of diagram can also be used to identify common and segregated collection lines for wastewater treatment, for concentrated process solution management, and for ventilation collection systems.

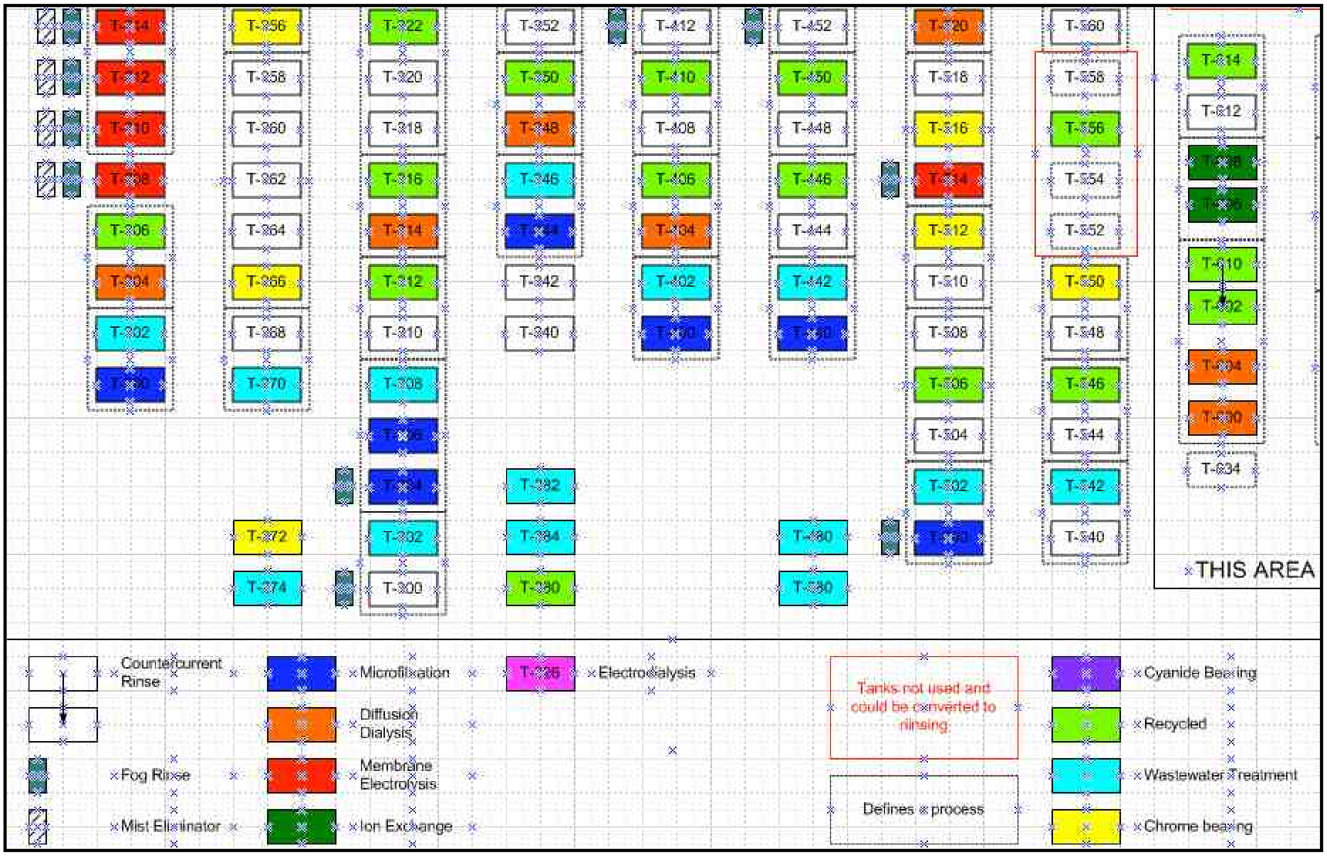


Figure 3: Shop Recovery Adjacencies

3.4 Flow of Information Diagrams

Figure 4 illustrates a simplified schematic of flow of information steps necessary to control process solutions. Samples are collected and analyzed and then the results are interpreted. The decision tree indicated by the review and interpretation of the results can be quite involved. For example, consider a cyanide cadmium plating solution. Analysis of the solution will examine the cadmium, cyanide, hydroxide and carbonate concentrations. Each component will have an operating range and optimum set point. Depending on the results, additions, decants or possibly decants followed by additions could be required to maintain the solution. In addition the ratio of cyanide to cadmium is important to the character of the deposit formed. The ratio is also monitored and must be factored into the decision tree. Streamlining the information flow can be accomplished by incorporating the decision making process into a computer program. The flow diagram of the decision tree is turned into logic based rules that allow the laboratory management software to automatically calculate and evaluate analytical results and to make decisions based on the logic and even automatically determine the appropriate action. This is particularly true of decisions that are routine like the size of additions or decants and some of common troubleshooting decisions that can be defined by conditional rule sets (9, 11).

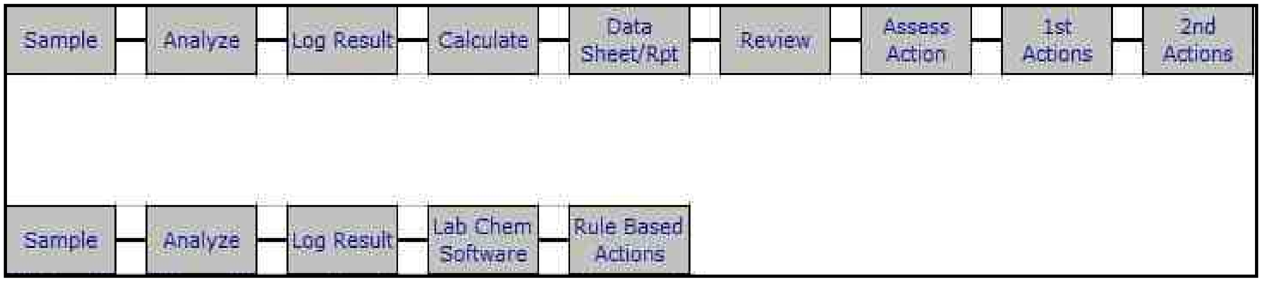


Figure 4: Information Flow Diagram

3.5 3-D Process/Plant Layouts

Since plating shops are complex inter-related systems during design it can be useful to build a three dimensional representation of the shop. 3D modeling is a feature of CAD programs and while it adds cost to process design, it can save money by showing in advance of construction potential interferences within the facility. During construction, inferences are often discovered between ventilation and hoists, bussing and hoods and material and part movement with the shop. 3-D modeling provides advance visualization allowing clients and designers to work together to better define optimal process layouts and spatial configurations/clearances yielding more functional process/facility installations that provide superior operations and maintainability.

4.0 Process Modeling Tools

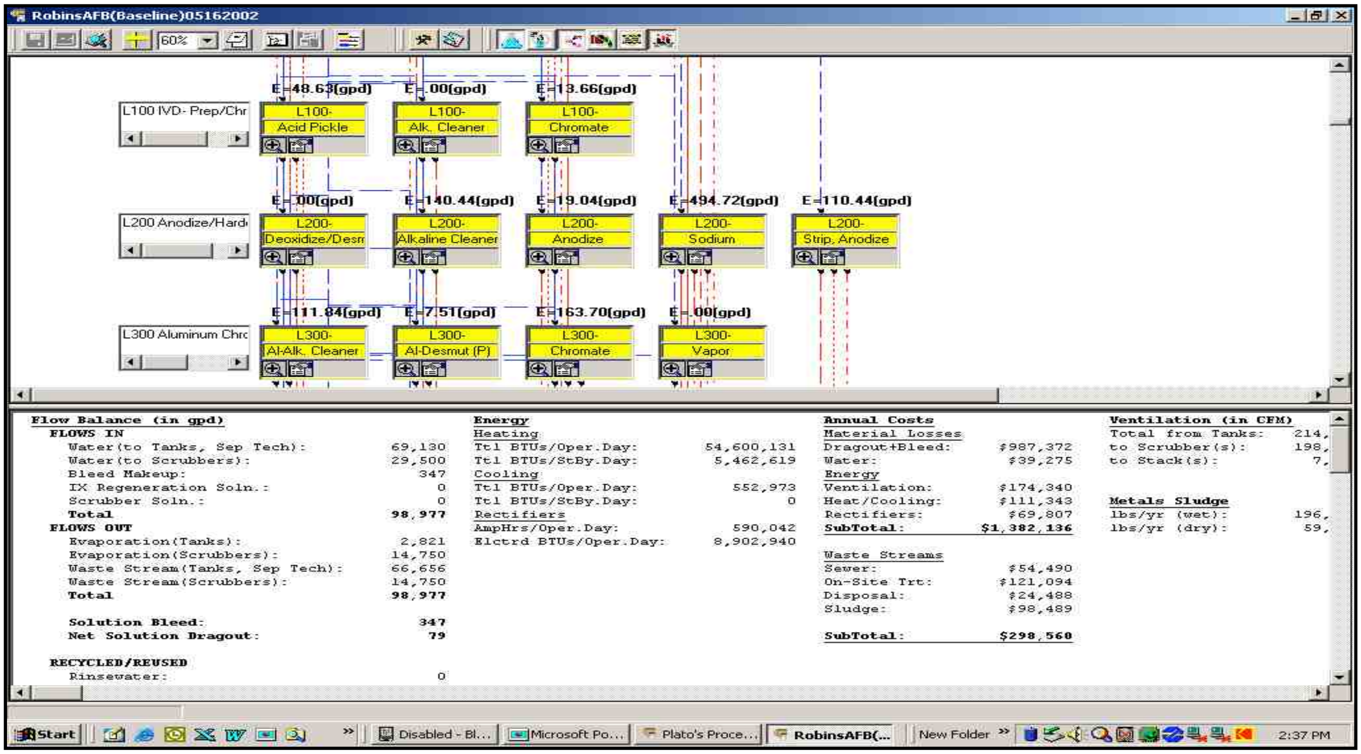
Once the mapping of the processes has been completed, more detailed models can be constructed to evaluate the processes (10-21). These models are generally computer-based and have been developed to aid in calculating complex and interrelated facility and process variables. Computer-based modeling programs can create comprehensive “snapshot” models of processes using simplifying assumptions. Commercial software is available for metal finishing applications and spreadsheet applications can be built. Creating a spreadsheet can be time consuming and can become very complicated and cumbersome when expanded to include more detail and linked process and facility parameters and calculations. Specialized commercial software packages provide off-the-shelf solution and chemistry libraries, comprehensive facility and process calculations, and capabilities to quickly create and model different scenarios ranging from current to potential future production. Existing commercial process modeling software can provide comprehensive report and documentation capabilities.

Models estimating facility/process design requirements such as rinsing requirements, ventilation requirements, energy consumption, plating efficiency, water usage and chemical usage are all commercially available. Generally these models use steady state analysis or perform finite element mathematical modeling of the features they cover. They allow the investigation “what if” scenarios to look at changes as part of process design and/or optimization activities. Careful evaluation of the data can also aid in justifying the expenditure necessary to make the change by modeling different returns on investment (ROI) periods.

5.2 Production-Based Process Consumption & Waste

Commercially available models create steady-state representations of process chemistry, drag out, bleed, product out and other chemical depletion mechanisms. They can be used for ranges of production scenarios by modeling changes in process temperatures, tank surface area, drag-out rates, evaporation rates and electrochemical metal consumption. From these inputs the user can quantify water, material, and energy usage at facility along with providing data on waste generation and material usage. This information allows the design or optimization team to better define process-specific costs and provides information needed to identify, prioritize and justify process improvement opportunities.

These models can be configured to evaluate metal finishing wet processes and can also evaluate recovery and purification technologies. Constructing the models requires detailed process inputs and allows the user to build accurate representations of the process, process line or entire process area. These models can be used to investigate the effect of changes on the process area as a whole and on individual process lines and even individual process tanks. Ranges of “what if’ scenarios can be quickly evaluated to determine the ability of change to result in an improvement. Shown in Figure 5 is the output of one of these models summarizing water, energy, waste and ventilation costs for the processes shown.



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Flow Balance (in gpd)                          Energy                                     Annual Costs                          Ventilation (in CFM)
  FLOWS IN                                     Heating                                    Material Losses                       Total from Tanks:    214,
    Water(to Tanks, Sep Tech):       69,130    Ttl BTUs/Oper.Day:         54,600,131      Dragout+Bleed:          $987,372      to Scrubber(s):      198,
    Water(to Scrubbers):             29,500    Ttl BTUs/StBy.Day:          5,462,619      Water:                   $39,275      to Stack(s):           7,
    Bleed Makeup:                       347    Cooling                                    Energy
    IX Regeneration Soln.:                0    Ttl BTUs/Oper.Day:            552,973      Ventilation:            $174,340
    Scrubber Soln.:                       0    Ttl BTUs/StBy.Day:                  0      Heat/Cooling:           $111,343      Metals Sludge
    Total                            98,977    Rectifiers                                 Rectifiers:              $69,807      lbs/yr (wet):        196,
  FLOWS OUT                                    AmpHrs/Oper.Day:              590,042      SubTotal:             $1,382,136      lbs/yr (dry):         59,
    Evaporation(Tanks):               2,821    Elctrd BTUs/Oper.Day:       8,902,940
    Evaporation(Scrubbers):          14,750                                               Waste Streams
    Waste Stream(Tanks, Sep Tech):   66,656                                               Sewer:                   $54,490
    Waste Stream(Scrubbers):         14,750                                               On-Site Trt:            $121,094
    Total                            98,977                                               Disposal:                $24,488
                                                                                          Sludge:                  $98,489
    Solution Bleed:                     347
    Net Solution Dragout:                79                                               SubTotal:               $298,560

  RECYCLED/REUSED
    Rinsewater:                           0
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Figure 5: Process Model Showing Annual Costs

5.4 Computational Fluid Dynamics (CFD)

Ventilation design is a critical area for metal finishers. Hazard ratings for the materials used in the plating shop and the exposure limits have steadily decreased over the years in order to insure the protection of the workers. Shown in Figure 6 is a shop layout using colors to show different ventilation connections. Ventilation designs use industry guide books (16). These designs generally don't quantify adverse affects from area ventilation and capture flow interferences. Computational Fluid Dynamics (CFD) modeling (17, 18) allows a more refined look at air flows and should be part of the design process for the critical ventilation systems. This sort of modeling is especially important for "right sizing" ventilation to meet the new chromium PEL and will become more important as other shop hazards approach these. Just as 3-D layouts can identify interferences for process equipment and facility systems, CFD can provide a similar evaluation by modeling room drafts, obstructions, the proximity of make up air ducts and adjacent ventilation to provide a more accurate picture of ventilation requirements. CFD modeling provides graphic air flow patterns that will allow protection for the breathing zone of the operators beyond those of manual calculation methods. CFD will usually result in less total air movement because the model is more precise and does not require safety factors for uncertainty as do manual methods. The lower CFD air flows use less energy and cost less to operate.

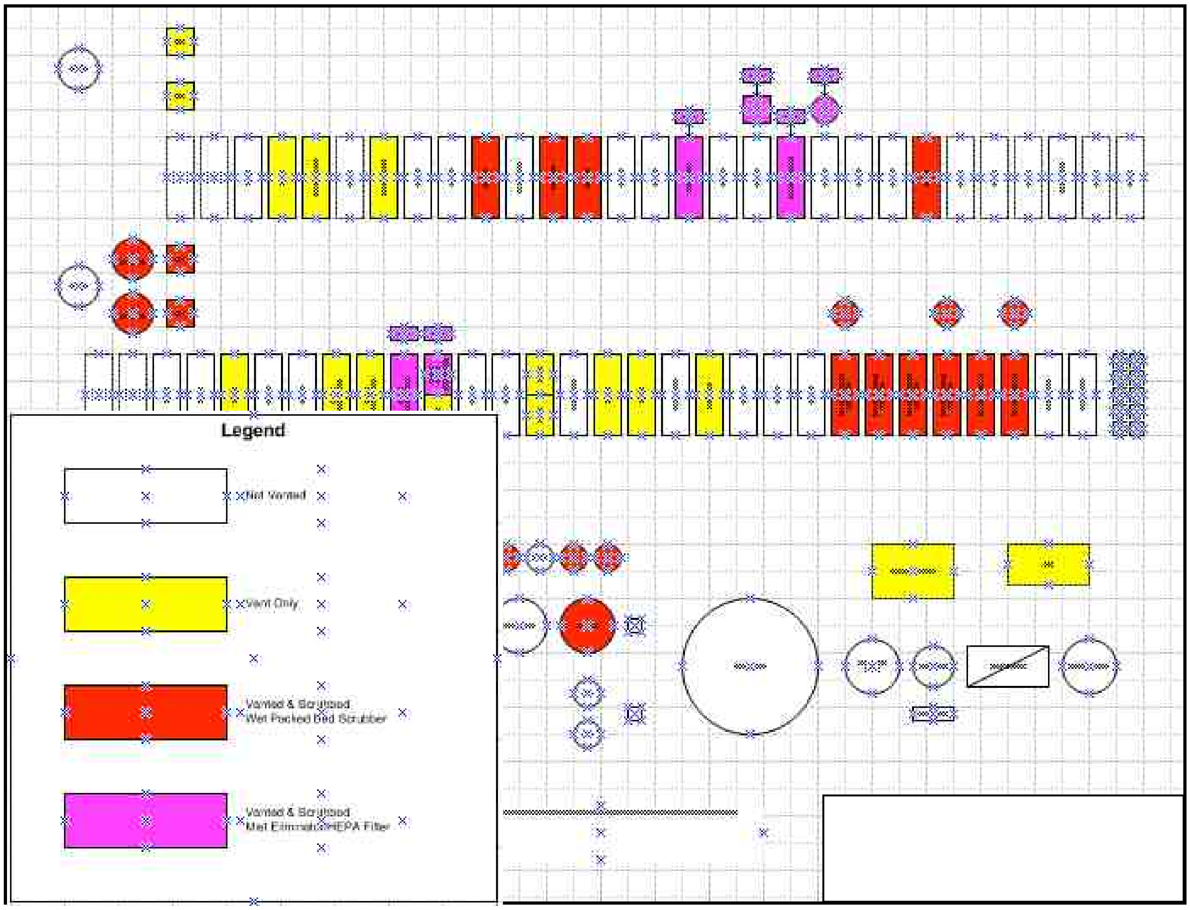

Figure 6: Process Layout showing Ventilation Segregation

4.4 Electrochemical Modeling

Electrochemical modeling is a finite element mathematical method to accurately model current distribution and predict plating coverage on parts (20). The program takes input from CAD design programs and performs complex calculations based on the boundary element method (BEM) to allow for design of rack fixtures, thieves and shielding to produce more uniform plating coverage on parts. This allows the user to optimize rack configurations and minimize wasted plating both on rack fixtures and parts

4.5 Hoist Production Time Sequences

Modeling software is also available to design and optimize manual and automated hoist systems (19). These models provide real-time visual indication of production schedules. It can be used both to plan and to optimize production based on the current production. The model can be used to evaluate different production scenarios at multiples of normal production speed to identify bottlenecks, adjust designs and to deliver needed production capability. These models can also be used to optimize daily production based on the processing cycle and part loading information of the facility. The scenarios visually represent the production model on a timeline chart that includes both tank and crane utilization.

5.0 Conclusion

Improving process efficiency and performance, reducing wastes and improving profitability have been important goals in manufacturing industry initiatives over the past two decades. Achieving these goals is limited by the ability to define and justify cost-effective process improvements. In recent years, process mapping and modeling tools have been used effectively in the metal finishing industry to provide:

1. Schematics to better visualize and understand existing processes with respect to flow of materials and information, and opportunities for improvement
2. Combined facility-wide process and individual process level quantities and costs for material and energy consumption and waste generation for ranges of existing and potential future production scenarios
3. Visualization/evaluation of process improvement changes, before they are made, to help identify potential problems and optimize functionality and return on investment
4. Documentation essential for successful funding requests
5. Documentation for effective master-planning and production implementation

Cost and schedule are common perceived barriers to process mapping and modeling and can become constraints when companies define the need for process improvement yet allocate funding and timelines before considering the value of better decision support information. Appropriate process mapping and modeling tools and application-specific use need to be defined. Using appropriate mapping and modeling tools, overall project implementation effectiveness can be increased:

1. Saving implementation time by avoiding mistakes and identifying implementation efficiencies
2. Significantly reducing life cycle costs by implementing superior integrated process improvement that is specific and right-sized for the application

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