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A Comprehensive Model For Manufacturing Analytics

Louis Halvorsen
Chief Technology Officer
Northwest Analytical Inc.
111 SW Fifthe Ave.
Portland, OR 97204
USA
503-224-7727
503-224-5236
lhalvorsen@nwasoft.com

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ABSTRACT

Title: **A Comprehensive Model for Manufacturing Analytics**

Manufacturing systems now collect unprecedented quantities of process data. The investment made in these systems, when combined with pressures to reduce costs, increase yields, and meet regulatory and supply-chain requirements, is generating strong interest in the use of Analytics to leverage the value of process data. In addition, process improvement programs such as Lean Manufacturing and Six Sigma have increased the demand for more effective data analysis capabilities.

Current approaches to analyzing process data have typically been too simplistic to make critical decisions with confidence, or have required specialized knowledge that limits the number of practitioners.

This paper describes different approaches to analyzing manufacturing data and identifies their strengths and weaknesses. Case studies from companies that have successfully applied analytics to process data on a broad scale are used to develop a model for building an effective Manufacturing Analytics capability. The model includes details on data connectivity and aggregation, choosing and applying statistical analysis techniques, the importance of role-based reporting, and managing the transition from a reactive to a predictive system.

PAPER

A Comprehensive Model for Manufacturing Analytics

The need for a new approach to the analysis of manufacturing data

The increasing use of systems such as SCADA, DCS, Historians, LIMS, MES, and now ERP to collect and manage information means that manufacturers are collecting unprecedented amounts of process-related data. With the increased pressure to reduce costs, increase yields, conform to regulations, and meet supply chain requirements, manufacturers and their systems vendors are both looking for a more visible return on their information systems investments.

Past approaches to analyzing manufacturing data have generally been piecemeal – provided by stand-alone applications or by simple tools embedded in larger applications. A typical manufacturing facility may have a dozen different software products providing some level of analytics.

Process Intelligence, and the associated portal and dashboard technologies, provide a uniform mechanism for consolidating and reporting, but these applications do not themselves typically include comprehensive analytics of the type required to understand and improve processes (except as add-on components).

Although there is a parallel situation on the business side of the enterprise, where Business Intelligence and Business Analytics combine to provide a comprehensive analytics framework, the techniques and methods that work for business do not address the difficult issues presented by manufacturing data.

The complexity of process data and the difficulty of applying effective statistical analysis are significant barriers. Most manufacturing facilities have limited statistical capability and a wide range of individuals that need to benefit from analyzing process data. Decisions are typically rear-facing; intended to fix an existing problem, rather than forward-looking; able to anticipate and prevent a problem. Overcoming this problem requires a new approach to analyzing manufacturing information and making decisions.

Manufacturing Analytics is the statistical and rule-based analysis of manufacturing data that enables users to better understand and improve their processes, identify and reinforce best practices, react quickly to process events, and anticipate potential problems before they affect product quality, yield, or cost.

Key differentiating elements of Manufacturing Analytics are:

Role-based analysis and reporting

High-confidence decisionable results

Standards-based integration

Facilitates shift from reactive to predictive operating models

Enabling Technologies

The application of Manufacturing Analytics is enabled by the increased integration of manufacturing information systems, including plant floor control systems, historians, MES, LIMS, and now ERP. Factors that contribute to this improved environment include:

Mature products (SCADA, DCS, Historians)

New technologies such as SOA (Service Oriented Architecture)

Effective standards such as OPC, SQL/ODBC, and ISA S88 and S95

The resulting marshaling of data from process and measurement through HMI to portals and dashboards creates an enormous increase in visibility and drives opportunities for a new approach to analyzing data.

Manufacturing Analytics within the ISA-95 Model

The S-95 Production Performance Analysis Activity Model, which is part of the Production Operations Management Activity Model, as described in section 6.11 of part 3 of the standard, outlines the need for robust systems, methodologies, and tools to improve the ability to make very informed decisions based upon extensive and varied analysis functions. The Manufacturing Analytics approach contributes to this activity as part of the functions defined in sections 6.11.5 Product Analysis, 6.11.6 Process Analysis, and 6.11.9 Performance Management of the standard.

Current Use of Analytics in Manufacturing

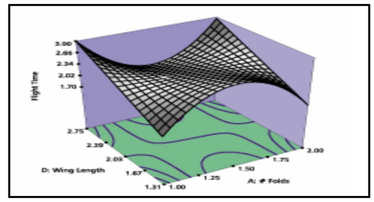
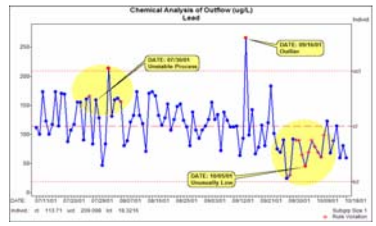
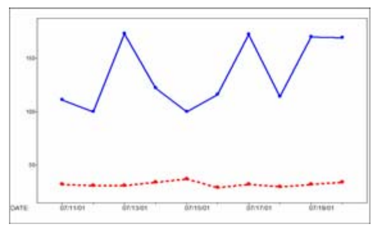
Currently, analytics functions are performed by a collection of embedded and off-the-shelf applications. SCADA, DCS, Process Historians, and manufacturing portals typically provide some built-in trending, SPC, and related charting and analytical components, and often offer add-on modules that provide more capability. MES, LIMS, and ERP systems also offer some built-in analytics, but often rely on 3rd-party products that connect to the underlying database. The most common off-the-shelf analysis and reporting tool is often Excel, either used by the information system itself as a key reporting tool or connected by the user. More capable products such as SPC packages, sophisticated statistics products, and high-end optimization software round out the list. Since most manufacturing organizations use applications from multiple vendors, often supporting competing products at the same facility, there is a fragmentation of the analytics function.

Some attempts have been made to use BA/BI software for analyzing manufacturing processes, but the results are not promising. The typical mission for BA/BI is to find undiscovered relationships in highly regular data such as financials, sales, inventory, and human resources. The most common technique is the creation of a “data cube” to facilitate the “slicing and dicing” typical of the BA process. Manufacturing data is often expressed in very different structures and schemas, is susceptible to major sampling and reduction problems, and is usually present in large volume.

Categories of analytics applications

Current analytics applications fall into three broad categories. "Trend and Threshold" applications are often embedded in information management and control systems to provide rudimentary analytical and graphics capability. More "sophisticated" products are typically third-party packages or specialized modules, and are aimed at advanced statistical applications. As shown in figure 1, Manufacturing Analytics aims to bridge these two extremes and provide effective analytics for the largest base of users.

Figure 1

"Sophisticated" Analysis and Presentation	• Complex statistics • Hard to interpret • Requires specialized support	
Effective Manufacturing Analytics Appropriate complexity Meaningful presentation	• Statistically based • Role-based presentation • Identifies significant events • Predictive capability	
Trend and Threshold Analysis Limited value	• Threshold based • Can't detect patterns • Missed and false signals • No predictive capability	

Characteristics of effective Manufacturing Analytics

The key capabilities and characteristics that identify a well-designed Manufacturing Analytics solution include:

Focus on role-based analysis and reporting

Emphasis on visualization

Includes comprehensive selection of appropriate statistical techniques

Effective for all types of manufacturing data

Capable of reactive and predictive behavior

Integrates with existing manufacturing applications and standards-based technologies

Can be implemented, maintained, and used by existing plant personnel

Aggregates data from different sources while preserving statistical validity

SPC, Six Sigma, and Manufacturing Analytics

Given the mission of Manufacturing Analytics, SPC is an ideal data analysis technique to incorporate. Long used for process improvement and meeting vendor requirements, SPC is still not adopted as widely as its historical success and capabilities would suggest. One of the limits of SPC adoption is that its typical output can only be consistently used by trained "practitioners", while the meaning of SPC output is of use to anyone trying to manage and improve a process. The goal of implementing SPC as part of Manufacturing Analytics is to provide a variety of output modes that match the roles and capabilities of individual users.

The most readily identifiable initiative in manufacturing that uses statistical analysis is Six Sigma. A key part of Six Sigma are the process improvement projects required for advancement and expected as part of the value of the program. One of the major tools used in Six Sigma is DOE (Design of Experiments), which is typically performed under special controlled conditions. Two of the key issues affecting Six Sigma success involve ongoing analysis of the process which is performed by a comprehensive application of Manufacturing Analytics:

> The use of DOE and similar statistical techniques requires a predictable process to be successful. All parameters used in these analyses must be stable and exhibit normal variation.
>
> Once successful Six Sigma projects are completed, one of the biggest problems is "keeping the gains" – preventing a return to the initial conditions. Constant monitoring is required of parameters that reflect the gains made, with quick reaction to potential slippage.

Data Connectivity

Manufacturing facilities are full of databases. Manufacturing Analytics should not add another data repository to the mix. Analytics applications should read, analyze, and report, and have a minimal effect on the underlying database. Virtually all significant storage of manufacturing data is done using database products that support industry-standard connectivity. Stable technologies such as ODBC/SQL can often provide better integration outcome than proprietary interfaces.

Data Aggregation

Many manufacturing applications provide data "aggregation". However, aggregation has many meanings. In most cases it refers to the gathering of data into a data structure that can be used for analysis and reporting. Although some mathematical and structural manipulation is supported (such as averaging, min/max, and summation, and pivoting and keyed merging), the proper application of Manufacturing Analytics typically requires more.

Data aggregation to support Manufacturing Analytics needs to deal with very complex problems that are specific to a wide range of data sources. Consider a typical specialty chemical process:

> Raw Material >> Batch React >> Continuous Process >> Batch Blend >> Discrete Fill

Data is collected at test stations, by SCADA or DCS, stored in Historians or LIMS, and applied to WIP and scheduling applications in MES and ERP. The data often passes through programs such as Excel and SPC products. Data needed by the Manufacturing Analytics applications combine discrete, averaged and subgrouped, high-speed continuous, historized, visual, and financial data.

Putting this data together for the purposes of data analysis while still supporting the key characteristics of an effective Manufacturing Analytics system is beyond the aggregation capability of most current manufacturing systems. Aggregation functions for Manufacturing Analytics should be able to:

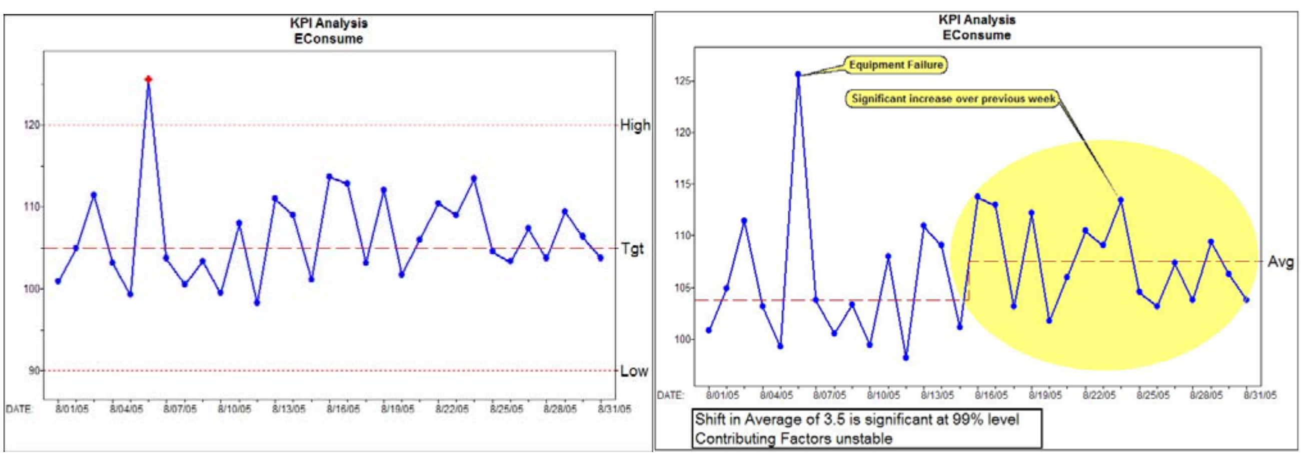
- Resolve time-based and sample-based data
- Provide statistically valid sampling methods
- Perform mathematical transformations
- Deal with missing data and indeterminate values (<, >)
- Resolve lead/lag relationships
- Support "event linkage"
- Balance contributions to multivariate relationships

Role-based Analytics

Role based reporting takes into account the knowledge level of the user, and provides the same information in different forms to different people. This is essential in typical manufacturing facilities where everyone from operators to quality control to process engineers to supervisors and managers need benefit from application of analytics to perform their jobs properly.

A simple example of role-based output is to remove the "Control Limits" of an SPC chart and instead supply the interpretation in an easy-to-understand form as illustrated in figure 2.

Figure 2



To meet the goal of being "role based", MA applications should make use of innovative visualization techniques to represent data more typically displayed as trend lines, histograms, and SPC charts. These techniques are particularly useful when comparing information from different elements of the process or identifying subjects for further investigation. Care must be exercised to keep the graphical content simple and to control the scale to facilitate visual comparisons. Examples of some visualization techniques that can be applied to MA include:

- Box-and-Whiskers plots

Small multiples

Data density diagrams

"Data brushing" techniques

On the other hand, complex representations such as response surfaces and other 3D techniques can be difficult to interpret and often do not provide a stable method of making visual comparisons. Problems with scaling and resolution can obscure important information. These types of charts are very difficult to use in proving a point to those not familiar with the representation.

Example of Role-based analytics: Fill Weight Control (Giveaway) in Food

Overfill "giveaway" is usually the highest controllable cost in food processing. Although many food companies focus on giveaway, many companies and facilities lack an effective means to consistently analyze, react, and improve the process. Metrics at the plant floor often focus on weight instead of cost. There is a time lag for use of cost-based metrics. Conflicting motivation (cost, production goals, risk avoidance) influences reactions.

The solution is integrated, role-based analytics combined with comprehensive data acquisition at the fill line. Each employee and level involved with the process sees an analysis and reporting function tailored to their needs and capabilities. Fill weights from the QC stations are analyzed and combined with cost data from the ERP system to create a "Giveaway" KPI.

Technician/Operator: Alarms on specifications and SPC. Operator uses specification violations to intervene, SPC to initiate corrective action when needed, avoid unnecessary adjustment (over adjustment), and collect AC/CA information.

Supervisor: Alarms on specification violations and excess giveaway. Sees status/exception display based on SPC and Process Capability, plus cost of giveaway assigned to products and lines. Includes ability to quickly drill down to underlying data, look at SPC and Capability analysis.

Plant management: Focus on "giveaway" KPI. Looks at costs per time period and compared against previous time period. Alarm when KPI or underlying components violate thresholds, exhibit unusual behavior, show excessive costs. Focus on target (high value) products, provide drilldown to underlying analysis and related information.

Enterprise: Monitor and review fill-related costs per plant and product. Focus on high-value products. Compare products, plants to identify problems and best practices. Alarm on excessive or unstable costs, problem products, or significant differences between plants.

Application of Manufacturing Analytics to KPIs

Creation of KPIs is a response to the large number of process variables required to understand and control a process and the need to combine multiple information sources to tell the right story. The typical application of KPI's is to select several variables to reduce to a single mathematical combination and then set fixed limits to interpret results and initiate action.

However, a KPI combining two or more factors is, in reality, a "model", and has many of the potential drawbacks of more sophisticated models. These drawbacks can significantly affect their validity and subsequent adoption, and include:

Non-rigorous design

Arbitrary fixed “action” limits

Problems aggregating multi-factor data

Sensitivity (or lack of sensitivity) to change

Uneven contributions from component factors

Difficulty in interpreting signals

Lack of validity monitoring

A KPI model is typically not statistically derived, and limits or thresholds assigned to KPIs behave like specifications. The result is a combination of false positives, missed signals, and lack of predictive capability.

However, due to how KPI’s are usually derived, they have some significant advantages when Manufacturing Analytics is applied:

They are discrete values, and tend to work in SPC analysis without concern for sampling issues, the type of chart used, and data characteristics (normal distribution, etc.).

If Manufacturing Analytics is applied to the KPI and its underlying components, its “model” is continuously validated.

Given access to the source of the underlying components, KPI behavior can be tied to process events and potential outside influences.

The following KPI example is a composite of problems that often go undetected.

In the following KPI:

K = (A+B+C)/(X*Y) * 100

A contributes 95% of A+B+C

X is averaged over long time periods

Y can be less than 1, and sometimes even negative

C shows signs of instability

Value is multiplied by ‘100’ in an attempt to use a common scale

Result: K is not sensitive to many process changes, is most influenced by A, does not reflect the process that underlies X, reports extreme values when Y drops below 1, and is obviously invalid when below zero. Scaling by 100 gives false meaning to the number in comparison with other KPIs. The result is that K provides false security for those who don’t understand the underlying process and is ignored by those that do.

By applying the various analytical techniques provided by a comprehensive Manufacturing Analytics solution, the KPI can be “tuned up” and its health constantly monitored, increasing its value:

K = (A+D+E)/(X*Z)

D & E are transformed from B and C to balance contribution

X is no longer averaged (or averaged over shorter time period)

Z is an equivalent to Y without the excursions below 1 and 0.

The stability problem of C was resolved by application of SPC

Multiplier is eliminated

A,B,C,X,Z are now routinely analyzed for stability

K can be monitored against set limits and statistical limits and now tracks the key elements of the process. K can be used to tell how the process is doing, can compare the process over time and against other similar processes, and can signal some problems in advance.

However, it still turns out that monitoring the KPI often fails to provide advance notice of some potential problems – by the time K has exceeded its fixed or statistical limits, the process it monitors has already gotten into serious trouble. Why? First, the combination of 5 parameters has a damping effect – changes can cancel each other out, and K remains stable. Small but significant changes in individual components do not show up in K until the problem is well developed.

So, A, D, E, X, and Z should also be individually monitored statistically to detect instability. This can be done 'behind the scenes' and only generate output when a significant event has occurred, meeting the information reduction goal of creating the KPI in the first place.

When A,D, E, X, or Z start to show signs of instability, it is time to investigate. When K starts to exceed its set or statistical limits, it is time to act.

CONCLUSION

An effective Manufacturing Analytics application can be used by personnel at all levels, works with all types of process data, and allows users to better understand their processes. These users can then detect and anticipate process problems, identify sources of excessive variation, locate candidate areas for process improvement, and validate best practices.

CASE STUDIES

Food Safety in Poultry - Example of the use of analytics for early prediction.

Problem: A poultry processing plant monitors regulated bacteria, including salmonella. Salmonella typically runs an order of magnitude below the legal "take action" limit. When the level exceeds the limit, the action required is costly and time-consuming, requiring destruction of inventory, possible recall of shipped goods, and an extensive sanitation process. Exceeding the safe level happens quickly, with little time for corrective action if detection is based on the enforced limit.

Setting an arbitrary "reaction" limit can lead to a tradeoff between false positives (reducing staff reliance) and missing signals (resulting in an event).

Solution: Application of Manufacturing Analytics using SPC-based event detection and pattern rule violations results in early detection of an unstable process, predicting the high likelihood of an event and enabling corrective action and process improvement steps to prevent the event and reduce its likelihood in the future.

Result: Events eliminated by early detection and process improvements. Accumulated assignable causes and corrective action builds a knowledge base to improve process management and problem resolution in the future.

Energy consumption in dryers – Example of role-based reporting and KPI component analysis.

Problem: Detecting potential increases in energy cost in a facility that uses large, continuous process ovens. Energy costs are affected by multiple parameters. None of the existing systems has access to all the parameters and cannot provide a consolidated view. Each staff member only sees a part of the problem and may not be able to react to early signs of change.

Solution: Develop a KPI consisting of financial, operational, and measured parameters that accurately represents total energy costs for the primary energy consumer, the dryers. Apply manufacturing analytics to provide role-base reports to different employees based on the KPI and its components. Include drill-down support to allow examination of individual parameters to assist in resolving source of problems.

Result: A small change in a key factor of the KPI was detected, while the KPI itself remained in its acceptable range. Process engineers used other visualization techniques to break down the data to locate the source. The cause was a small change in operating procedure by one shift. The initial cost was small, but a rapid rise in energy costs would have multiplied the effect and may have masked detection for a significant period of time.