This article presents a framework and industry best practices allowing for the definition of usable metrics and intelligence that employ all the available operational data in the organization from the shop floor activities to business operations.

Harnessing Untapped Information for Enterprise Manufacturing Intelligence

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Manufacturing Intelligence and Performance Management

It is sometimes said that accounting is the language of business and as such accounting allows us to describe and interpret business and its performance. What is then the language of manufacturing operations? Is it quality, operations, inventory, or something else? According to ISA-95, manufacturing needs quality, operations, inventory, and maintenance for an adequate description. What does that mean and how can this help with the challenges of modern life sciences manufacturing business operations? The sheer volume of data and information that is generated from the factory floor can be overwhelming. What is missing is the ability to interpret this information and use it as the “language” of manufacturing, and in the absence of this “language,” many organizations are sometimes driven to ignore it. The challenge is to provide a level of visibility that connects and relates the entire view of business, including finance, planning, the supply chain, and the multitudes of operational information that are available from manufacturing. This connected view yields aggregated accountability at any level of the organization.

The Manufacturing Enterprise Solutions Association (MESA) recently released the results of a survey titled “Pursuit of Performance Excellence: Business Success through Effective Plant Operations Metrics.” In this survey, the business movers are those companies that have improved more than 10% on average unit contribution margin and revenue per employee, and improved in their usage of fundamental metrics. These business movers show that measurement processes must be swift and deliver easy-to-digest, actionable information. The results clearly show that the business movers are finding value in connecting metrics from operations to financial and business metrics - Figure 1.

The “language” of manufacturing is often underutilized and misinterpreted by an organization’s financial group. The everyday tasks in a manufacturing organization involve problem solving, decision making, and complex analysis that require:

1. All of the available information has to provide visibility to all aspects of the organization.
2. Data is combined from multiple sources and put into a common context.

Figure 2 depicts the typical relationship between financial data and manufacturing data in the context of the manufacturing business. The triangle represents all of the data available from a plant or facility with three main levels of data, each of which has different sources. The base represents the greatest amount of data from the manufacturing floor operations. The middle represents data that is aggregated and contextualized with financial information. Last, the top represents key aggregated information about the overall performance of the organization. There is a tendency to use data
that is readily available typically from a business system, such as Enterprise Resource Management (ERP), which invariably is financial information. This leads most organizations to focus on the financial data while ignoring operational data from the shop floor as indicated by the red line in Figure 2. This is typically the only information that is used to drive business decisions. Thus, a large portion of the available information from manufacturing is often ignored or underutilized for tactical and strategic decisions. This skewed view of a manufacturing organization causes the manufacturing operation to be regarded as a “black hole” where material goes in and product comes out. Yet, in reality, the manufacturing process is where value and quality are created, which are critical factors for any life science manufacturing business. The goal is to utilize all of the information and remove this “red line” of separation - Figure 2.

**Using Business Goals to Define Metrics**

In manufacturing, performance is ubiquitous be it financial or operational; therefore, it is important to measure performance. Performance in itself is an indicator of how well a goal is being met. These goals are the critical aspect of any business and can have varying degrees of granularity or scope. Commonly, goals used to run a manufacturing business are defined at a high-level and may include customer satisfaction, quality, regulatory compliance, supply chain responsiveness, resource usage, etc. However, these goals are too vague to be practical and need to be specified in an appropriate resolution in order to be useful. Frequently these vague goals are used directly to define specific metric targets and introduce the risk of measuring irrelevant performance and unwanted behavior.

A metric is a measure, and as such, it has to be interpreted relative to a baseline and in the context of what is being measured. This may seem trivial, but with the pressures of modern manufacturing business, this is sometimes forgotten. The question is what are we measuring and is it a good indicator of what we need? Often the measurement itself becomes the goal and this lack of clarity is a common symptom of flawed performance management. To quote Dr. Deming, “Running a company on visible figures alone is one of the seven deadly diseases of management.” He also said that “You have to manage what you can’t measure. You can’t measure everything of importance to management, yet you must still manage those important things and take them into account to be successful.”

So what do we measure? Manufacturing operations are complex and dynamic, and it is a challenge to account for metrics used to evaluate manufacturing performance. Manufacturing management is barraged with top down measurements, such as improve return on investment, maximize cash flow, reduce unit cost, and explain variances from overhead to material consumption. While they have every intention of being forward looking and forward thinking, manufacturing managers are often faced with too many daily pressures. Mining the manufacturing and enterprise systems for data while at the same time, maintaining plant production metrics can become overwhelming. Digesting the variety of metrics, such as quantity produced, throughput, quantity rejected, exception by batch, batch throughput by time, etc., is a challenge let alone analyzing cause and effect.

Manufacturers also must deal with the challenges of connecting the state of their shop floor with the business metrics. They have to understand the casual relationships that production performance has on the overall business. It is a common gripe of a production manager that they have to spend extra hours consolidating information from a multitude of systems to provide metric information and have to rely on administrative help to tie this information to the financial data in the ERP. Misunderstandings about performance occur because financial accounting and external reporting principles often do not reflect the reality of the plant. The continuous improvement process in manufacturing operations means a constant cycle of change and therefore need for information. Yet the information about the improvement cycles may not be exposed through all levels of the organization if it does not have a significant impact on the financial metrics. Most companies are still based on a set of very standard financial reports (financial accounting) that have little if anything to do with the work manufacturing operations is responsible for.

It is in the environment of the plant where cause and effect are the rule, and what is needed is a tool that relates the cause and effect reality of the plant floor to the financial layer of the enterprise. The missing element is best...
practices that guide companies in the process of identifying and assembling the causal relationships thus linking business goals with operational metrics in an effective and practical manner. The practice of using metrics often focuses narrowly on a specific aspect of the manufacturing operations, such as engineering improvements, product development, process, or specific areas of improvement. The potential for these metrics to drive value up or down the internal and external supply chain is often overlooked. An important reason for using metrics is to empower people and focus on value creation, i.e., manufacturing operations, and provide them the required visibility into these so appropriate actions can be taken.

To exemplify this, examine the following scenario from a bioreactor process. There is an unexpected rise in Kilowatt hours consumed by the bioreactor agitation motor over a period of time. This information is interpreted in the following manner by different people across the organization and illustrates how a simple event can have an impact across different functions:

- **Supervisor or Reactor Suite Manager** – as a potential increase in speed of the agitation and therefore possible damage to the cell culture in the reactor.
  - **Action:** check agitation speed – take immediate corrective actions
- **Maintenance Department** – this could indicate mechanical wear of the agitator. Maintenance needs to prep for repair when the batch is completed.
  - **Action:** plan for a repair of the bioreactor and agitator part availability.
- **Plant Manager** – review the overall reactor and batch performance and begin to plan options that may require another batch run or other alternatives to satisfy order demand.
  - **Action:** keep the reactor running if possible. Plan for some downtime or low capacity run.
- **Financial Managers** – will see a costs increase for that batch lot number if the batch processing time is extended, increased consumption of electricity, and possibly lower yield.
  - **Action:** adjust forecast of the planned daily production and profitability reports.

Another example is production throughput as measured in tablets pressed per minute. This as a metric could be meaningless if tablets are rejected because of quality issues. The correct metric should be throughput of “quality” tablets. This is calculated from the two data points of tablet press speed and number of rejected tablets. This is a Key Performance Indicator (KPI) as opposed to the two independent data points and is used to drive value.

**A Framework for Defining Metrics and Intelligence**

During the mid-1990s, formal templates and scorecards for tracking performance were introduced and used by manufacturing organizations to create baseline benchmarks, identify potential problem areas, and prioritize plans for improvements. This process has evolved and become more formal in recent years with common best practices and various “types” of metrics identified for various
scenarios. Metrics are being used by all major industries, often as part of corporate initiatives involving lean, quality, ISO, or other improvement or compliance programs. The widespread use of metrics today often begins with product development, where engineering and manufacturing collaborate and use engineering systems and manufacturing systems for planning manufacturing processes and collecting performance results. As stated earlier, there is a clear need for an approach to identity and assemble operational data and the causal relationships that link operations metrics to business goals. The goal is to enable a better understanding of performance of the manufacturing business.

One such approach – the Resource Consumption Accounting (RCA) – was independently evaluated as illustrated in Figure 3. This approach begins by defining quantity structures and causal relationships to develop the connections from manufacturing operations to the financial layer.

RCA includes a three step approach that requires the cost model developer to obtain an intimate understanding of the manufacturing operations and that manufacturing operations management learns more about the overall business.

Step 1: define the organization’s key strategic objectives, the critical and common decisions managers make, define the key value creating processes, the resources that directly contribute to final product, and what level of support they provide.

Define the manufacturing and business resources – know the plant, the business, the people, and the problems each are working with daily. This is a challenge since it requires realignment of the prevalent mindset and entails understanding all the different viewpoints and motivations in the organization, including the people in the financial department. It is critical to understand the responsibilities of each business area and stakeholder, including cost centers, capacities, assets, and the metrics each are held accountable for. The goal of this step is to define how value is generated from the resources (e.g., materials, equipment, facility, or plant) and identify misalignment in perception between manufacturing and business operations.

Step 2: define resource groups, metrics, measures and their relationships. This involves three sub-steps as follows:

A. Model the resources into their quantities (metrics), capacity, and where and how they are consumed. Quantities or metrics define what drives costs to the resources. This step should identify the metrics needed to measure performance of each resource and resource group.

B. Associate the quantities (metrics) with causal relationships by identifying how resources causally relate to where and how they are consumed or used.

C. Monetize the values of the quantities by adding the costs or monetize each unit or quantity identified in the model.

Step 3: visualize the model with a “storyboard.” Figure 4 provides a holistic view of the plant and the business. This will give all the manufacturing and financial operations a clear and

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**Figure 4. Example of storyboard.**
candid perspective of the operational metrics that affect business and vice versa. It also allows a more granular and almost instant view of operational and financial data and metrics.

The simple example in Figure 4 shows a plant that is divided into three primary cost areas:

1. Raw materials
2. Production labor
3. Machine maintenance

In the center of the storyboard are the quantity structures that drive value to each of the cost centers, and their measurable units. The output from this story board is seen to the right and is:

- A standard corporate Profit and Loss (P&L) statement
- A breakdown of a more granular plant view of performance
- A more refined product, lot number, or SKU level performance statement

**Defining Data and Information Requirements for Usable Metrics**

Obtaining the required visibility into the performance of modern life sciences manufacturing operations with their inherent complexities is an important challenge that can only be addressed with information technology and manufacturing systems software applications. In the modern manufacturing plant data, information, and software systems exist in abundance; as exemplified, it is seemingly still a challenge to gain this required visibility into the performance of business operations. Data is being collected, sometimes in terabytes by different systems, yet it does not have the appropriate arrangement for effective decision support and analysis, i.e., intelligence. Even when the data is arranged in a usable format it is statically focused around a particular metric or problem.

Knowing the data exists, manufacturers are inclined to first consider the plethora of offerings with buzz words such as “metrics,” “digital dashboards,” and “business intelligence platforms” to address the manufacturing intelligence challenge. Yet, it is remarkable that one of the most commonly used tools to capture and manage information from the shop floor is the spreadsheet - typically Microsoft’s Excel. In some cases, even with a major ERP system investment, the spreadsheet is still the primary source of timely data about manufacturing operations. In other cases, expensive solutions are put in place to capture and collect data from automated equipment, but fail to provide the information in a useable context and once again users resort to spreadsheets.

Why is it then that manufacturing organizations resort to spreadsheet solutions? It is typically not because of lack of understanding about information systems or the skills required to use these tools. It is because a spreadsheet provides the flexibility to manage and present manufacturing information in the most usable and advantageous manner. It is important to note that information use or “information consumption” is driven by the role a person plays in the overall operations. For example, a manufacturing manager’s main focus can be productivity and quality. Hence, he will use information to obtain metrics about the value stream that he is trying to manage because he needs to know how the operation is performing in real time. This need is similar to that of a sport’s team, where you know where you stand every second of the game. You don’t have to wait until tomorrow morning’s newspaper to know who won the game. Running a manufacturing operation without real time metrics is like bowling without being able to see the pins. You can see some of the action, you know that something happened, but you don’t know what the result was.

It is critical to consider how people use information to solve problems and gauge performance. There is a clear need to provide effective and relevant information necessary to support the information consumed by the different roles in the manufacturing operations. As described in the sections above, identifying what needs to be measured is a fundamental principle, but it is not sufficient, the information also has to be arranged in a usable manner. Therefore, it is important to study and understand information consumption patterns by roles. Figure 5 exemplifies an information consumption pattern for a specific role.

In this example, the production supervisor glances at his dashboard and observes that the cell density is not within acceptable limits. He immediately navigates to view the “cell density by time” trend over the last two weeks and observes a negative trend beginning around “Monday” that
indicates something is seriously not in order.

To begin the analysis, he examines the “media batch feed schedule” to see if there is any correlation between the trend and the media that is being fed to the bioreactor. This action is obviously based on intuition possibly because he has seen that before. Seeing that there is a correlation between the change to a new media batch feed when the trend started he decides to take a look at the “exception by batch” information and notices that this specific batch had an unusual number of exceptions. He then dives deeper into the data by analyzing an exception Pareto for the suspect batch. He finds a high number of operator errors, which clearly highlights the root cause of the trend. Finally, since he is accountable for operational profits, he decides to take a look at the cost impact of this event in order to understand what the impact is to the plant’s financial performance as seen in Figure 6. Unfortunately, the cost impact is substantial and thus he as to take action to mitigate this increased cost.

The scenario shows the power of “actionable intelligence.” The supervisor has all the information he needs in order to quickly and effectively analyze the situation to determine root-cause and he can take action based on the results. The scenario that the supervisor decides to take in the example above is one of several that could have been used to detect and diagnose the cell density performance issue. It is this type of self-guided or self-serve analysis that really shows how information is consumed to meet a specific goal and should be the common pattern for the information required by a specific person or role. These requirements have direct bearing on the information context and data structures that must be provided, and the dimensions by which the metric is analyzed or “sliced and diced.” Although this seems trivial at first the requirements that these analysis patterns have on the underlying information and data structures are significant and is a critical component of the system design. It is not enough just to collect the data; it has to be arranged in a manner that enables this unique type of analytic information consumption.

Experiences and best practices about information consumption are varied and differ from organization to organization. This in fact is a testament to the inherent challenge with this type of system; however, it is possible to compile a number of key points that are valuable when tasked with providing manufacturing intelligence.

- Performance management should be focused on the business processes and not a tool, system, or ability to see metrics or information. Focus on what the information tells you, rather than the way it is presented.
- Actionable intelligence is the ultimate goal of the information. The action to perform should be clearly evident, even intuitive after a short interpretation of the information.
- Defining relevant metrics is the toughest part of the exercise closely followed by identifying the data requirements.
- Presentation and visualization of the information is the “minor” part of the battle and typically differs by users’ needs.
- Garbage in – garbage out applies universally, i.e., incorrect or inaccurate information presented in an appealing visual format is still incorrect. You must trust the information.
- Trends matter more than actual values. Humans have a natural ability to identify or observe patterns. Hence it is invaluable to include the trends exhibited by the information; in most cases, this elevates information to “actionable intelligence.”
- The context of the information provides added value, isolating it can be detrimental. Context is a vital part of the analysis process and is another ingredient in the transformation of information to “actionable intelligence.”
- Understanding the source of the information enhances the ability of users to interpret context and patterns.
- The source of metrics information should be automated or computerized to prevent the possibilities of influence by “personal interpretations.”
- It is critical information about the manufacturing operation is as close to real-time as possible. It is critical for diagnostic and analysis purposes to be able to react in an effective and timely manner to solve the operational problems as they occur.

It is common to see a multitude of reports, dashboards, and metrics in an
organization. People will use data in any form in order to understand their performance and analyze problems. It is part of our creative nature and flexibility. Because a system constrains information to specific formats or simply lacks, it does not mean that business stops, people will strive to meet their goals regardless. Therefore, it is vital that metrics are driven by users’ end goals and that the information that users need is provided in a manner that enable the dynamic and creative decision process. This puts a new dimension on the information structure design and the functionality of the information delivery solution that can provide true manufacturing intelligence. As a guiding principle, the manufacturing intelligence solution should provide overview, visibility, and actionable intelligence - Figure 7. These are considered the three pillars of information consumption and are meant as a guide when considering strategies for transformation of data to information and finally to actionable intelligence.

**Summary and Conclusions**

Performance indicates how manufacturing operations are progressing toward a goal, while intelligence aids in interpreting performance or lack of it. In simpler terms, intelligence is used to gauge and manage performance. This may seem straightforward, yet usable and useful manufacturing intelligence as it turns out is not easy to obtain both technically and operationally. Not only is it necessary to define what data is needed and how to transform it to information, there needs to be a definition of what is good performance and how can it be measured. This seems to be a universal challenge for manufacturing industries, not only the life sciences industries.

In recent years, manufacturers have gained substantial visibility about the performance of their manufacturing operations with the increased application of technology, but they still fall short of what is possible. Most manufacturing intelligence vendors are clearly aware of these needs and are working to bring applications with the flexibility and convenience that are really needed. The best way to guide the evolution of manufacturing intelligence solutions is to understand the true needs of the organization. This means a holistic view of the required intelligence that includes the appropriate scope and granularity of information linking operational shop floor metrics to financial metrics. It requires a mindset shift at all levels of the organization and best practices for utilizing more of the information to obtain and drive operational decisions.

Additionally, with the amount of available data growing daily we need new more robust methods to sift through the data to help us point the way to the value we all bring. The immense amount of data in a typical life science manufacturing organization is generally a hindrance to performance management. Companies know that they need to improve their performance and are actively pursuing operational excellence; however, it is a constant struggle to get a clear picture from the data and information in the different systems. The easiest system to get data from is typically the ERP and as such, there is a focus on the financial metrics, which do not necessarily give a complete picture of the performance of the organization. Knowing that, companies are looking for ways to link financial information with operational information. One approach that meets these needs is Resource Consumption Accounting (RCA). It provides a method to gain visibility of the linked information about operations on the factory floor to the financials.

Last, it is important to note that it is not enough to only link the data. The information has to be delivered in a manner where it can be consumed to drive performance. In order to do that, the behavior and creative way in which people operate has to be studied and used to design the appropriate functionality of the manufacturing intelligence solutions. Intelligence means that information must provide overview, visibility, and most importantly, actionable intelligence.

**References**

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