Smart Fab

Industry 4.0 a Data-Driven Imperative

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Executive Summary

Smart Fab/Semiconductor Industry 4.0 is a data-driven approach to semiconductor processing that focuses on using data to make better decisions to minimize excursions and defects and increase productivity, quality and yield.

It is not a prescriptive series of actions but a commitment and a company-wide engagement. Industry 4.0 is adapting the data-driven approach that has been disruptive in every industry and applying that to semiconductor manufacturing.

The huge advances in data analytics over the last 3-5 years mean that continuing with an outdated approach to data collection, management and manipulation is rejecting the opportunities to improve product and process - there is a cost to not taking action and persevering with business as usual.

Providing engineers with tools – better tools – to view and monitor data is undoubtedly a continuing requirement, but automating more analysis removes the repetitive tasks from overburdened engineers and technicians and frees them to perform the tasks for which they have been trained and are highly qualified to perform.

Smart Fab goes far beyond saving costs by automating tasks that would otherwise be performed by high-cost employees it solves problems that have previously been impossible to resolve.

Automation is better than people at much advanced data-science. It’s very difficult for anyone to visualize interactions in a complex, multivariate system. Engineers will generally monitor one parameter which they consider critical, missing the possible interaction of all other parameters that may also contribute to inferior processing.

Traditional computer analysis, even quite advanced statistical process control, suffers similar problems. The complexity of the analysis scales badly – big, multivariate dataset are tough to analyze.

Over the last 3-5 years advanced analytical techniques, artificial intelligence and neural networks have emerged, and matured that transcend these problems - algorithms where the complexity of the application does not dramatically increase with the size of the dataset or the number of variables. Innovations that have no problem with finding patterns, anomalies and correlations in data regardless of the size. This can be a simple run-to-run analysis based on tool logs, to the relationship between data in the fab and the huge amount of data collected in final testing.

Advanced predictive analytics detect problems before they occur. Applied to predictive maintenance this decreases unscheduled and scheduled tool downtime. If you can accurately predict the life of a component you can extend the time between preventative maintenance events and keep the tools running longer. Predicting process problems allows the tool engineers to be alerted to an issue before bad product is made.

Above all, Smart Fab is a recognition that correctly adopting these practices increases quality which drives, productivity and yield in a way that significantly offsets the cost of the implementation. Industry 4.0 is a profit center, not a cost center.

A Call To Action

The technological advances that make Smart Fab possible have been disruptive in every other industry. Manufacturing as a whole and semiconductor in particular has recognized that the improved quality, including not only better quality products delivered to the customer but also more reliable delivery schedules are compelling reasons to proceed. Industry 4.0 includes the entire supply chain - better products and better ontime delivery by controlling scrap events, tool downtime, process activities and integrated scheduling. Customers can be increasingly expected to ask for these approaches when selecting suppliers.

The adoption rate of the “Big Data” and advanced analytics that make Smart Fab possible - the “hockey stick” growth - reflects the power of these new techniques. Two enabling technologies have matured along in the same timeframe - “Big Data” has driven advances in “Cloud” computing. The Cloud is a cost-effective way to manage vast amounts of data from different systems and perform analysis in a single “location” and an opportunity to integrate “best-of-breed” tools for data integration. IOT (or IIOT – Industrial Internet of Things) completes that architecture by providing a manageable way to collect and control the data pushed to the Cloud.

Big Data, Data Transparency and the Cloud

The Cloud architecture provides infrastructure. Like electricity and water it’s essential, but this infrastructure is well understood. Fundamental features of Cloud computing – security, component decoupling and abstractions and being vendor agnostic - the ability to integrate solutions without a “vendor lock” - are common to all implementations. The solutions from a various vendors provide different features – different applications and components – which are important consideration when choosing a Cloud vendor but don’t radically change the approach.

It’s possible to host a Cloud solution in an internal datacenter, but understanding that this is infrastructure and not something unique to any organization, allows significant cost benefits by purchasing this service, with support, from a Cloud provider. The traditional ideas of in-house systems, each unique and each requiring expensive support contracts is replaced with the idea of “Platform as a Service” (PaaS) where all the standard pieces – the parts that are not within the core competencies of the fab and which do not provide a competitive advantage – are simply outsourced to organizations specializing in this area. Examples including Amazon’s AWS, Microsoft’s Azure, Google’s App Engine, Pivotal’s Cloud Foundry and many more. While every semiconductor manufacturer is unique there are, increasingly, platforms that provide “Software as a Service” (SaaS) that include not only the infrastructure but also analytics and other applications and components beyond the PaaS model. Siemens’ MindSphere is an example of this approach.

Every fab has a huge amount of data that could be mined for process, yield and quality improvements. However, without a clear understanding of the value of this data, it’s significantly underutilized. The data is also scattered through various systems in the fab such that access is not always easy.

The Cloud brings data transparency and data integration to an organization. That is, it makes data, regardless of where that data originated or where it is stored, available in a consistent fashion throughout the enterprise.

While this appears to be a vast amount of data – and the goal would be to increase data collection - storage and analysis capabilities that define Cloud/Big Data dwarf the requirements of manufacturing. For example, advanced analytics is used to find fraudulent charges in the 1.5M credit card transactions that occur daily – easily 10x the number of interactions that occur in any manufacturing facility. Manufacturing gets to benefit from a very capable system that others are pushing to the limits but from which, we are using the more mature technologies.

The Cloud architecture provides abstractions and component decoupling making it easy to integrate collected data, data from business systems, such as ERP or MES and to add features and applications as appropriate but at the same time is largely vendor agnostic so you're not tied to one vendor for all systems. You can pick the best-of-breed – you no longer have to use inferior tools because that’s what appears to be available.

In a future that is increasingly software-driven, the limitation of software are also the limitations of a manufacturer. If the software tools are not available and cannot be made part of a whole system, engineering cannot perform the analysis. Managing the proliferation of “best-of-breed” application is important to avoid the existing situation where various groups have selected a tool that meets many of their needs but which they will then apply to any problem even inadvisedly because that’s the tool they “own”. Industry 4.0 must have corporate oversight whose role it is to understand the huge benefits from best-of-breed software without the system degenerating into unmanaged islands of tool usage. Industry 4.0 applications being Web/Cloud based are easier to maintain – there is no requirement to install the system on each desktop – which makes possible better selection of best-of-breed without dramatically increasing management overhead.

IOT – Data collection and Automation

IOT – the “Internet of Things”, or IIOT – the “Industrial Internet of Things” refers to using many small systems typically located close to a tool or other equipment. These small boxes in close proximity to the tool allow for data collection and possibly automation. These systems are typically small Windows computers or Linux systems – for example the Raspberry Pi. They can be headless (no monitor but with possible web-displays) or have a monitor for operator interaction.

Typically these systems have a small amount of local-intelligence related to the tool or equipment. They should know how to collect data from the system, and to a lesser extent what data to collect.

When part of a fab automation system they could display user interfaces, either conventional or web-based. Under these circumstances they would abstract out the unique features of a particular tool, including the idiosyncrasies and special requirements for that toolset.

Typically, logic that is fab-wide, or even area wide, is not implemented by IOT. These types of configurations, especially where engineering action may be required, should be handled at the Cloud level.

For example, the IOT system collects alarm information, but decisions based on those alarms - stopping the tool, holding the lot for inspection, etc. - will be made in the Cloud and sent back to the IOT device.

Recognizing the value of collecting data close to the source also requires that the IOT systems become “Edge” devices for the Cloud. That is, to be workable and manageable it’s important not to embed business logic in these Edge devices. Logic in the Cloud is supported, enhanced and modified in one location, not in a variety of small IOT system. IOT provides essential data collection and local feedback, but the decisions should be made elsewhere.

Actionable Data – Making Smarter Decisions

The analysis currently prevalent within most fabs works on data in isolation – ignoring relationships between data or even between runs on the same tool. Some data is in databases. A vast amount of data is in MES systems and much is still in data files. SPC and other rules applied at various levels to this data are all valuable tools but limited.

The data in tool log files is often still on the tools and used by engineers for forensics. Manual viewing, rule-based evaluation of control charts and other manual or semi-automated actions are still the principle anomaly detection approach.

Much of this data is of poor quality. Metrology data is too often entered manually. A 1% error rate in manual data entry is considered good – that means at least one data point in 100 is incorrect in some way.

The most obvious downside of all these approaches is that they are, largely, reactive and not predictive. The rules and the simple predictive analysis are not based on the in-depth analytics of Smart Fab.

Not having critical data readily available, is often daunting enough that this data will be ignored or rationalized as unimportant.

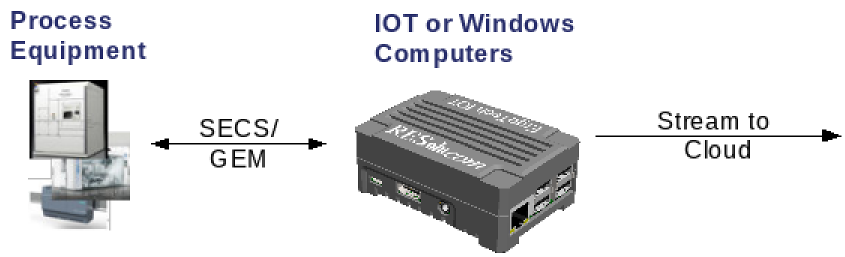
Cloud/IOT synergy allows fabs to make the leap to the types of automated big data analysis that is Industry 4.0.

With IOT and application integration feeding all the data into one place we have a central “reading room” where all data is at our fingertips and we can compare, visualize, analyze and decide without having to search around for the required data.

With this, we can start to apply basic and advanced analytics to not only react to problems but to also make forward-looking decisions based on a solid, data-centric, informed basis rather than on an engineer’s gut-feeling.

Technical Overview

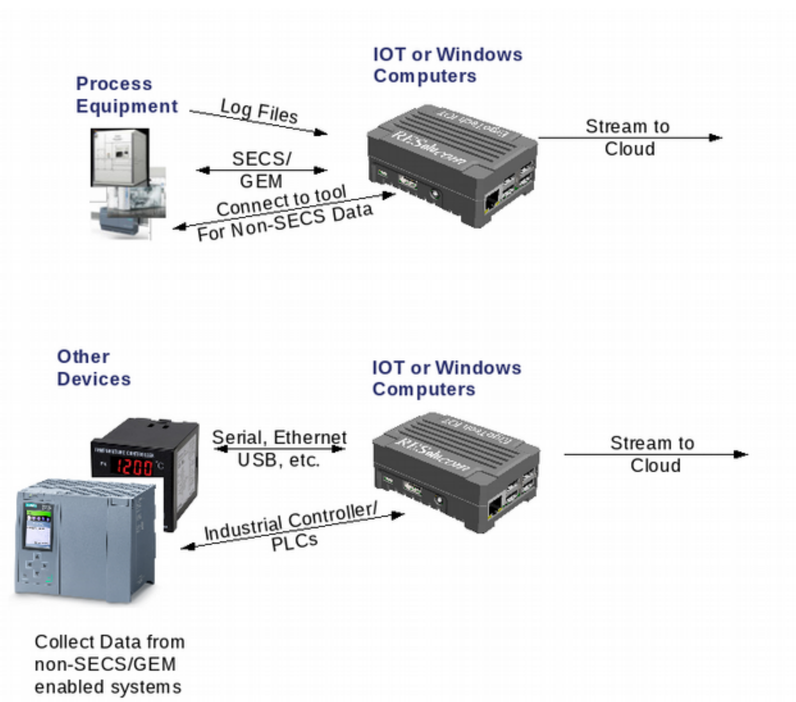
IOT – Data Collection



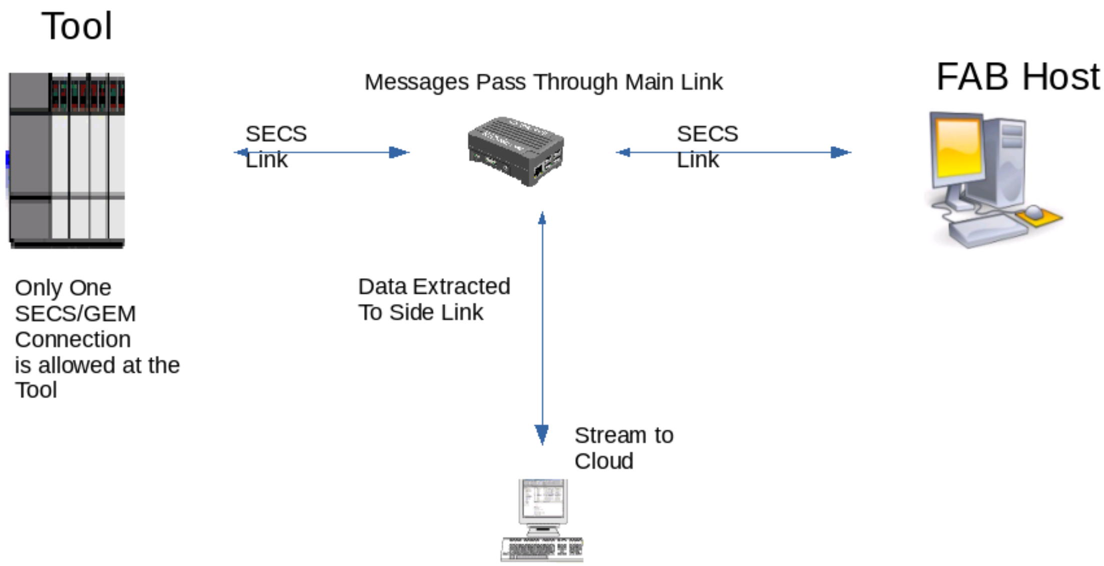
IOT concepts are relatively easy to understand. In a fab, tools usually communicate using SECS/GEM making the primary function of IOT to transmit SECS/GEM data to the Cloud. For data collection, some newer systems support "Interface A" an XML based stream protocol for data collection.

Unfortunately, even in a fab it's never quite that simple. While most systems use SECS/GEM , some require other approaches. Even systems that do have data collection, it's often incomplete and data residing in log files or other files on the tool needs to be collected. The IOT system must be capable of more than just SECS/GEM.

There are ancillary systems in a fab, temperature, pressure, chillers, gas cabinets, etc. that are often not part of a SECS/GEM system, but still need to be monitored.



Finally, SECS/GEM allows only one link to the tool. If that link is used by, for example, fab automation and Interface A is not an option, then IOT needs to use what's known as a "Y-tap" to collect data while not interfering with automation.



An IOT system in a fab must have broad, flexible capabilities not just basic SECS/GEM.

Time Series Data

Almost all data, but especially manufacturing data, is a time series. That is, a usually infinite, stream of data points each with a timestamp of when the data was collected.

One important role of IOT is to move the data, as much as possible, from a specific domain/protocol (such as SECS/GEM) to a generally accepted and easy to manage domain.

In the Cloud, probably the most common format for data is JSON. JSON provides an extremely flexible, well understood widely supported format for streaming and static data.

{ "STARTED": [
  { "RPTID9": [{"GasFlow":"17.406", "type":44 },{"ProcessTemperature":"49.293", "type":44 },{"WaferCount":"1203", "type":54 }] , rptid:101} ,
  { "RPTID10": [{"ControlState":"5", "type":54 }], rptid:101}
], ceid:7501, timestamp:"2019-02-12 14:53:35.330"}

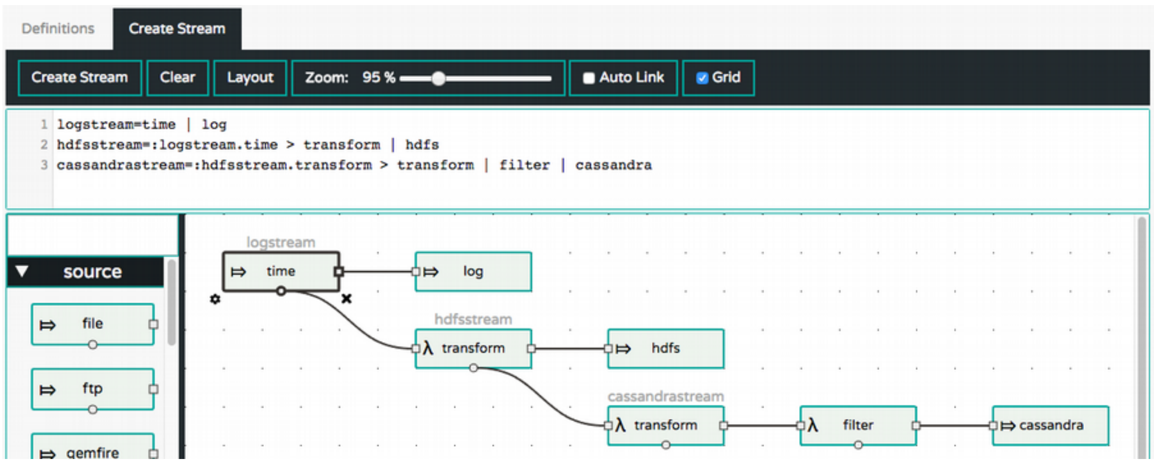
With a stream of JSON data the next step is to determine which applications have an interest in that data – controlling the stream's data flow.

There are alternatives to JSON, especially for higher volume applications where a text-based protocol is inappropriate. It's still generally time series data and the approach is fundamentally similar.

Data Flow

Streams of data make some processing easier and some more difficult. The Cloud is capable of handling streams and provides tools to direct the incoming streams, possibly with some filtering or other manipulation to the appropriate action or application.

Multiple applications can act on the stream, either completing a full action, determining the correct recipe was run, saving to an historical database, or providing a filter and passing data through based on aggregation, or particular features of the data.



For example, to populate an MES with metrology data is simply a matter of a filter that finds the message with the data and a sink that puts it into the MES. As another example, to count lots completed on a tool, it would be easy to build a data-flow that allows the filtering of the stream, based on the tool and lot complete, and counts those lot complete indications and stores the to a database, MES or similar.

Data Buffering/Timeseries DB

The simple counting example is fine until you start refining it to, for example, count the lots processed in a day. Now rather than counting indefinitely on an infinite stream the count must be just for the lots that were processed in the previous day. The solution to this is to buffer the stream for a certain amount of time – typically a month or more. The buffer/timeseriesDB will automatically purge obsolete values avoiding excessive data storage and the tuning and management issues associated with large data stores. In the example above, we can now query the buffer for all the lots that were completed in the last day and simply count those.

Triggers and Extract-Transform-Load Operations

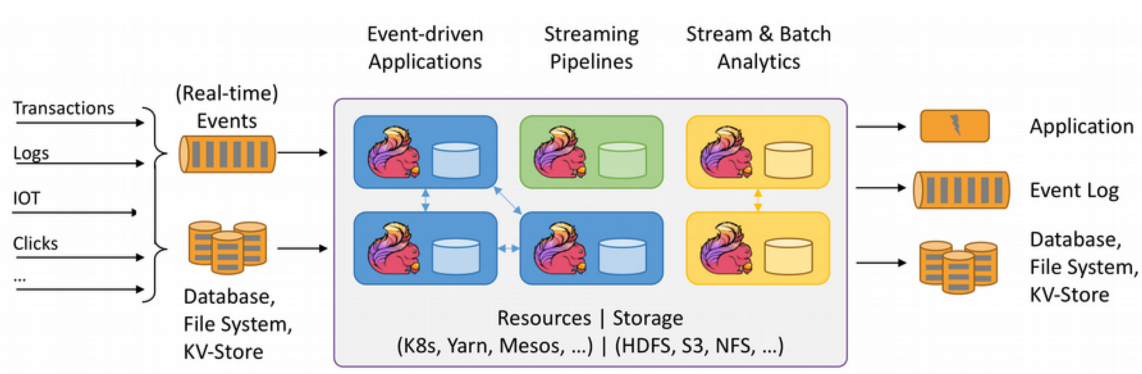
In a technical sense, to count wafers over the previous day we need a “trigger” to indicate that a new day has started and then perform an “Extract-Transform-Load” (ETL) operation to manipulate the data. In this case, we extract the data, transform it from raw data to simply the count of lots and load it into another database, display, MES or wherever that data is required. We can transform it back into a time-series stream and reintroduce it to the data flow if we want to consume this in many places. This might make sense, for example, if we have an application that’s plotting the daily product numbers – it’s still a stream albeit with quite distant timestamps.

Any data we could require is in the buffer/TimeseriesDB and so the triggers, and what we extract and analyze is simply dependent upon the requirements of the application. We could extract all the data from a particular process step for comparison with previous process steps, or run SPC calculations or advanced analytics.

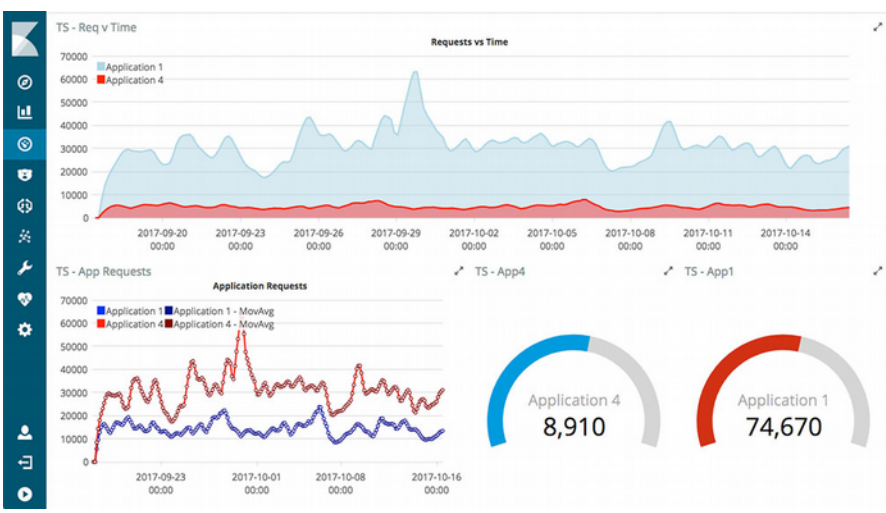
Best-of-Breed

Not every problem in a semiconductor fab is unique to semiconductor or manufacturing in general. As the Cloud and IOT solutions have grown, powerful tools to operate on data have been developed. Many of these are “FOSS” (Free And Open-Source) software – developed by the Cloud communities for anyone to use.

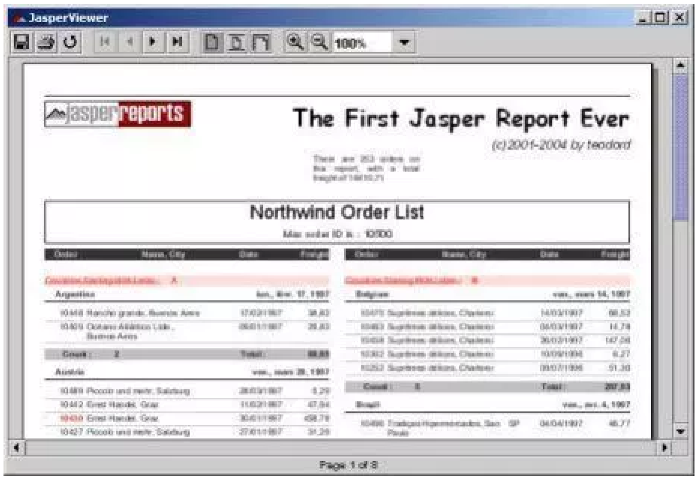
This includes ETL applications like Apache Fink:



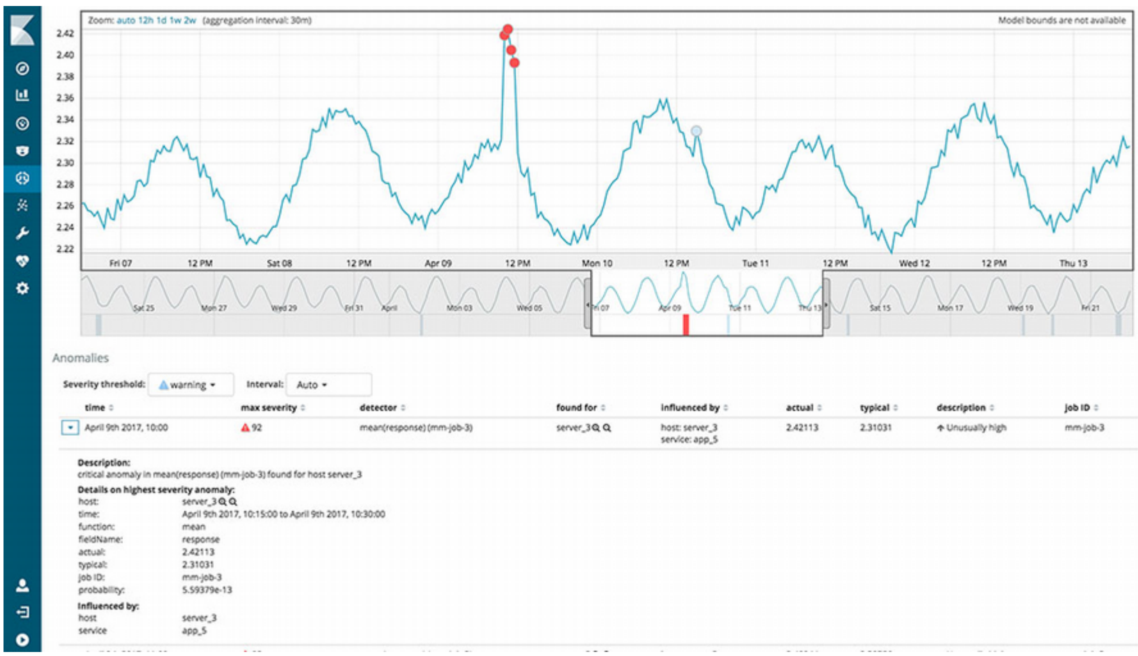
Dashboard and graphing application like Kibana



And analytics of all types in Apache Spark and Kibana. JasperReports is a very popular, very capable report writing tool.



There are a great many Cloud-based solutions addressing common problems of data management and analytics in the Cloud environment.



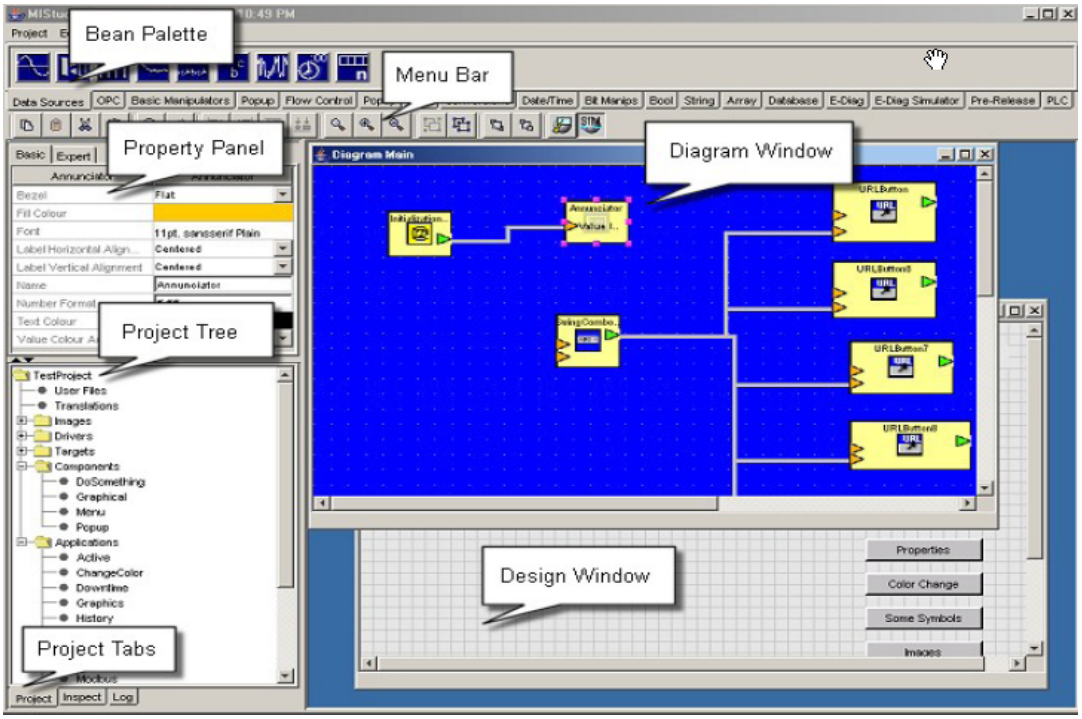
Best-of-Breed – Semiconductor

The vast range of very capable FOSS tools cover many of the general purpose and some very specialized applications in the Cloud. These can be designed and configured to meet many of the requirements of fab data. These solutions, however, would not normally be maintained by process engineers and technicians, they are, more correctly, managed by developer, IT and data scientists who are familiar with and qualified to produce these solutions.

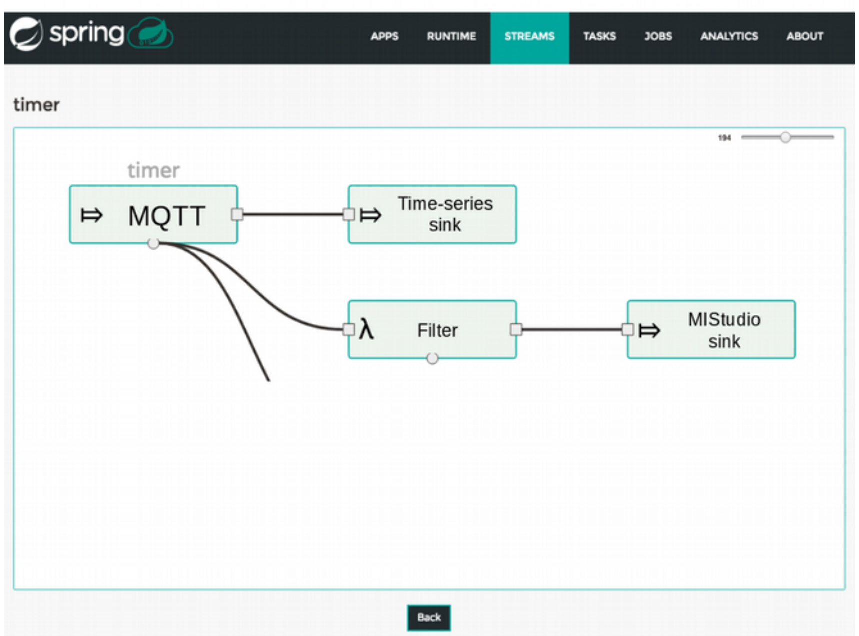
Nonetheless there are cases where engineers do want to be able to create dashboards, analysis and visualization that is more tailored to their needs.

ErgoTech specializes in these applications and provides a drag-and-drop application builder aimed at non-programmers (more broadly “Operations Technology” (OT) – production and production support engineering) but which is nonetheless capable of building advanced visualization, FDC and analytic applications.

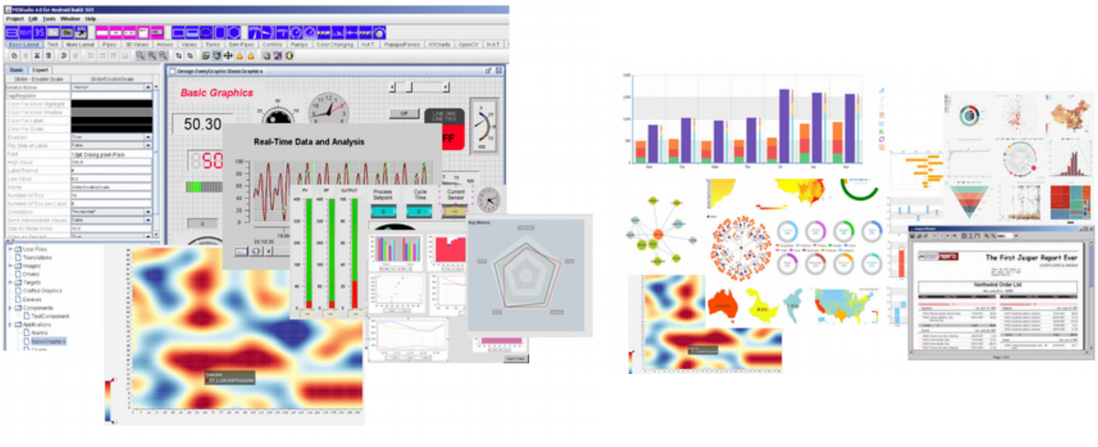
ErgoTech's MIStudio integrated development environment (IDE) provides a design window that generates a web-based HMI and a diagram window that lets end-users create applications by connecting components.



MIStudio can source and sink Cloud streams so generated applications can be placed anywhere in the data flow.



MIStudio's Design environment is extremely rich, providing everything from simple displays to unlimited charts.

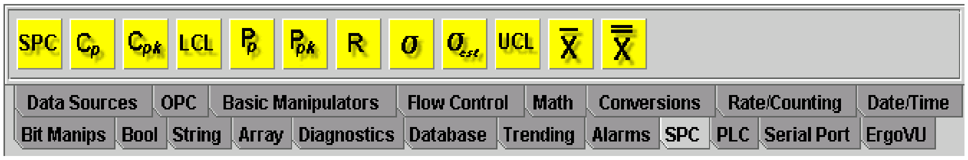


Integrated report generation allows data to be exported to Excel, HTML, PDF, etc. A full suite of database components allows easy querying of both the timeseries DB/buffer and long term historical values. Integration with MES systems allows data from all sources to be compared and charted on the same screen.

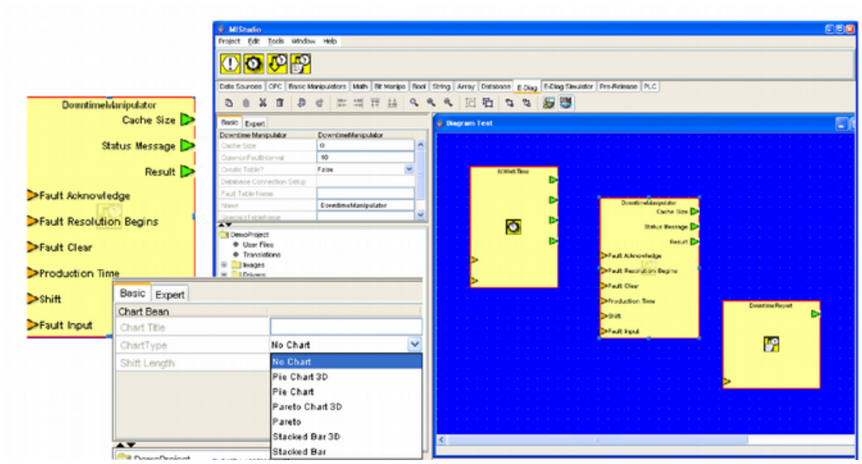
Queries can be time based, lot-based, or ad-hoc, so data from multiple runs can easily be visualized on the same chart.

Easy access to databases allows MIStudio to provide complete recipe management, including the idea of a "Golden Recipe". This can be coupled with automated recipe upload/download to prevent issues where a recipe is inadvertently modified at a tool. MIStudio components perform comparisons of formatted recipes to isolate unexpected changes.

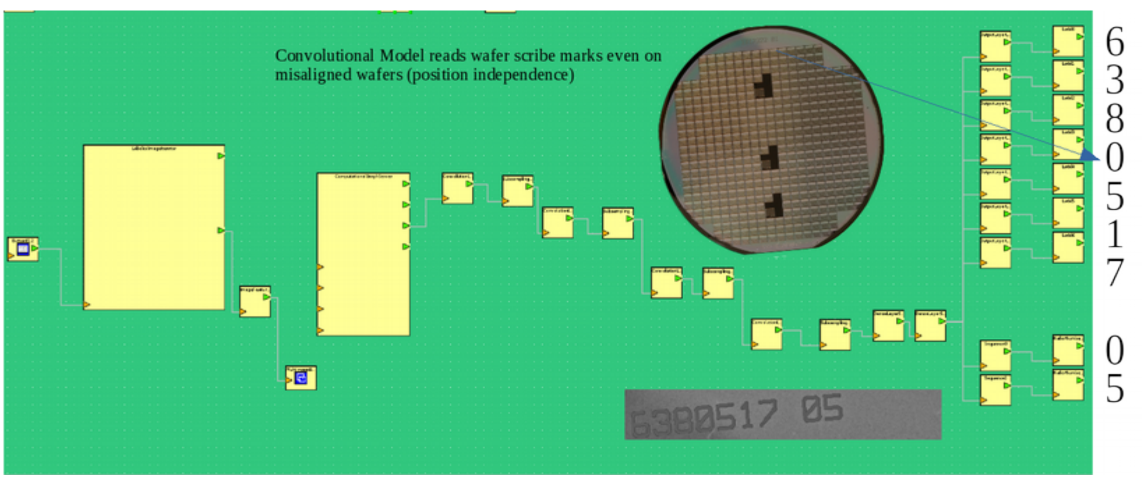
More sophisticated components, such as suite of SPC components allow for drag-and-drop analysis and comparison.



MIStudio components for tool uptime/downtime. Alarm management provides support for alarm priorities and cascading alarms.



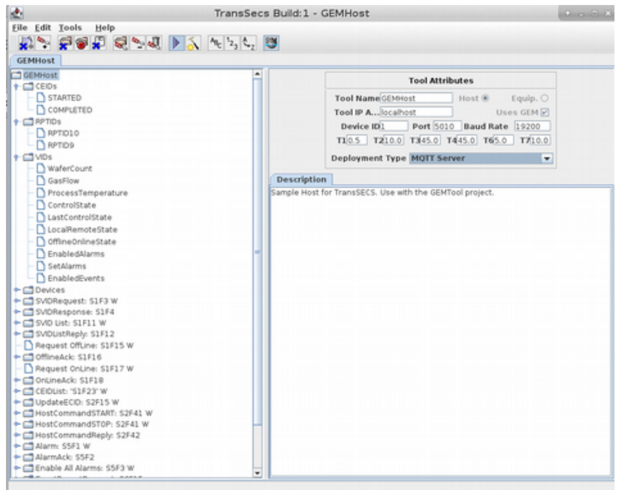
ErgoTech is an industry leader in advanced analytics, machine learning and artificial intelligence. Advanced analytics, including drag-and-drop machine learning can be part of the MIStudio suite. Cloud streaming support also means that raw or processed data can be passed to other analytic engines within the Cloud – for example Apache Spark.



Applications built in MIStudio deploy directly the to Cloud. The generated logic will run 24/7 in the Cloud environment and the views are available on demand as rich HTML5 web pages.

Best-of-Breed – SECS/GEM IOT

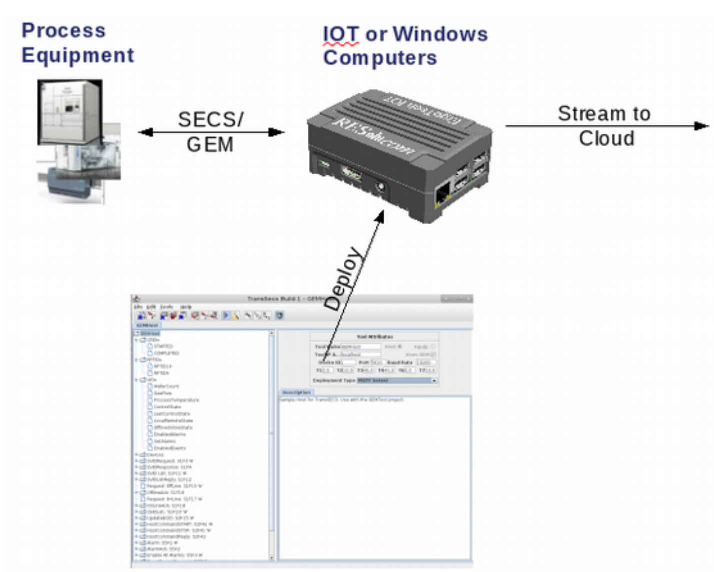
ErgoTech's TransSECS a graphical SECS/GEM application builder. More than just a graphical editor for a SECS/GEM interface it allows you to go live-online with the tools for testing and



characterization. No other SECS/GEM solution provides the ease of use, capabilities and flexibility of TransSECS. SECS/GEM is a complex protocol but the TransSECS environment quickly reduces this complexity to the specific requirements of the particular tool and application.

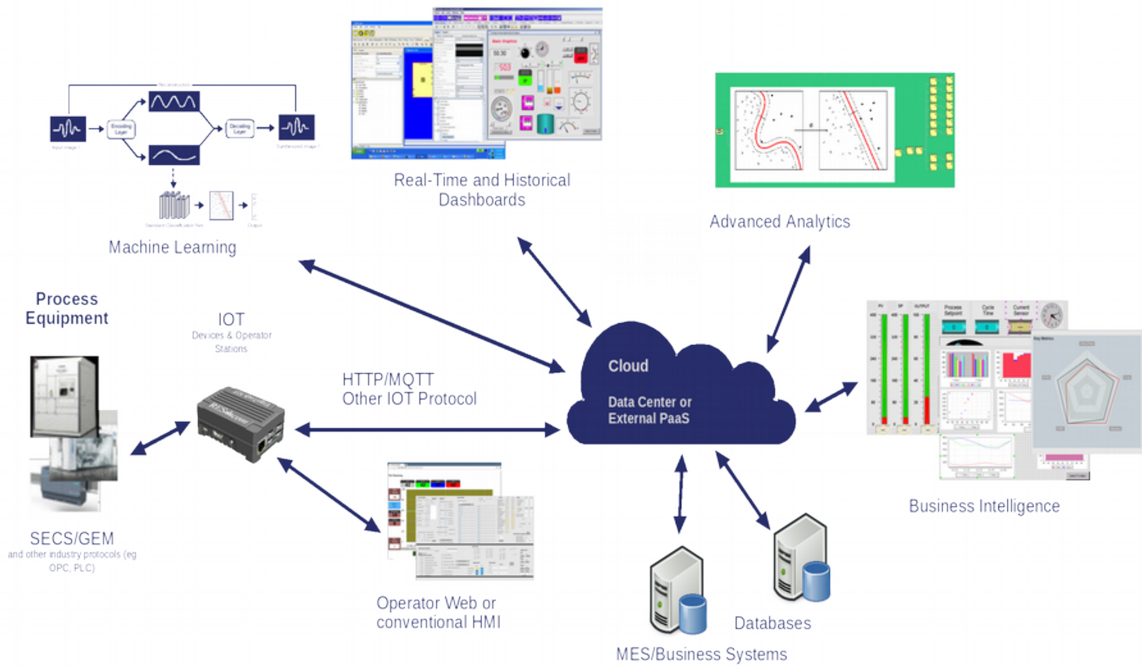
TransSECS lets you pull log files or similar data from a tool by providing support for scripting in Javascript – the most popular scripting language. If more complex features, or tool automation is required TransSECS also integrates with the IOT version of MIStudio. This allows for the drag-and-drop creation of user interfaces with any of the more advanced drag-and-drop logic capabilities of that product.

In a Cloud environment, the function of the IOT devices is to stream data to the Cloud. TransSECS supports a number of IOT/Cloud protocols, such as REST, MQTT, OPCUA, etc. Typically the easiest choice is MQTT and TransSECS will create a fully annotated JSON stream from the cryptic SECS/GEM input.



Conclusion

There is an increasing urgency to move from exclusively engineers analyzing data, determining data limits and manually looking for anomalies to an advanced automated approach. Advances in data collection and data analysis that have occurred over the last 3-5 years cannot be ignored. It is a disruptive, transformative technology and there is a cost to any semiconductor manufacturer of clinging to outmoded approaches to data management and analysis.



ErgoTech's Industry 4.0 Solutions