

Business Activity Monitoring: Process Control For the Enterprise

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Abstract – Business Activity Monitoring Applications are becoming increasingly common and sophisticated. Much can be learned about the analysis and visualization of real-time data from comparisons with previous generations of process monitoring and telemetry systems. While there are similarities, there are also significant differences in the technology involved in the handling of real-time data. This paper discusses practical issues regarding the analysis and visualization of real-time data in BAM applications. Further, it will discuss how lessons learned from the process control industry's decades of experience in providing real-time visibility can be applied today to deliver more effective and successful BAM solutions for the enterprise.

I. INTRODUCTION

Analysis and visualization of real-time data is nothing new. It is at the very core of manufacturing automation and process control systems, network management applications, and telemetry systems that have been in-use for many years.

More recently, we have seen increasing interest in the monitoring and automated control of high-level business applications. The integration of disparate applications for such functions as supply chain management, customer relations management, or business intelligence has created a new and unique set of problems.

Such enterprise software applications are often automated and can be viewed in many ways like a factory or manufacturing facility. For example, a series of applications runs in the background collecting orders from customers logged into a web site, processes and fulfills those orders, and issues invoices, with little or no human intervention.

Monitoring the activity, health and status of such operations has come to be known by a variety of names, one of which is Business Activity Monitoring (BAM). Practically speaking, the goal in these systems is to provide event-driven situational awareness, where the current state of the operation and supporting systems is visible at any instant.

Observing activity in these systems in real-time is much like monitoring and controlling a manufacturing facility. In both, there is a need for real-time data acquisition, analysis of that data, and presentation in a variety of forms. Yet, some characteristics of these functions are very different from the earlier systems.

Because of these differences, the legacy systems used in traditional process monitoring and control do not work very well. New products and technologies are emerging to satisfy the requirements for this new breed of monitoring application.

This article introduces various approaches used to deal with real-time data in Business Activity Monitoring systems. The goal is to facilitate an understanding of the unique nature of the real-time data and the types of analysis and visualization that are required. In particular, important requirements and techniques for dealing with real-time multi-dimensional data are presented and discussed.

The author of this article and SL Corporation have 25 years of experience with monitoring and visualization applications, with particular expertise in Java. The company's RTView product has been specially adapted to deal with real-time data produced by many different types of applications, and has features to address most of the common requirements seen in business monitoring applications.

This experience in both the traditional process monitoring world and with modern enterprise applications provides a unique perspective on the requirements and the solutions for these systems.

II. BUSINESS ACTIVITY MONITORING

By a well-known Gartner definition, a Business Activity Monitoring system provides real-time access to critical business performance indicators to improve the speed and effectiveness of business operations [1]. BAM applications accept events from multiple sources, update metrics and evaluate conditions in real time, provide an output in the form of a dashboard and emit complex events or alerts [2].

There is some debate about the distinctions between traditional Business Intelligence applications (BI) and BAM, primarily relating to the definition of "real time" [3]. There are also many other types of applications that have some overlap with BAM.

A pure BAM solution may focus on the upper end of the many sources of data, specifically key performance indicators (KPIs) derived from lower levels. Yet, in order to improve the speed and effectiveness of business operations, it is often necessary to combine this with navigation to and analysis of the supporting data.

For this reason and for the purposes of this paper, BAM could be considered to subsume or include many of the lower levels of monitoring, sometimes referred to as Business Services Management (BSM) or Infrastructure Monitoring (IM). The table below highlights the different levels and important characteristics of each:

Table 1 - Levels of Monitoring

Level	Source	Key Performance Indicators
Business Activity Monitoring	Custom or Packaged Applications	# of web site visitors # tickets booked Sales conversion rate
Business Services Management	Messaging Middleware, BPM Engines, Web Services, Custom	Messages sent / sec Message latency between processes
Infrastructure Monitoring	Components, Processors, Routers, etc.	CPU utilization Available Memory Network Packets Sent

In general, one could say that real-time data for BAM, in the purest sense, represents the content of the business data exchanged in the supporting processes, such as number of web site visitors or tickets booked. The lower-levels of data, such as number of messages sent, represent information about the health and status of the supporting services or infrastructure.

In many cases, these are, in fact, one and the same. In an on-line web store, the latency in the supporting processes is directly correlated with the number of items sold on that site. If users experience delays, they will go elsewhere. In this situation, a BAM application must analyze and present data from all levels. This is where one might say that BAM subsumes monitoring of the supporting services (BSM).

At each level, the applications involved produce real-time data. These data can be used by the monitoring application to better understand the workings of the system and lead to ways to optimize performance. This is the stated goal of BAM.

III. SOURCES OF REAL-TIME DATA

For decades, monitoring of real-time data was primarily associated with certain types of applications, such as telemetry and process control systems. In these applications, individual components, such as a temperature sensor or a level indicator, generate measurements at a regular interval which are transmitted to a central server using standard protocols like OPC (OLE for Process Control) [5].

A lot of sophisticated technology was developed to analyze and archive thousands of data "points" so that trends could be analyzed, alarms generated, and anomalous conditions detected before they turned into real problems. Additionally, quality control was facilitated by dynamically adjusting processes based on real-time measurements.

In contrast to this, the monitoring of business applications today can be considered quite primitive. Many independently developed applications support various functions of an

organization, such as customer relations or order processing. The relational database acts as a cornerstone of enterprise application development, but numerous stand-alone desktop applications like spreadsheets complicate the picture. Islands of independent applications with duplicate data abound.

Tying multiple systems together and automating interactions of business process applications has become big business. Many companies offer products that provide Enterprise Application Integration (EAI) and Business Process Management (BPM), along with supporting services. These products typically orchestrate business applications, but do not provide much real-time monitoring capability.

At the core of many of these systems is Message-Oriented Middleware (MOM) [6]. Companies like BEA, TIBCO, and IBM developed messaging systems that transmit structured packets of data around a network in order to share data between applications. The Java Message Service (JMS) emerged as a standard on which most of these systems are built, and for the first time, supported real-time streams of data between applications.

In financial services applications, such as program trading, performance is of the utmost importance. New technologies have emerged, improving performance by orders of magnitude over the early MOM systems and providing built-in analytics and complex rule processing. These Complex Event Processing (CEP) [7] systems make more advanced applications, such as automatic fraud detection, possible.

Other sources of real-time data include applications using Java Management Extensions (JMX) [8], an emerging standard for management instrumentation within applications. Relational databases, when polled regularly, can also provide "near" real-time data. Additionally, real-time infrastructure monitoring data are available from systems like Big Brother, and others.

By tapping into these many sources of real-time data, analyzing and presenting the content, it becomes possible to provide a system for Business Activity Monitoring. Each is a rich source of raw data whose content contains a wealth of information about the health and status of a business operation.

IV. MULTI-DIMENSIONAL DATA STRUCTURES

The nature of real-time data obtained in various types of monitoring systems has changed over the years. Traditional process control and telemetry systems operate on many individual data "points," each with its own timestamp. A simple example of data from two valves is shown below. Note that each contains its own timestamp.

Table 2 – Example of Individual Data Points

Time	Valve 1	Time	Valve 2
7:01	Open	7:01	Open
7:02	Open	7:02	Closed
7:03	Closed	7:03	Open

Messaging middleware systems, on the other hand, evolved around the need to transmit a group of related data points in a single message. For example, a message between applications might contain information about a purchase order, including the purchaser, quantity of goods, price, and other related information. A typical message consists of a “row” comprised of a number of individual data fields, along with a common timestamp for the entire row.

Table 3 – Rows of Structured Data

Timestamp	Branch	Agent	Bookings	Cancel	Failed
7:05	North	Mary	1	0	0
7:05	East	Joe	2	1	1
7:10	East	Bob	0	1	1
7:15	North	Mary	2	2	0
7:15	East	Bob	1	1	0

To the developers of enterprise applications, this notion of a message with multiple fields is obvious. It is just a set of structured data. Yet, this is very different from the data in common process monitoring and control applications. As a consequence, the systems used to collect, transmit, analyze and archive traditional real-time process data cannot readily be used in the monitoring of enterprise applications. Much can be learned and carried forward by studying these systems, but new techniques must be developed to handle the data.

Another important aspect of the data in business applications has to do with the nature of the fields in the data. In the row data example above, the fields can be organized into time, index, and data columns as follows:

Table 4 – Sample Fields in Categories

Time	Index	Data			
Timestamp	Branch	Agent	Bookings	Cancel	Failed

All real-time data must contain a timestamp, whether coming from message streams or from point data. The message arrives at a specific time or there is a timestamp contained in the message indicating when the measurements took place. This is necessary in order to perform trend analysis.

The “index” fields are often related to the source of the data. For example, in a reservations system, these fields might include the Branch office and the Agent in the branch making the reservation. In a different application it could be the page on the web site from which a user placed an order. These are often the fields by which data are analyzed. For example, in monitoring the activity of a business web site, one might want to know how many orders came through each page on the site, or from each IP address that hit the site.

The “data” fields contain the actual measurements. These are the values that are stored in the message. Often there can be more than one value obtained in the same time interval sample, or grouped together in some other way. For example, the number of successful bookings made in the last minute and the number of failed bookings could both be stored in the same message. These are related but distinct metrics.

Data described in this fashion are referred to as multi-dimensional. Rather than a single point dimension, there are several columns of data related by a common timestamp, i.e., multiple dimensions. Understanding what is going on in the business involves “slicing and dicing” the data along these different dimensions.

The multi-dimensional nature of the data greatly influences how it will be analyzed and visualized.

V. VISUALIZATION

There are some useful parallels between visualization applications for traditional process monitoring and for BAM applications. One common requirement in both is to show the current state of the system, either the business itself, or the subsystems supporting it.

A. Abstract Nature of BAM Visualization

In traditional process monitoring systems, visualization often involves the use of mimic diagrams, i.e., displays that attempt to mimic the actual process or plant being monitored. These show the current state of each valve or control in the system, along with measurements like temperatures pressures, and so on, as in the example below:

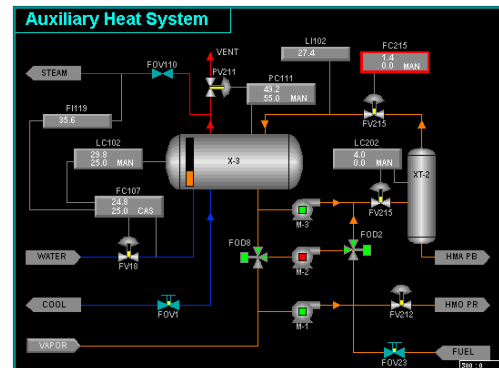


Figure 1 - Example of a typical process control mimic diagram

In Business Activity Monitoring, the process being monitored is typically abstract. There is not a boiler or pump performing some function or sensors that can be represented in a mimic diagram.

Rather, business processes are software applications funneling data from one subsystem to another. Such processes are often represented as “bubbles” or circles, with an icon inside to hint at the nature of the process. Many of these processes can be chained together, as in the following diagram:

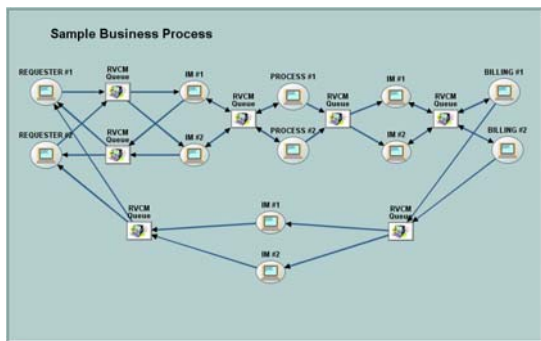


Figure 2 - Example of a business process diagram

The state of the processes can be represented as values, colors, or icons on the bubbles. Sometimes, it is the latency between steps in the process that is of interest, or it is the total number of orders processed or requests received. Instead of sensor values being shown, it is a set of calculated values representing the time difference between process steps. This information can be shown on the lines connecting the bubbles.

Viewed in this way, the bubble diagrams seen in business process displays are not unlike the mimic diagrams in traditional process monitoring systems. The difference is that the information being shown represents the state of abstract software processes, not hardware elements.

In fact, there are many parallels between the two types of systems, which can be highly instructive. One of these relates to the parameterization of displays. This turns out to be one of the most challenging and often overlooked issues in visualization. The most successful process monitoring products provide good techniques for parameterization.

B. Parameterization

A display used for visualization of real-time data must be designed with references to data elements whose values will be shown in the objects on the display. In order for a display to be used multiple times against different sources of data, those references need to be indirect, or parameterized.

Parameterization is found in two areas. In one, a composite graphical object is designed to show several values that are relevant to a specific process. This object could be instanced several times on the same diagram, each attached to a different row of data, uniquely identified by one of the index

columns in the table (a branch office, e.g.). In designing such a display, the index value that is used to select the right data is passed as a parameter to the object when it is drawn.

An example of this is shown below. Here information about each subsystem is summarized in an icon representing one row of data in a table.

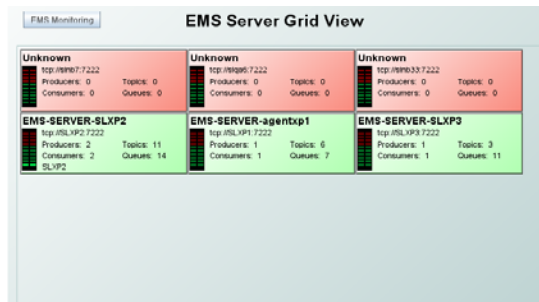


Figure 3 - Object grid showing icons attached to multiple data rows

In a second case, there is a need to drill down to more detailed data in order to determine what may be causing a problem shown in a high-level display.

When the user selects an object in a display or a row in a data table, there needs to be an easily configurable way for the system to pick up the value of the parameter driving the selected object, and pass that value down as a parameter to a new display invoked in the drilldown process. The parameter is used to show detailed data specific to that selected object.



Figure 4 - Same display showing data from different sources

Support for both of the above scenarios is important in an effective BAM system. Without the support for parameterization, multiple copies of a display must be constructed, each making a specific data reference. In the drilldown case, much programmer time could be spent writing code to support the selection and parameterization process if the tools used do not support parameterized navigation.

It is easy to pop up a trend chart showing data variable(s) in real-time. How to develop parameterized displays that can be reused in a variety of situations is the real problem, and is often overlooked.

VI. PERSISTENCE OF REAL-TIME DATA

Real-time data is transient, that is, it comes in and then it is gone when the next record comes in. In order to analyze and present the data in useful ways, each data row must be stored

long enough to operate on it or compare it with previous data. This requires some form of “persistence,” i.e. storage or archival of the transient data.

Real-time data persistence is often confused with database archival. A complete persistence implementation must include archival, but there is a more important function that comes into play with multi-dimensional data.

A. Current Value Table

Much of the real-time data seen in BAM systems arrives asynchronously. When an event occurs, a message is sent and is quickly received and processed. Events coming from different sources may occur at different times and “out of sync” with one another.

When multiple rows of real-time multi-dimensional data arrive asynchronously, there is a problem. For example, if several branch offices are sending events that register new orders, there is no easy way to look at the data from all branches at once. Each data event contains information from only one branch and is overridden when the next event arrives.

To solve this problem, the system needs to maintain a “current value table”, indexed by the columns of data that uniquely identify the source of the data. The index could consist of a single column, such as the Branch, but it could also be a combination of multiple columns, like Branch and Agent. When each data event arrives it is stored in a specific slot in the current value table. In this way, access is provided to the latest data for each uniquely indexed record.

Table 5- Example of a current value table

Branch	Agent	Bookings	Cancels	Failed
North	Mary	4	2	0
North	Sam	4	1	0
East	Joe	0	2	1
East	Bob	1	1	2
East	Mary	2	3	1

It is common to archive real-time data to a relational database (as discussed in next section). However, it is difficult to maintain a current value table by using a relational database. It would be necessary to continuously perform a query against a large set of historical data to determine the latest value for an individual source.

Instead, the ability to construct a current value table in-memory is an important feature of a complete BAM solution.

There are numerous requirements that can make the current value table somewhat complex. For one, objects in the table must be removed when they are no longer active, otherwise the table could grow too large in size. There are also certain applications in which the table must be cleared when switching to a view of a completely independent subsystem.

Some process monitoring applications, such as LABView [9], do provide a current value table, primarily to provide distributed access to current data. The implementation for BAM applications extends this basic concept to include the handling of multi-dimensional data.

B. In-Memory Cache

The current value table efficiently provides access to the last row of data from each indexed source. If it is enhanced to retain more than just the last row – i.e., some limited set of prior rows – it can be referred to as an “in-memory cache.”

Like the current value table, the in-memory cache of prior data must be indexed as well. The length of the cache may be controlled by specifying either the number of rows, or the time range for which storage is enabled.

By its nature, real-time data is time-series data. This denotes a sequence of measurements that are ordered in time. Analysis of such data is performed by plotting the data over time.

A good in-memory cache system provides efficient access to a rolling time window of stored time-series data. This is essential for performing analytics on the data in real-time, e.g., the detection of short-term anomalous changes in trends in order to alert operators to potential problems.

C. Relational Database Archival

Real-time data coming from most BAM sources is in row form, so it seems natural to archive the data in a relational database, using a “historian” process. The advantage of this is that common reporting tools can be used to process the historical data and generate reports.

Archival is also done so that if the program looking at the data exits for any reason, when it comes back, the current state of the data can be retrieved where it left off.

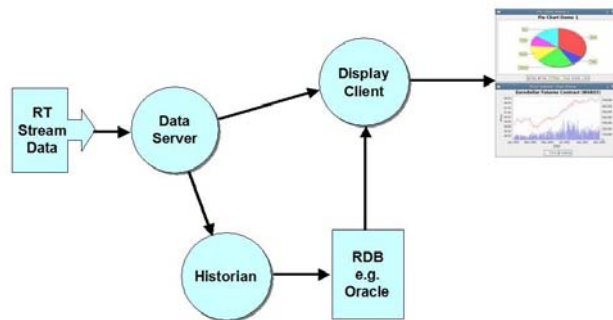


Figure 5 - Real-time data archived in a relational database

The architecture shown above makes it possible to obtain true real-time performance in a Display Client. A Data Server process is used to buffer all access to real-time data. The Historian and Display Client both have direct access to the Data Server to obtain metrics that must be displayed or

archived. The Display Client can obtain archived historical data by making SQL queries from the database.

The in-memory cache provides efficient access to short-term data for analysis, while the database provides access to long-term data for analysis involving longer periods.

One problem with this approach is that relational databases only partially share the definition of the SQL language. It is not possible to perform time-range aggregations on historical data in a way that is portable across all databases. This is another reason for the use of an in-memory cache to perform such functions.

A variation on this is to make use of an OLAP database, especially one that performs time-series functions in-memory. These provide more sophisticated functions for handling time-series data. One drawback is that the syntax for OLAP queries and configuring cubes is too complicated for most users. There are very few OLAP developers compared to SQL developers.

D. Special-Purpose Historian Databases

In traditional real-time process monitoring applications, archival is an established and evolved technology. A number of companies provide special-purpose historian products that specialize in the archival of time-series data. For example, the OSISoft PI System [10] is one of the most commonly used historian databases found in many process control applications. AspenTech produces a similar product [11].

A common feature of these systems is the ability to compress many data points into a single record if the value of the data point is unchanged. Additional options are provided to average out the data primarily to reduce the amount of memory that is required to store large amounts of such data.

The real-time data seen in BAM applications is typically multi-dimensional. The traditional process control historians deal with single point data. This introduces a complexity that makes them difficult to use. Multiple related measures need to be stored together in a single record. The point database does not provide an easy way to do this. As a result, none of these products has emerged to achieve real penetration in this area.

One product that has seen some penetration in BAM is an open source product called the Round Robin Database, or RRDtool [12]. The RRD product also compresses data over time. The simplicity in the way it does this has made it a viable option in some situations. However, it is point-based as well.

Traditional process historians, such as the PI System, have been used for years in mission-critical applications. A full-featured BAM system must include important capabilities found to be essential in these established systems, but must also include support for more complex multi-dimensional data.

VII. ANALYSIS

Analysis and visualization of real-time data are highly related, as analysis performed on incoming real-time data is often part of a visualization process.

Analysis is often thought of as averages, totals, least-squares trend, and the like. These are essential analytic functions and are commonly used. It is easy to put these in place, but BAM requires another type of function entirely. Rather than mathematical analysis of the trends in the data, much useful information can be extracted using simple aggregation and breakdown functions.

The suggestion has been made that BAM is best served by the capabilities of a Complex Event Processing engine. There are valid use cases for a CEP solution, but these appear to be in the higher strata of application complexity, such as detection of fraudulent activities, involving complex time-based relationships and determinations.

In practice, it has been found that the optimal solution for BAM analysis and visualization is a tight coupling between the analytic functions and the graphical objects used to present the results. The functions provide aggregation and breakdown of multi-dimensional data and the properties of the graphical objects directly display the results of the analysis.

The analytic functions are essentially transformations of tabular data from one form to another. A large percentage of the requirements in BAM applications are served by a set of aggregation and breakdown functions in various forms.

For example, an incoming stream of car reservation data is stored in an in-memory cache. All the data are available in a time-series table structure. A built-in time-range aggregation function can be used to transform that table of data into a smaller one breaking down the number of reservations made each day by each reservation agent. The resulting table is fed directly to a bar chart, which displays that important information to users.



Figure 6 - Bar chart showing breakdown in two dimensions

The advantage of this approach is to greatly reduce or even eliminate any programming involved in the development of a sophisticated BAM application. A collection of analysis and visualization patterns is provided. Most of the cases encountered are variations on these patterns. It is simply a matter of specifying a different source for the data.

Some of the common patterns that have been encountered are briefly illustrated below. There are many others, but these are representative.

A. Aggregation and Breakdown – Group By

Just like a SQL Group By, these patterns operate on data tables containing multiple index columns, aggregating the data in various ways. Users can do sum, average, min, max, etc. over all the elements that belong to a certain index column or set of indexes.

There are a number of variations on this pattern depending on the number of dimensions in the index columns and the type of object used to display the data (bar chart, table, area graph, map, etc). A simple one-dimensional pattern is shown below in which the total number of hits on a URL is broken down by incoming IP address.

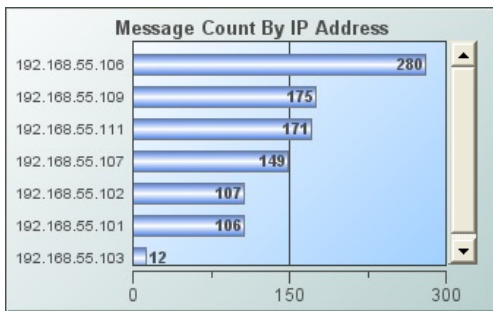


Figure 7 - Breakdown of message counts by IP address

A more involved example is shown in the image below. In this system designed to monitor activity in a Massive Multiplayer Online (MMO) gaming application, the latest location of players and creatures are shown on the map, where the size of the icon represents the relative game strength of each character.

In the bar charts at the bottom, counts of players and creatures are shown broken down by race and class. In the left panel, trends show total activity of combatants over time broken down by type of interaction. Each chart in the display is directly mapped to a table that results from a transformation function applied to the incoming data. Interestingly, the raw dataset for this visualization is the output of a CEP application, performing correlations against real-time events.

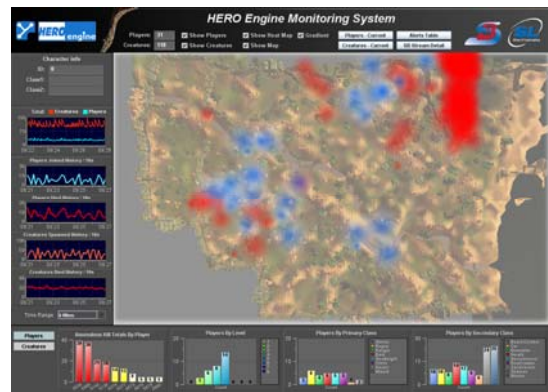


Figure 8 - Gaming application showing breakdown by player and creature classes and activities

It is notable that all of the logic defining the aggregation and breakdown of the raw data is contained in the display definitions. The functions themselves are configured to run automatically within a Data Server, minimizing the load on each client viewing the application.

B. Baseline Trends

Presenting trend charts of real-time data metrics has been around for a long time. In process control or telemetry applications, the technology for displaying these in strip charts was worked out many years ago.

For enterprise-class BAM applications, there are two things that make the trending of real-time data different from what was seen in these earlier applications.

The first has to do with the nature of the trending itself. In most process applications, the process is continuous and may run 24 hours a day. Monitoring of the values is done to ensure that the values are staying within a specific range at all times.

In BAM applications, the data being monitored may fluctuate wildly during the day. For example, the number of messages being processed on a server, or the number of users logged onto a web site at any one time will vary according to the time of day or the day of the week. Of interest is whether the current value of the data lies outside of a typical range for that time period, or its “baseline” (it is not a flat line, but cycles up and down during the day).

Below is shown an example of a baseline trend in which the number of users logged into a site is plotted against a baseline “channel”, i.e., a range 30% above and below the average over the last 4 weeks of data, taking into account the day of the week and time of day.

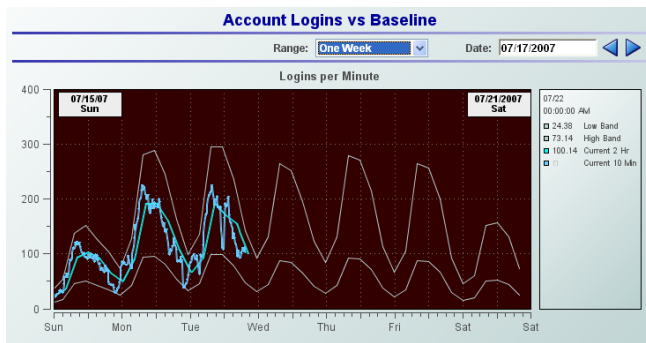


Figure 9 - Example of a baseline trend comparison

The use of a baseline channel is one of the most important ways that real-time business-related data is visualized in a useful manner. Alerts can be configured to fire only when the value of interest goes outside of the baseline channel.

Another area in which real-time business data is unique is in the importance of aggregation along dimensional lines as applied to trends. For example, a system might consist of eight servers processing purchase orders, and you are interested in analyzing the system to provide the best possible response time for users. In this case, it is the total of all messages sent across all servers that is important, not just the total on one server. Automating this process of aggregation along different dimensions, and permitting the user to select all or just one of the servers is an important feature of any business-related metrics monitoring system.

VIII. CONCLUSION

Historically, there has been an interesting evolution in the nature of real-time data obtained in various types of monitoring systems.

Traditional process monitoring and control systems deal primarily with point-based data. Business Activity Monitoring applications obtain data from messaging middleware and other structured real-time data sources, introducing complexities in the analysis and archival of these data. However, many of the requirements for analysis and visualization are similar in both systems.

Important lessons can be taken from traditional process monitoring systems, as these systems have proven themselves in a multitude of mission-critical applications. New technology must be developed to address the requirements of the new breed of BAM application, but companies that have experience in these traditional applications have a leg up on those starting from scratch.

It is often tempting to consider building a Business Activity Monitoring application in-house, but given the wide range and depth of features required, this should be given careful thought. Specific requirements for handling real-time data are often overlooked. Applications that make simplistic assumptions about how to analyze and present data quickly become unwieldy and difficult to maintain and enhance.

Techniques for the in-memory persistence and database archival of real-time data are evolving. Current systems use standard relational databases but are slowly evolving into systems designed specifically for handling real-time multi-dimensional data. In some cases, legacy database systems are adapted to deal with faster real-time data. While this works to some extent, dealing with real-time data is difficult in older environments.

Techniques for analysis are also evolving, starting with standard SQL and attempts at applying stream processing. In practice, it has been found that most requirements are met by a standard set of transformation functions that operate on time-series multi-dimensional cached data.

In summary, to make BAM effective, real-time data must be dealt with efficiently. Relevant information must be extracted from real-time data streams, analyzed, and presented to a variety of users, typically in web-based dashboards or via alerts. Many lessons can be learned from earlier process monitoring applications dealing with real-time mission-critical data.

The important principles involved in developing a successful BAM solution are not dissimilar from those of process monitoring applications that have been established through decades of use, but with a new twist. One could almost think of BAM as a form of “process control for the enterprise”. It is clear that a combination of both old and new technologies is required to address the requirements for analysis and visualization of real-time data in a full-featured Business Activity Monitoring application.

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