# A Vision for the Intelligent Pipeline System and The Role of the Intelligent Engine

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## 1.0 Abstract

According to projections by the Energy Information Administration (EIA), natural gas demand will grow at an unparalleled rate over the next 20 years. These projections indicate growth from the current level of 23 TCF to over 30 TCF by the year 2015. This comes at a time when the industry's prime mover infrastructure boasts an average age of over 40 years; an infrastructure that struggles to meet peak gas demands today. Some of the key issues faced include:

- Shift of business environment from regulated to more competitive non-regulated;
- Indications from industry experts that the U.S. current infrastructure can operate reliably at only 90% of certificated capacity;
- New and challenging operational demands on transmission pipelines, including higher-pressure requirements and widely varying load profile, stemming from the primary growth market segment – power generation; and
- Introduction of non-traditional supply (LNG, Rockies CBM, Western Canada and Alaska) and corresponding challenges with transmission to market areas.

It is interesting to note that both the marketing / planning and the operational sides of the natural gas industry have both made significant progress over the past 10 years, introducing technology and business processes to effectively meet many of the challenges presented by the changing landscape. From a marketing and planning standpoint, these include real-time nomination systems; forward looking demand and systems planning models, and real-time pipeline simulation and scenario models. From an operational standpoint, these include extensive microprocessor based controls, asset management programs, condition based and/or reliability centered maintenance programs, and real or near real-time gas control.

However, the author suggests that the pipeline industry, with all of these advanced technological capabilities, has yet to fully leverage the real underlying potential to bring the kind of value at the system level that will be necessary to meet the challenges of the coming decade. These challenges are not fundamentally about mere technology. They are challenges that require radically new ways of thinking; they are knowledge problems. Technology must be part of the knowledge vision and solution, but is not the solution itself.

This paper explores the need for a knowledge vision characterized by the need for "Intelligence." It presents key concepts regarding system level thinking versus component level thinking. It challenges the assumption that technology is the answer. It begins to define and describe at a conceptual level "Intelligence." Lastly, it presents an analogy that paints a picture of what intelligence looks like in action.

## 2.0 Concept Introduction – Necessary but Not Sufficient

In the book entitled "Necessary But Not Sufficient"[i], author Eli Goldratt makes the bold claim that technology is necessary but not sufficient. The book, a Theory of Constraints Business Novel, delves into the ERP software and implementation industry to paint a picture of how technology, with all of its features, functionalities, bells and whistles, is necessary, but not sufficient. Technology is necessary in that it is essential to meeting the demands of the modern, fast moving, global enterprise that feeds on data and information from the entire organization and yet not sufficient in and of itself to drive enterprise value; true system level value that not only helps, but fuels the realization of the most fundamental business goals and objectives.

The novel is an extension of Goldratt's work on the subject of Theory Of Constraints (TOC) wherein the fundamental challenge of every complex organization is to move from overwhelming levels of complexity to what the author defines as "inherent simplicity." The concept is that the more complex the "system" or organization, then the more profound is its inherent simplicity, for there can only be a relative few real constraints that impact virtually the whole system. It is in this fundamental reality that inherent simplicity lies and real focus is found – hence the subject name "Theory of Constraints." Furthermore, the author proposes that value is found in exploiting these constraints, subordinating everything else to the constraints to move from it being a constraint or liability to being a strategic asset.

Another very insightful and useful concept from the author's work regards the contrast of system optima with local optima. Goldratt emphatically states in all of his work that one of the most impactful issues facing the enterprise is the pervasive focus on local optima; that is the focus of groups, departments, elements, components of the enterprise on achieving local optima in their particular area of control. In so doing, Goldratt suggests the real goal – system optima – cannot be attained nor is even truly being considered as a result of the rules and metrics that are put in place to ensure local optima. In another of his works – "The Goal" – Goldratt very simply asserts that the goal of the organization is to maximize "throughput", minimize operating costs and minimize inventory. In so doing, the organization maximizes profitability. So, the goal has everything to do with the productivity of the system and not the local optima of the components of the system.

## 3.0 The Gas Pipeline Industry – A Time of Change

The gas pipeline industry, in fact the energy industry, is in a time of great change. At a macro level, our nation and the world exist in political tension between entities possessing natural reserves of energy and those most needing it. In our nation, a grand struggle is playing out regarding the right mix and balance of energy sources, taking into consideration matters of national security via dependency on other nations, political and economic pressures from the most influential factions, environmental concerns, labor market concerns, regional, state, and local interests, the list goes on.

Even within the gas industry, projections of tremendous demand growth over the next 20 years, from 23 TCF to over 30 TCF, have collided with the harsh realities of supply and infrastructure limitations. Currently, the topics under fierce debate include issues like how to tap the vast Alaskan gas reserves, and how many and where to locate LNG terminals that extend supply to stranded energy assets worldwide. The words uncertainty, change, energy and natural gas are more often associated now than perhaps any time in recent memory.

The transportation sector is certainly not exempt from the impact of these major issues and challenges, as it finds itself between two very significant sets of challenges. On one hand come pressures to swiftly respond to market demand signals calling for rapid expansion and new infrastructure; on the other come painstaking new regulatory requirements that make it difficult to build such infrastructure, as well as to achieve and maintain compliance with its existing infrastructure. Both require significant capital expenditure plans over prolonged periods of time. The combination makes it difficult to properly focus on the challenges that each represents.

What is of growing concern to a relative few industry insiders is that, while issues like these consume precious management attention, somewhere lost in the background noise is a serious question about whether or not the current infrastructure has the ability to deliver at its assumed and rated capacity when called upon to do so. Past years have seen substantial increases in average system utilization rates and load factors, as well as the number of historically recorded peak delivery days, and yet, the industry as a whole has still yet to operate for any length of time within the 80+% utilization and load factor range. Several industry representatives, representing both owner / operators and consultancy, have publicly stated that the current infrastructure may only be capable of delivering 90% of rated capacity. This author cannot confirm nor refute such statements, however, asserts that with the projected growth in demand, the uncertainty and unfamiliarity associated with the operation of the current infrastructure at or near rated capacity must be addressed.

## 4.0 Complex Systems and "Optima"

As with any complex or multi-component system, the closer the system is to operating at maximum "design capacity", the more susceptible is the system to constraints and bottlenecks that prevent reaching that level. These constraints and limitations include a myriad of factors including off optimal performance, faults and failures, external factors and unexpected conditions outside of the sphere of control. The basic laws of supply and demand reflect these phenomena with respect to value and price increases that begin to exponentially increase as capacity approaches maxima. In fact, this is one phenomena that actually comes into play in shortage situations on the coldest winter days in the northeast, as gas price spikes have reached upwards of $50 / MMBTU.

Also true of complex or multi-components systems is the very real possibility of artificially and unintentionally constraining maximum capacity via the use of compounding buffers and / or safety margins (operating rules, procedures, limits, thresholds) on individual elements of the overall system. In the world of "Theory of Constraints", this phenomenon has been referred to as "striving for local optima." In essence, when buffers and safety margins are conservatively set for each element of a system so as to protect the whole system, compounding occurs. For maximum system capacity, performance or reliability, "striving for local optima" is often in direct conflict.

When the goal is to maximize throughput and thus transportation revenue and do so at the minimum total transportation cost, it is the system, not the individual elements, that must be the focus. Furthermore, it is the constraints and bottlenecks of the system that are of greatest concern, not the efficiency and utilization of each individual element. System capacity / throughput is a function of the weakest link in the chain – the bottlenecks. Therefore, the strategy becomes to absolutely maximize the throughput of the bottleneck(s) and everything else must be subordinate so as to exploit that constraint.

## 5.0 Current State of Technology – Pipeline Industry Overview

Technology has played a vital role in the evolution and growing sophistication of the gas pipeline infrastructure. While it is fair to say that the pipeline industry is not on the leading edge of technological advancement, this mature industry, like many mature industrial segments, continues to embrace evolutionary technologies at a steady rate. Let's take a closer look at the current state of technology in a few key areas of interest to the topic of "Intelligence."

### 5.1 Controls and Automation

Microprocessor based controllers, whether falling under the heading of programmable logic controller (PLC), PC based controller, remote terminal unit (RTU), or just plain controller, have become commonplace in the pipeline industry. This is not to say that microprocessor based controllers can be found on every engine or turbine in the industry, as a significantly large percentage of the population of such equipment has yet to be equipped with modern-day controls and automation. However, with the onset of automation in the pipeline industry approximately 30 years ago based on Motorola chip RTU technology, the adoption of microprocessor-based controls produced by leading players including Rockwell / Allen Bradley, TI – Siemens, GE, Bristol Babcock, and numerous others is now widespread.

Of equal impact is the utilization of controls and automation beyond the unit level, including growing sophistication at the station level and the SCADA and system levels. Today, most every large interstate pipeline company possesses automation and controls infrastructure that is mature in comparison with that of many other similar transportation market segments in the U.S. The pipeline industry employs technologies that follow the evolutionary path of communications technology over the past 30+ years, from hard copper lines to microwave, to LAN / WAN, to satellite, and now including cellular technology. With interstate pipeline systems that include assets spread over tens of thousands of miles, the pipeline industry has fully embraced the necessity of a well-connected infrastructure.

As with the growing sophistication of technology in many industries, however, the pipeline industry has yet to fully realize the potential of such capable technologies. At the compressor station level, with the exception of newly installed equipment and equipment that has been highly upgraded in the past several years, most controls and automation of the past several decades has focused on simply replicating and replacing the functionality of pneumatic and analog controls of the past. At the pipeline system level, technologies have been employed in a silo-like manner, each attempting to address unique challenges within a certain discipline. While this approach has delivered benefits in reliability and availability that are not to be downplayed, the real power of the technologies employed is merely operating at an idle state.

### 5.2 Gas Planning / Control

The past ten years have seen significant progress in the areas of gas planning and gas control. Specifically, pipeline companies and software vendors have invested significantly in advanced modeling tools, moving from steady state hydraulic models to a number of additional tools that include transient models, forecasting and optimization tools, and "intelligent" software that assists with decision making based on complex and diverse business factors.

As an example of such progress, Tennessee Gas Pipeline has developed and presented to industry its "Expert System" referred to as the "Proactive Controller's Assistant" or ProCA.[ii] This system is built on a platform from Gensym called G2, a comprehensive, object-oriented environment for rapidly building and deploying real-time expert system applications that dramatically improve complex business operations. In effect, TGP imbeds operating knowledge in the system in the form of rules and procedures. Information is then added to the knowledge base on a continuous basis, resulting in a dynamic and constantly improving system that aids not only gas controllers, but also marketing, measurement, and transportation planning. Functionally, this systems assists with alarm management, pipeline efficiency, reliability, fuel efficiency, development, documentation and education, real-time volume balancing, unit operating efficiency and data integrity.

### 5.3 Asset Management

Five to ten years ago, "asset management" was quite the buzzword in the pipeline industry. Implementations of packages like Maximo, the leading MRO and asset management software platform, were numerous. Other providers included Avantis, OsiSoft, Endus Passport, and many more. Regardless of platform, pipeline companies raced to implement asset management programs that promised improved business efficiencies, reduced inventories, enhanced compliance capabilities, streamlining of business processes, reduced cost of O&M, and improvements in reliability. The list of buzzwords entrained with this wave include, but are most certainly not limited to:

- CMMS – computerized maintenance management system
- AMS – Asset Management System
- EAM – Enterprise Asset Management
- CBM – Condition based maintenance
- RBM – Reliability based maintenance
- RCM – Reliability centered maintenance
- PM – Predictive or preventive maintenance

Today, nearly every major pipeline company in the U.S. has an asset management program and software platform in place. The extent to which pipeline companies utilize this program and platform, however, varies widely. For many if not the majority, these platforms act as a glorified preventive maintenance (PM) task managers, providing reminders and serving as a database for information about what needs to be done and when, then capturing the information to be used for reporting and documenting compliance. A few companies have leveraged more of the capabilities of their asset management platform / program to realize some of the purported benefits of streamlining business processes and reducing inventory, etc.

### 5.4 ERP / ERM Systems

The past 10 to 15 years have seen dramatic shifts in corporate business infrastructure, from the world of VAX mainframe applications through the transition of client-server applications still leveraging the mammoth mainframe databases, to the new world of enterprise resource planning (ERP) and enterprise resource management (ERM). This is true of all large industrial enterprises, not only energy industries. It is safe to say that this transition is still underway. The major players in this game include Oracle, SAP, JD Edwards / Peoplesoft, and many more. The cost and complexity of these organization pervasive software implementations is nothing less than enormous. The challenges and issues are much the same.

The beauty of ERP / ERM platforms is the power of what is characterized as "one big underlying database." Theoretically, data and information is available to any and all applications that a user might need across the entire organization. These platforms include very extensive reporting and analysis capabilities that make accessing data and information theoretically like sending and receiving email – easy and fast. Providers and implementers of such technologies purport cost and effort savings from streamlining, waste reduction, inventory reduction, transaction cost reduction, the list goes on.

The experience of most organizations who have implemented or are in the process of implementing is a bit of a mixed bag, however, one thing commonly expressed is the pain and disruptiveness of the process, as well as (at least) the initial disappointment of what could actually be done versus what was indicated or promised could be done. Perhaps this is just an issue of the learning curve for adoption of anything new, especially new technology. Perhaps there is a bigger underlying issue regarding the need and value of data versus information leading to knowledge.

## 6.0 Question: Is Current Technology Sufficient?

It seems evident that the pipeline industry has, in fact, employed advanced technologies: sensors, controllers, communications technologies, modeling technologies, advanced software platforms, etc. Yes, the pipes are connected and mega amounts of data are flowing on a continual basis. In many cases, however, there is too much data and not enough information and knowledge; there is a lack of integration of multiple "silo" systems; there is insufficient focus on exploiting the power of the "network" that exists to achieve substantially greater system level impact. These technologies play a vital role in minimizing or eliminating limitations, however, do not guarantee that the desired value, much less the full capability of the technologies, is truly realized.

Why? Goldratt suggests, based on the theory put forth underlying the concept "Necessary but not sufficient" that removing physical limitations of technology is not enough. The limitations, even when removed, are still there; they are there because the ***rules*** that were developed to operate effectively under such limitations ***keep them alive***. Furthermore, adding (new) technology to address the limitations often presents another sizeable distraction and obstacle due to unfocused pursuit of more data and information in lieu of addressing which rules acknowledge the limit we are about to or have already diminish(ed). They must be rewritten or abolished in order to substantially realize the progress that is possible.

In the process of conducting research for this paper in other leading non-energy industries, an interesting quote was found in a vision document developed by the "Integrated Manufacturing Technology Initiative" wherein Intelligent Control received an immense amount of focus.[iii] The statement follows:

> ***"The state of the art is far more advanced than the state of practice"***

Well said! In fairness, however, will this not always be the case? Look around your office at the technology gadgets at your fingertips and think about the value you realize from them versus the full potential of the technology. A gap always exists. It is inevitable.

Consider Moore's Law, initially a forward-looking prediction that emerged as the guiding light for the computer microchip industry. Moore's law stated that the transistor density on integrated circuits doubles every couple of years, driving growth through ever-shrinking transistor size, exponential increases in processing power and dramatic decreases in cost. Technologically, this law has well described what has happened over the past 20+ years with microchips. However, business and technology experts alike point to the fact that such rapid technological advancements have moved at such a pace that only the most sophisticated user can keep up with, appreciate, discern, and realize the benefit from the technological advancements.[iv] Less savvy users simply cannot change and adapt their "rules" at such a rampant pace.

To illustrate the point, consider comments from an article entitled "Asset Management Opportunities"[v] from a recent edition of Pipeline and Gas Technology, the author describes what he calls "cognitive myopia" in terms of how we, as humans, deal with risk and uncertainty as characterized by the tendency to:

- Anchor on readily available information
- Let recent events that are vivid in our memory unduly influence our judgment
- Overweigh information that supports our point of view
- Fail to recognize implicit assumptions
- Suffer from high sensitivity to the way facts are framed and presented
- Underestimate rare events and their risks (being ill-prepared for their potential occurrence)
- Overestimate dramatic events and overpay to mitigate their risks
- Have extreme aversion toward risk
- Suffer from context effects when choosing among risk options
- Have excessive confidence in our ability to predict the future and fail to consider alternatives sufficiently
- Exhibit an undue dislike for ambiguity

The author is speaking within the context of information technology in the energy industry. He states that "most energy companies tend to be drowning in data…" and that the situation will likely get worse due to the excessive demands for data and information and the relative low cost to acquire it. He also points out, however, that "the differentiating factor for energy companies is in the ability to process the data and extract valuable insights and knowledge out of it" and that information technology is only a mechanism to help facilitate this objective. Also important is the fact that the challenge of "integrating" humans and machines for optimal results has yet to be solved.

## 7.0 Intelligent Pipeline System – Intelligent Engine

### 7.1 Definition

So, what does "Intelligent System or Engine" mean? The word "intelligent" evokes images of unmanned air or space flight or artificially intelligent robots that adapt to their environment. To understand what is meant by "intelligent", let's start with Webster and some of the key phrases included in the definition of the word. These phrases include:

- ***To understand***
- Revealing or reflecting ***good judgment*** or sound thought
- ***Quickness in perceiving and understanding***
- Success in ***coping with new situations*** and ***solving problems***
- ***Promptness in finding answers***

Certainly, the popular use of the word in industrial and technical circles often relates to artificial intelligence (AI) and (self) learning systems. These are certainly key aspects of what the author suggests. However, a key difference regards the context within which the "engine" operates – the "pipeline system." Much attention has been paid to concepts like optimization, which also are key attributes of "intelligent", but of what? Of the engine?

As discussed in section 4.0, the real goal of pipeline owners / operators is not to optimize performance or reliability of engines; it is to maximize throughput revenue and profitability of the pipeline system(s) while minimizing the operating costs of such systems. So, the intelligent engine has, as its highest calling, to contribute its intelligence to an intelligent pipeline system to attain the highest good.

So, what is intelligence within the context of "Intelligent Pipeline System" or "Intelligent Engine?" What is meant by the term "Intelligent Control"? In a paper by Jim Albus of NIST, intelligent control systems are defined simply as those able to operate in uncertain environments to increase the probability of success.

### 7.2 Basic Elements

Let's examine some of the basic elements of "Intelligence":

- **Advanced / Intelligent Sensors (and actuators)**
  Sensors are key enablers to intelligence. Sensors can be physical or virtual in nature. Intelligence must be built into sensors to incorporate processing, direct communication to other sensors and actuators, self-diagnostics and self adjustment to compensate for health and wear. Sensors must also incorporate wireless technology to eliminate cost and complexity of hardwiring. Advances are needed to support "Sensor Fusion" wherein multiple sensors are integrated for processing and communication, and incorporation of sensory input into intelligent actuators that make decisions locally.

- **Real Time Access to Information**
  Every function of enterprise should have real-time access to information it needs to execute its function and meet its objectives. Knowledge and information is not the same as data. Information must be timely, representative, accurate, and relevant. Information comes from distillation of data. Knowledge is built and refined by leveraging models with process information. This process has been referred to as "Data Fusion".

- **Adaptable, Self-Evolving Model-Based Planning and Control**
  Transformation is needed to move from a simple "models" based on empirical correlations and coefficients that are representative over relatively narrow windows to science-based (first principles) and heuristic models with built-in self-learning capability. Models should effectively and accurately represent how system and components should behave and perform over the full range of operation, including known upset conditions. For highest value, models must be compared to actual performance information, not just indicating parameters and empirical correlations, which cannot accurately reflect the current state.

- **Model Based Fault and Failure Prediction, Prevention and/or Mitigation**
  With an underlying base of continually learning science based and heuristic models, systems must utilize advance diagnostic and prognostic technologies and techniques to compare models with actual information to indicate current health and detect failure trends. Further, systems must trigger appropriate action including self-healing, alternative strategies, alarming and call for human intervention, and interaction with maintenance management scheduling.

- **Reasoning & Adaptation**
  Intelligent systems must include strategies, rules, reasoning / cognitive tools and other high-level decision support elements that permit the control system to optimize the process in response to new or differently weighted parameters; to adapt to change, especially to conditions outside the norm. Systems must provide intelligent alarm handling and expert advisory feedback / options / recommendations.

- **Decision Making and Task Decomposition**
  Planning and decision-making must consider control parameters and actual state of performance and health. System and components must interact to negotiate adaptations to best match process demands and respond proactively to external events. Intelligent systems must provide advanced tools and technologies to solve the challenge of effectively integrating humans and machines, recognizing the role and value of each, for optimal results and assured performance / reliability.

Notice that intelligence is not a thing like an advanced sensor, a more powerful controller, or a better algorithm. Intelligence depends on such key components, but goes well beyond just technology. Intelligence is built on a strategy of well-thought integration of technologies, but is fundamentally rooted in a vision about knowledge.

### 7.3 Analogy – The Living Organism

In the typical world of controls, automation, and IT, we use architecture diagrams to see how all of the pieces and parts fit together, what is connected to what, and how data flows. To visualize the architecture of the intelligent system and intelligent engine (components), however, we must go beyond connectivity diagrams to understand what the role and functionality at each level are and how they interact and behave together within the overall system to achieve system level objectives. To best illustrate what intelligence looks like in practice, let's consider an analogy in the biological world – the organism.

The living organism intimately knows its actual state, both as a total organism and at every cellular level within the organism in real, not pseudo terms. As well, the organism knows what it is capable of doing based on a detailed understanding of what each and every cell is capable of under both ideal conditions and real (present) ones, which may be different.

The organism is capable of planning, operating and maintaining itself at all times, all of which require understanding, interaction and coordination with all of the other high level functions. All knowledge needed for each "silo" function is known and usable by every other function, and is in fact used to make the best decisions in each and every area all of the time.

So, the organism can plan based on not only what is theoretically possible, but what is really possible at the present moment considering all factors regarding health and external factors. The difference between these two possibilities may include either net decreases or increases in performance, as health affects to the negative, but conditions also exist allowing exploitation of opportunity as well.

The organism continuously communicates with each cell within, providing high level direction and instructions that allow the organism to accomplish its desired performance; the cells work locally to play their role, whether asked to perform at peak or at near dramatically off optimal levels, but as efficiently as possible, for the sake of the whole organism.

Cells continually communicate with the organism, letting it know how it is doing presently, as well as any indications that there may be changes upcoming based on early signs or hunches. A dialog takes place between the organism and the component about what to do and when to do it, if anything, to meet both the current and future (anticipated) needs as best can be determined. The organism gives flexibility as it becomes possible and prudent to do what needs to be done at the cellular level to do its own repair and healing, with continuous progress monitored so that no potential is wasted.

The organism is continually in a state of knowing; knowing its present state; knowing its possibilities, even its reach capability if called upon; knowing its health, both now and what appears to be in the near future; knowing how to best do what is needed or requested of it.

You might say that this illustration is not far from how things work today. If the organism is the organization and cells are departments, groups, people, equipment, etc., then there is certainly a similarity. However, is it not a stretch to believe that the system of cells in an organization really operate like a unified and completely integrated organism. The difference is the veil of separation that exists between each and every cell with not only every other cell, but also with the whole system. Never is anything fully known outside each individual cell. What gets past the veil is heavily filtered by "local" rules, policies, practices, and preferences, much of which is focused on serving the good of the cell.

Certainly this has happened for good cause, as how could a system of numerous cells actually handle "data" pouring out of all of its cells without local rules, policies, procedures, etc.? It would be chaos. But, technology now provides the means to remove many of the limitations of rules that were needed in a time when information flow required high levels of human processing and interpretation.

The difference is not real time data or even information, although these are key parts of the infrastructure, but real time knowledge. That is real time in-depth resident understanding of information, not only of what is currently happening, but what is doable, really doable right now and in the near future. Perhaps intelligence is really this – in depth, resident, accessible on-demand knowledge; knowledge of what is, knowledge to understand why it is, knowledge to determine what could be, and knowledge to (help) make decisions to achieve it.

## 8.0 Knowledge Vision

Data. Information. Knowledge. This progression is the key to understanding the evolution, in fact the breakthrough, from our current definition of state-of-the-art to the realization of the intelligent system. The fuel that will propel this evolution is not technology but a clear and compelling knowledge vision. Technology will continue to be a primary enabler. A powerful vision for knowledge, its value, its purpose, and its utilization will unlock the door to greater realized value of technology and hence greater value from our "systems".

This vision must go beyond the level of rhetoric, of perfectly crafted semantics. The right knowledge vision must paint a clear picture of the role knowledge will play in: 1) identifying the most fundamental and causal constraints and limitations of the enterprise, 2) exploiting those constraints and limitations to transcend the current reality, and 3) enabling and driving the enterprise, through leveraging knowledge to unexpected levels of performance and capability. The task is both incredibly complex and inherently simple. Powerful visions most often are.

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[i] Goldratt, Eliyahu M., *Necessary But Not Sufficient*, North River Press, Copyright 2000.

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[iii] "Intelligent Controls for Continuous Processing, Integrated Manufacturing Technology Roadmapping Project", IMTI, Inc., 1999-2000.

[iv] Christensen, Anthony, Roth*, Seeing What's Next – Using the Theories of Innovation to Predict Industry Change*, Harvard Business School Press, Copyright 2004..

[v] Jabbour, Dr. Salim J., "Asset Management Opportunities – The ability to extract good information from overwhelming data helps facilitate improved decisions", PipeLine and Gas Technology, July / August 2004, Hart Energy Publishing, LP.