Effective Control in Peopled Systems

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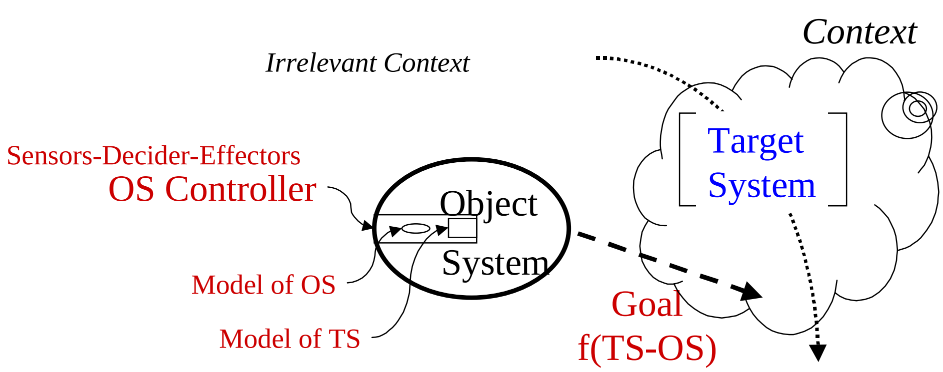
Abstract. This paper suggests approaches to and guidelines for installing, instilling and inspiring control in peopled systems. These guidelines apply to mission systems, to the projects that produce mission systems and to organizations which determine the competencies and culture of the project teams. With the right control peopled systems can be highly efficient and highly innovative, simultaneously.

A REVIEW OF CONTROL TERMINOLOGY

James Watt's simple flyball governor has been cited as the trigger of the industrial revolution. Later, Norbert Weiner's cybernetics triggered an era of increasingly larger and more effective information and control systems. Although abundant literature exists for designing systems composed of hardware and software not much literature exists regarding control in, of, and by systems that depend on people. The people factor is significant because non-peopled systems are generally state-determined and predictable whereas peopled systems can exhibit quite surprising behavior.

For context, Figure 1 illustrates the ontology of control for regarding the scope of this paper**.**



OS	Goal	TS
Missile	Intercept	Aircraft
Aircraft	Safe transit	Airspace
Salesman	Sell Aircraft	Airline
Proj. Mgr.	Reward	Project Completion
SE	Reward	System Effectiveness

Figure 1. Ontology of Control

A Target System, TS, is moving through a coordinate system. The coordinate system may be spatial, temporal, gravitational, or any combination of these and other forms. An Object System, OS, located in the same coordinate system, seeks to achieve a specified relationship with TS. This relationship specification is the OS Goal that the OS seeks to achieve. For example, the goal may be to detect the TS or to describe the TS or to measure the TS or to shadow, pace, intercept, displace or collide with the TS. In addition to pursuing a relationship with respect to the TS the Goal may be concerned with causing the OS to morph into a different form or structure such as increasing the rate of OS operation, mimicing the TS or becoming invisible to the TS.

The OS has Context which consists of the TS and of other pertinent relationships and entities including distubances to both TS and OS. The OS has Other_Context which consists of all the stuff that doesn't make any difference to achieving the Goal. Finally, the OS has Control in the form of one or more controllers which may be within, partially within or outside the OS. The purpose of the Control is to achieve the goal regarding either the TS-OS relationship or the OS content, structure or behavior.

MODEL-BASED CONTROL

Higher performance controllers contain a model of the system to be controlled. For example, the operators of an crude oil refinery use a process control system to maximize refinery output. Such process control system measures temperatures, pressures and flows at more than 150 locations throughout the refinery. The control system then decides which situations need to be adjusted and makes the adjustments in the right sequence. This occurs several times per minute. The control system contains a model of the refinery that consists of several hundred equations which represent what happens to crude oil under a program of temperature and pressure with specific catalysts present. The process control system, by solving these equations often enough, can control the proportion of gasoline, kerosene, heating oil, and other products extracted from each barrel of crude. Further, when the market changes the demand for gasoline vs. home heating oil, management can easily respond to by changing the set points in the process control system. The system, in turn, will cause the desired ratio of output products to change.

.Note that real process control focuses on results as well as the process that produces the results. Although the process is the subject of control the results are the object of control. This is an important distinction because much current literature regarding management, business process reengineering, systems engineering standards and capability maturity emphasizes process without relating process to results and outcomes adequately.

So much for an oil refinery. How does a manager make an organization highly efficient and highly innovative? By bringing that organization under control, toward specific goals, with a controller that contains a model of the organization as a system. Such controller will measure orders, inventory, employee enthusiasm, resource utilization levels, inventory levels, cash and numerous other variables. It will decide which are mutually consistent and which are out of bounds. It will make adjustments to the business rules to bring the organization to a state that causes its outputs to meet expectations.

Bringing a team, project or organization under control requires a mental model of; work products, events; and activities as well as a model of how activities are supposed to transpire and the roles, responsibilities, and authorities for making it all happen. Additionally, that model must have high fidelity with the real world. Quality management guru, Phil Crosby summed it up best, “As the organization grows the leader finds it harder to know what is going on and nearly impossible to know what is not going on.” In fact, the only way a leader can detect what is not happening is by having an *a priori* model of expectations and a report-by-exception scorecard. And hueristics indicate that these become pertinent by the time the team reaches as few as fifteen people.

Dynamic Stability: Helicopters and hummingbirds are instructive examples. Both have dynamic stability. When aerodynamicists declared that the hummingbird could not fly they had not yet understood dynamic stability even though many of them had been riding bicycles for years. Like a hummingbird a helicopter is both stable and maneuverable because it has a very effective control system. In fact, a high proportion of the cost of a helicopter is the cost of its controls.

Dynamic stability applies in peopled systems, as well. Under a control system capable of producing dynamic stability peopled system can achieve high levels of stability and maneuverability simultaneously. A dynamically stable project can outperform ad hoc projects or rules-driven projects or competitor-mimicing projects which emphasize benchmarking and best practices. Further, the project can progress from seeking tactical goals to seeking strategic goals to seeking self improvement goals. Some even achieve the ability to perform as distributed, virtual, collaborative projects.

Controller Content: A controller is made up of four basic subsystems (Bateson 1993):

1. **Sensor.** Measures and reports state of assigned variables.
2. **Evaluator.** Collects sensor data and, using its OS-TS model, interprets all sensor reports for maximum likelihood representation of the TS-OS situation. Selects appropriate criteria for mission/objective/goal of OS because the applicable

criteria may depend on the perceived situation. Performs mensuration or applies judgement to ascertain degree of gaps between situation and criteria
3. **Decider**. Assesses significance of gaps. Performs Root Cause Analysis to identify the sources of and/or reasons for the gaps. Decides what changes may be transpiring in the TS. Decides what changes are desired in the TS-OS relationship. Decides what changes are desired in the OS. Selects most appropriate effectors of the changes. Updates the TS-OS model. Commands a scenario of effector actions. Actions scenarios are limited by design -- primarily to minimize cost. Typical action scenarios are; bang-bang (as in the household thermostat), proportional or PID (as in HVAC and most industriall process control) and Goal-seeking (as in air-air missiles, orchestras, race teams and agile enterprises.)
4. **Effector.** Make and verify changes to the variables each control. Does not verify that desired OS-level behaviors resulted. That must await the next cycle of sense-evaluate-decide.

Effectiveness factors: If more resources are dedicated to control of operations then the operations may become more efficient and more maneuverable. However, there are limits. The expense of added control begins to offset the value of incremental improvements in system performance.

The initial and on-going cost of control is largely determined by the competency of the control system developer when designing the system. At least five factors must be balanced: objective of control, variety of behavior exhibited by the TS, method of maintaining the OS-TS model, inertia of the OS (due to size, complexity, and fear), contextual disturbances and disturbances internal to the controller, such as failures.

The factors affecting the effectiveness vs. cost gradient are:

1. **Model Fidelity:** The controller is not dealing directly with the physical world but with a model of the physical world. Accordingly, the performance and even integrity of control is directly dependent upon the fidelity of the TS-OS model relative to the real world OS and TS. Although obvious in electromechanical control systems, this fundamental is often overlooked in peopled systems. Hardly any organization has a high fidelity model of their business development process, system design process, development process, etc.
2. **Acuity:** The degree to which the process control system can sense or know about all the events and conditions throughout the system under control. Design decisions must include granularity, discrimmination, and coverage
3. **Latency:** The time delay between and event and the control system cognizance of that event. The dramatic effect of latency is described in (Senge 1994). For example, businesses are making current investments in systems for Data Warehousing, Data Mining and Balanced Scorecards. Although many of these investments produce previously unknown and sometimes startling facts about the users market, customers, production, people, etc. these reports are using data that was true 30 to 90 days earlier. As W. Edwards Demming remarked, “That is like trying to drive through Tokyo in rush hour using only your rear view mirror.”
4. **Accuracy:** means how closely the process control system can adjust the outcomes to the desired conditions. A significant factor in accuracy is the fidelity of the model contained in the process control system software relative to the real world it is supposed to represent. This is why model fidelity is a measure of management effectiveness.
5. **Power:** The power level of effectors vs. inertia of the system being controlled.
6. **Distance:** The separation, in time and space, between the actual operation and the controller. Distance may be secondary but greatly affects acuity, latency, and the accuracy of situation assessments.

CHOICES OF CONTROL OBJECTIVE

The control systems engineer must be very clear on the objectives of control. Beyond open-loop or ballistic systems in which no control is exercised after the system is put into operation there are at least five distinct categories of control objectives.

Homeostatic: Seeks to maintain a variable at a constant state despite changes in other variables. Model is simple and static. An examples are: human body (OS) temperature at 98.6 regardless of external ambient temperature (TS). House thermostat set at X. Customer is always right. Featherbedding by unions. The relative cost is Low.

Pursuit: Seeks to achieve a specified relationship to a target system regardless of changes in the relative location of the target system. Model of TS is simple and of OS a little more comprehensive. Model must be updated as often as the situation changes. Examples are: dog chasing car, smart bomb, house "setback" thermometer, and new product/process development team. Relative cost is Medium

Goal-seeking: Seeks to improve performance in the OS pursuit of a TS and simultaneously direct the evolution of the OS into a more effective pursuer. Model is more comprehensive than in the pursuit case and is updated in strucuture and well as situational data. Examples are: variable suspension on automobiles, aircraft changing speed or altitude during turbulence, staffing a project based on the risks to be mitigated instead seniority, and changing your normal persona when talking to your boss. Relative cost is High.

A Goal-seeking System, GSS, consists of; a **goal** that orients the system or gives it purpose, a **trigger** that causes the system to function, .**competency** that informs the system on what to do, **energy** that enables the sysstem to do it at the required rate, **statusing** that objectively assesses the gap between the system state and its goal and **feedback** (acutally, feedforward) that causes the system to direct its competencies and energy toward closing the gap (Livingston).

A GSS goes beyond Pursuit control by additionally changing OS structure and content. A GSS can even change the context that the OS will acknowledge in the future. Two subtypes of GSS that are emerging with the complex, adaptive systems movement are:

Autopoietic: Seeks to expand envelope of control by changing internal structure of OS to better cope with dynamics of TS and intertia of OS. Examples are: factory changeover for new model year, adding objectives for supplier satisfaction and employee satisfaction in addition to customer satisfaction, changing design team makeup as new challenges are uncovered during a project, and open book management. Relative Cost is Very High but trending to to Low

Autocatalytic: Seeks improved performance of OS mission through proactive collaboration with other systems. Includes modularizing and distributing the OS for multiple but orchestrated interaction with the TS. Examples are: formation flying (vs. solo dog fighting), a wolf pack, a kieretsu, a clique or a club. The more advanced forms of web-enabled eBusiness, beyond eCommerce, tend toward autocatalytic. Relative cost is Very High but trending to Low.

TRI-PURPOSE CONTROL

Peopled, goal-seeking systems embody a tri-purpose controller in order to accommodate the variability of the TS system as well as the content, structure and behavior of the OS. These three purposes are Operations Control, Supervisory Control and Alignment Control.

Alignment Control sets the stage and all three collaborate to follow the rules for sustaining dynamic stability or for ringing the alarm when the behavior of the TS gets outside the OS's envelope of operational capability. Supervisory control coordinates or orchestrates the individual operations controllers which are concerned primarily with nulling variances from planned operations.

A peopled GSS involves double-loop learning. It not only learns how to pursue the goal even if the TS is evasive or the OS is recalcitrant but also learns how to learn. This is important to peopled systems in general and to those desiring to perform world-class systems engineering in particular. For example, a practitioner (lawyer, doctor, or musician) is not marked solely by his domain of knowledge but also by his ability to apply ascending levels of behavior to the needs of his clients, in this case the TS. (Schon 1987). An advanced practitioner has two kinds of knowing; objectivist and constructivist (world making) and excels not only in familiar situations, marked by the routine application of facts, rules, procedures, but also in unfamiliar situations, marked by the the practitioner not only recognizing givens but also discerning "what is going on, here."

Design Reviews: The well known activity of a design review makes a good frame of reference for putting all the foregoing into one picture. There can be several ways of doing a design review (when or how often? how thorough? against what checklist? with formal discrepancy reports,? is complete when the discrepancies are found or when they are closed?). The "best" flavor may be different for each project. But above the level of accomplishing some flavor of design review there are further considerations.

After the discrepancies are found and communicated, some companies take the trouble to reflect and learn from Design Reviews. They ask the question "What was the root cause of each discrepancy?" and require the answer before moving on to the next phase of the project (because the answer typically reveals a systemic problem which discovery can be used to find other errors that even the Design Review missed.) At this level, there may be very little difference between which style of review is best for one project vs. another.

At an “action learning” level, a Design Review Team, as they begin to see a pattern of discrepancies, modifies their own checklist or their allocation of time and effort to pay more attention to "weak spots" in the design. Clearly, this is the most effective team behavior for any project, providing, of course that it doesn’t cost more than the value of the outcomes it produces.

At the "reflection in action" level a Design Review Team would discover their own errors (both Type 1 and Type 2), as well as the designers' errors. Also, they would discern why they were making errors, and change their competency mix or change their allocation of time and effort to preclude such errors. Once again, this is the most effective team behavior for any project, providing, of course that it doesn't cost more than the value of the outcomes it produces..

CONTROL SYSTEM ARCHITECTURES

It is now appropriate to turn to the topic of how the tri-purpose control can be architected and how the architecture will determine the effectiveness of mission pursuit and accomplishment. Five forms of control are pertinent; Authoritarian, Oversight, Process Office, Embedded and the Systemic.

The Systemic mode will show about 100X better acuity and responsiveness than Authoritarian but can be harder to install and sustain in peopled systems. On the other hand if done right the cost of systemic control can be less than all the other styles.

The **Authoritarian** form of controller needs little introduction. This style allows no action that is not directed from "Headquarters" through Policies, Procedures, Rules -- and dismissals. Typically it uses the bang-bang scenario and seeks stasis in order to "keep on keeping on" even while the enterprise becomes non-competitive.

The **Oversight** Committee controller reviews past events, actions and outcomes and discerns which were appropriate and which not and then recommends new rules or guidance for such situations if they reoccur. An oversight controller typically is located some distance in space and time from the real action, thus usually several months behind the real world events. Examples are an oversight committee in the U.S. Congress or an annual CMM® Assessment of your organization. Oversight control has built in limitations in acuity, model fidelity and latency. It is the less expensive control architecture when only the cost of the controller is considered but may be very expensive if the cost of inaccurate control of outcomes is considered.

A Process Office, a recent invention of the organizational psychologists, is similar to an Oversight Committee but is closer to the action thus does not suffer the time delays and chances of mis-information endemic to Oversight. However, the Process Manager not directly involved in producing the deliverable work products of the the organization. In the "ham and eggs" analogy of commitment, the production manager is the pig and the process manager is the hen.

The **Embedded** style is woven into the OS at the scene of the action. Relative to Oversight the time delays are further reduced, model fidelity is futher improved and the decision rules are more likely to be updated when business objectives change. Autonomous vehicles rely on embedded control. When people are involved they become invested in the outcomes of the project even though their primary responsibility is for the methods of producing the outcomes.

The final form, called **Systemic** control, is quite different. In this form instead of one controller which contains the model of the OS and TS and to which all the data flows there are "N" controllers which are interconnected for collaborative control. This style of control does not work well until each of the controllers has a mutual model of the TS-OS and consistent goals for their aspect of the OS. But once each controller has these, systemic control is far more performant at far less cost than other forms. In people terms, each individual is brought to an understanding of enterprise Mission, Market, Strategy, Structure, Objectives and Process all ensured by shared Values. No model of the effectors is required because each person is the action system. The systemic form of control seeks "control from within" or, as coined by Peter Senge, "control without controlling." In this form, a manager ensures (by role modeling) that sufficient shared values (principles) and vision (purpose and meaning) exist and that each element has the fundamental behavior patterns needed to survive (plan, organize, integrate and measure is an upper level pattern and plan, do, check, adjust is a lower level pattern). Finally, the manager facilitates and ensures the setting of standards in terms of goals and objectives at a level that will ensure success in the face of competition, shortage of resources, and other adversities.

This form of controlling peopled systems has been around since the Halls of Montezuma and the Shores of Tripoli and modern management writers are re-describing it in the terminology of chaos theory and complex-adaptive systems. The power and promise of this is illustrated by the BOIDS simulation which Craig Reynolds demonstrated in 1987. BOIDS may not have completely explained the complexity of the flight patterns exhibited by a flock starlings as fascinated the poet, Colerige, in 1799 (Whyte 1994), but close enough.

The key to success in this form of control is the consistency and coherency of the rules and goals "instilled" in each individual. In the BOIDS simulation there was not a problem because each BOID followed identical rules. But in the world of systems which contain humans we have no such assurance. In fact, one of the often mentioned "truisms" is that one group of people will invariably act in a way that optimizes their domain and inevitably degrades the system of which they are part. In system dynamics literature this is called the Tragedy of The Commons. However, (Wymore 1997) has shown that there are conditions under which this is not true -- that a system performs optimally when each of its subsystems performs optimally. For this condition to be met the individuals do not have to have identical goals but they do have to have goals which are complementary (coherent) and consistent. This has been further explored and elucidated in (Axelrod 1997).

SYSTEMIC CONTROL IS FREE

> It started 2,500 years ago. In 508 B.C. a Greek philosopher articulated an astounding idea -- that people are capable of governing themselves with laws devised by themselves.

It continues today. The author has frequently experienced that people can a) perform a task while b) operating as part of a process, while c) operating at the level of principles. And most people are most happy, thus most productive, innovative and collaborative, when operating on all three levels simultaneously.

Clearly, we have a lot of learning to do about what to install, instill and inspire in the individuals who comprise control. But the point is, systemic control, by avoiding the deleterious time delays and mis-information of an external controller, is the right way to go and is more compatible with the way people work, think and feel.

Systemic control, like quality, is free. It is not cheap nor easy to attain but pays back far more that it costs. And it is largely achieved by appropriately modeling the TS-OS and architecting a GSS. Consequently, a leader's challenge is to put his/her energy into establishing meaningful and

Each style of control is a tradeoff in cost vs. performance. The Authoritarian style produces minimum levels of both. The Customer Oversight style (typical of government procurements) produces a higher level of dynamic stability and can produce very high levels of productivity at the expense of maneuverability and vise versa. Higher levels of dynamic stability are produced by the Process Office, whether it be in the form of a GSE/TD contractor on government projects or the Process Management office in commercial enterprises. Goal-seeking Workgroups are even better. These are not to be confused with "self-managed teams" which all too often have unclear purpose and insufficient authority. Goal-seeking Workgroups do not yield the best dynamic stability, however, because each group has a distinct purpose (as in subsystem) which still invokes delay and ambiguity during collaboration among the groups. Not until the goal-seeking workgroups are brought to a level of mutual understanding and purpose, where each workgroup is both a system and a part of a larger system, does system dynamic stability occur and "control without controlling" become possible.

OUR OPPORTUNITY

Think of your own responsibilities and what happens when you can't be everywhere at all times. What happens to your acuity, latency and decider? What would happen if your responsibilities were doubled? What if your team just knew what to do in every situation?

Given that we now know about how to create emergent behavior by installing rules locally in the elements of the system, the question becomes whether we are smart enough to write the "rules for managers." Also, it is clear that an optimizing organization, to the degree it means 'neat and orderly,' is not a desirable sufficient goals instead of trying to exercise corrective control. Improving and optimizing, in the adaptive sense, are not enough. The preferred behavior is 'exploring and recouping.' As Prof. Azides has pointed out (Adizes 1988), the non-innovating organization is near death.

Figure 2 shows the characteristic functions of cost effectiveness for the three main choices of control..

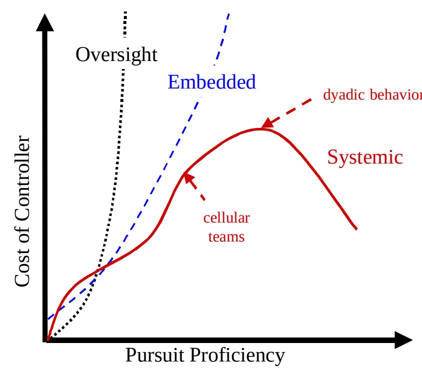


Figure 2. Cost Effectiveness of Choices

Oversight control is low cost but cannot cope with any but trivial pursuit. Embedded control can achieve higher levels of pursuit proficiency but gets more costly and evenutally limits regardless of cost. Systemic control costs more than the others even for modest pursuit proficiency because more participants have to be involved and have common purpose, goals and mental models of their roles in the process. But as this community of thought takes hold, higher levels of pursuit proficiency are achieved. A maximum is reached when the team learns to learn. Subsequently, increased pursuit proficiency can be had at decreasing cost of control.

Those wanting to explore systemic control in peopled systems should pay close attention to four heuristics:

MYOB - Model Your Own Business: Just as model fidelity is critical to TS-OS control it is equally critical when the TS is a yet-to-be-created system design and the OS is your team and their work context. You must lead the modeling of your own business and remember that the model must be available to and understood by all.

Treat your (part of the) organization as a system: Select the type of control and the control architecture based on the possible (not probable) future behaviors of the TS. Understanding the possibilities in the Problem Space is mandatory.

Use only the best components -- People who can: dialog, innovate (because continuous improvement is not sufficiently robust to deal with the punctuated equilibrium of your TS), and can establish meaningful and sufficient goals instead of trying to exercise corrective control.

Tend your fences: Left to itself a peopled system drifts toward spending an increasing proportion of its energy in random behaviors that are not aligned with the system's purpose. People, the sole source of software bugs, are also the source of "organizational noise." A good controller must be vigilant at detecting and nulling variances, both what is going on that should not be and what is not going on that should be.

SUMMARY

An organization can be controlled toward meaningful and mutually consistent goals. Organizational objectives can range from “make no errors” to “follow the rules” to “make the rules” to “zero defects.” The principle of requisite variety demands that the method of control, whether oversight, embedded or systemic, must be consistent with the objectives and the dynamics of the situation. The controller must contain a model of the organization context, content, structure and behavior. Several variables must be considered when designing a controller. Designing the cheaper controller may result in wasting dramatically more money nf undesirable system outcomes. The best models of organizations are built by members of the organization. The finest models should be expected from systems engineering organizations.

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BIOGRAPHY

Jack Ring earned his undergraduate degree in physics from Emporia State College, Kansas. He used his twenty years with GE, ten with Honeywell and ten as a coach to high tech executives as a learning laboratory about systems, people and management. He continues coaching regarding strategy, process, organization and innovation by treating the business enterprise as a complex, adaptive. Jack especially enjoys working with organizations of less than 200 people -- because they can still be helped.