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**Spacecraft COst REduction Team (SCORE) —
TQM/CI on a Massive Scale**

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A. Introduction and Summary

The business of building satellites and space systems has matured. Few missions require, or can afford, excellent performance at any price. The new paradigm is doing more with less, providing quality systems at lower cost — in other words, doing our job "FasterBetterCheaper."

The TRW Spacecraft COst REduction (SCORE) initiative was launched in 1990 by Daniel S. Goldin, then general manager of TRW's Space & Technology Group. The SCORE mission is to apply continuous improvement (CI) techniques to effect major reductions in the cost (our primary goal) and span time (as a corollary) required for the production of spacecraft.

SCORE is a multiyear initiative that is having a profound effect on both procedural and cultural aspects of how we do business. And the objectives of this initiative are being realized.

The focus of this paper is not on the results of SCORE per se, but rather on the things we have learned about how to do continuous improvement on a massive scale, with multilevel (hierarchical) CI teams. The following sections summarize the chronology of the SCORE initiative, from team formation to development of the year-end report for 1991. Lessons learned, the core of this presentation, are discussed — with particular focus on the unique aspects of SCORE.

The SCORE initiative is continuing and, as a part of our evolving culture, will never end. It has resulted in profound insights into the way we do work and (the topic at hand) how to do CI for large and complex multidisciplinary development activities.

B. SCORE TQM/CI Process Chronology

B.1. Team Selection and Formation

The SCORE team was a natural progression from the CI efforts started in 1989 by a number of "grass roots" teams in our operating divisions. Teams were formed in small work areas to look at local processes and determine how they could be improved. These teams were largely unfunded, meeting during lunch hour or after work. One of the recurrent frustrations in these early efforts was that when a team got to the boundary of its functional specialty, the participants had difficulty determining how their processes interacted with those of other areas. SCORE was conceived to bridge this gap.

The concept of SCORE is to employ a senior cross-functional team to look into all aspects of the process of designing, fabricating, assembling, and testing a generic spacecraft bus. The scope of the effort encompasses a bus project from authority to proceed (ATP) through launch of the first

satellite. Comprised of representatives from each of the organizations of Space & Technology Group involved in the processes under study, the team was formed in December 1990. Members were appointed by skill center managers from the Applied Technology Division (propulsion design and hardware), Engineering & Test Division (bus hardware design and spacecraft assembly/test), Electronic Systems Group Manufacturing Division, and the Space & Technology Group subcontracts and product assurance functions. Each member reported directly to the nominating manager and, in SCORE matters, spoke with his voice. All disciplines involved in the production of a spacecraft were represented:

- Program management
- Business and administration
- Mechanical engineering
- Control, sensors, and mechanisms
- Power systems and integration
- Spacecraft electronic systems
- Propulsion
- Manufacturing (including parts, materials, and processes)
- Propulsion
- Assembly, test, and launch
- Mechanical ground systems and environmental test
- Systems engineering
- Subcontracts
- Product integrity (quality assurance, reliability, producibility, maintainability, etc.)

To assist in helping this large group interact effectively and function as a team instead of a committee, we included a full-time facilitator. The facilitator's tasks were to observe rather than participate in the team's activities, provide training in team techniques as needed, and make sure that we followed the rules we set.

It was evident from the beginning that the team needed to establish norms of behavior, rules, and an operating philosophy. We jointly developed a set of rules, agreed to follow them, and posted the list prominently in the meeting room. As we progressed through 1991, we found that adhering to these rules helped significantly in achieving genuine teamwork. For example, the rules and operating philosophy require that team decisions be reached by consensus, not by simple majority. Decision by consensus promotes ownership by each team member. The rules further require that decisions be based upon data; this guideline helps members focus on process, not personal prejudice or emotion.

B.2. Team Training

Each of the team members had individually participated in our CPI® Boot Camp, an orientation to the principles of process improvement, but there was no group training prior to team formation. To get us started, we were trained in the techniques of defining the "as-is," "could-be," and "should-be" process flows, then determining barriers to implementation. As the team progressed, we received "just-in-time" training specific to the task at hand. While generally following a classic process improvement flow, we did deviate when it made sense. For instance, some teams approach the "as-is" step by constructing a flow chart of every process involved to the lowest level of detail before further analysis. Because we were trying to determine which processes had the greatest impact on the overall spacecraft process, we decided to define each process only in enough detail to be able to understand its impact on the whole.

B.3. Methodology Selected

The SCORE team employed a variety of TQM/CI tools and techniques in 1991, during a process that was largely one of discovery. We were determined to be driven by data instead of opinions. This commitment, coupled with the complex nature of modern spacecraft, led us to a hierarchical three-level teaming approach — and the use of a variety of tools, some quite successful and some less so.

Process Flows and Maps

Our first effort to define the total problem was based on detailed process flows. The SCORE team attempted to construct a comprehensive, detailed, cross-functional spacecraft process flow on a large wall (approximately 8 by 35 ft). After consuming several hours over a couple of meetings, it was apparent that this approach was futile. We concluded that another methodology was required.

Definition of Levels

Spacecraft development is by nature a multilevel process. We decided to emulate this hierarchy. Level 1 was defined as the total program, divided into time spans associated with major review milestones (e.g., ATP to PDR, PDR to CDR, etc.). The SCORE team became the Level 1 team. Level 2 was defined in accordance with major spacecraft development processes: requirements to design; mechanical design through manufacturing; electrical design through manufacturing; propulsion through manufacturing; assembly, integration, and test through on-orbit checkout; subcontracts; and program management. Level 3 was defined as the unit level.

Seven key teams were formed (Figure 1) to address Level 2 processes. Each of these teams validated the Level 1 flow developed by SCORE, and developed Level 2 process flows, defining Level 3 subteams where they were needed (primarily in the design-through-manufacturing teams). Ultimately, the seven key teams formed 38 unit-level teams involving more than 250 employees. All teams were cross-functional, with representatives from systems engineering, subsystem

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engineering, engineering specialties, design, integration and test, manufacturing, and subcontracts — as deemed appropriate by the Level 1 team.

Data-Driven Approach

The Level 2 teams defined process flows for the activities they addressed, with support from the related subteams. These flow diagrams (process definitions) were used to focus the collection of “as-is” data from selected existing and completed programs. The primary data collected and analyzed were cost (or man-hours of labor) and span time. Often it was necessary to modify the flows to better match the structure of data available from the programs. The quality (detail, documentation, definition, completeness) of data from the programs was a major hindrance, particularly when dealing with the “intellectual” phases of the programs (such as system engineering).

Selecting High-Leverage Processes

The need to focus on those processes having the highest leverage was apparent from the beginning. Our main tool in defining leverage was the Pareto diagram, with “as-is” cost the parameter addressed. This approach was applied with good success for those processes (design, integration and test, manufacturing) where the program data was relatively high in quality.

Pareto diagrams were less successful for the requirements-to-design (RTD) processes. Discussions in Level 1 team meetings, supplemented by more formal techniques (Ishikawa diagrams coupled with multi-voting) made it apparent that many of the downstream (e.g., design) problems were related to the quality of RTD work — and that simply reducing the cost of RTD work could well lead to a higher total program cost. This investigation led to the definition of a major 1992 initiative focusing on the Integrated Development Process (IDP).

Developing “Could-Be” and “Should-Be” Processes

“Could-be” processes were developed first, and were defined as the best processes possible without constraints related to organization, facilities, etc.; in effect, the could-be processes represent a long-term goal. The “should-be” processes were less ambitious and realizable in the near-term environment. In some cases, the could-be and should-be processes were very close in terms of the key cost metric; in a few they were not. The should-be processes were used to define attainable cost reductions, in terms of continuous improvement (CI) factors.

B.4. Summary of Results

We collected data on 553 “as-is” processes and combined them into 383 processes for analysis. Through a combination of Pareto analysis and brainstorming, we identified high-leverage processes and performed cause-effect analyses upon them. We defined “should-be's” for 107 of the 383 processes and developed 112 specific recommendations for improvement.

C. SCORE Lessons Learned

C.1. Team Composition and Commitment

Team members were nominated by their skill center managers. The main selection criteria were a good knowledge of the work area and a desire to contribute to a process improvement effort. In general, those nominated volunteered for the assignment. Each team member was asked to commit a minimum of 16 hours a week to the SCORE effort and to agree to attend all of the SCORE meetings.

C.2. Meeting Frequency and Timing

We started with two 8-hour meetings per week. We quickly found that no more than 4 to 5 hours of that time were productive, and there was no time left for members to follow up on action items outside the meeting. After experimenting a bit, we settled on two 4-hour meetings a week. That seemed to be a good compromise and was our schedule for most of the year. As the Level 2 and 3 team activities expanded, the core team meetings were cut to 2 hours twice a week, then to one 2-hour weekly meeting. When special issues arose, the meeting time was expanded to accommodate the need.

C.3. Team Leadership and Culture

Leadership

Leading a team such as SCORE is different from managing a project. The members are expected to interact differently in a team setting. In a project setting there is a clear hierarchy understood by all; in a team setting, members are expected to contribute equally and to have their ideas considered equally without regard for rank, status, or position.

Ideally, the leader acts as a coach. He must make sure that the group operates as a team rather than as a committee so that each member has a personal commitment to the result. For each problem encountered or issue addressed, the team must come up with its own answer. If the leader defines too detailed a plan for resolution, the members will fill in the blanks but not own the result. The leader also must be very careful to keep personal prejudices and preconceived solutions out of the process. To own the result, the team *must* develop it themselves.

To get the maximum benefit from a process improvement team, one must set a dramatic goal as a challenge to creativity. Small (10 to 20 percent) improvements can usually be accomplished easily within the existing process framework. To achieve true breakthrough improvements (40 to 70 percent), the goal must be seemingly unattainable. The leader must develop a personal vision of the goal and continually assert that it can be accomplished, then lead/nudge the team in the direction of the goal.

Requiring that decisions on team activities be made by consensus seems at first to be abominably inefficient. Nonetheless, the object is to have all of the team members fully involved in decisions so that they can support the result with one voice. Therefore, discussions must be continued until everyone can agree or not strongly disagree with the result.

It is imperative to have a clearly defined mission statement to focus upon, otherwise there is a tendency to wander. The statement need not be elaborate but must be sufficiently clear that you can tell when you have accomplished it. The SCORE mission statement, for example, is short and to the point:

The study is directed at a generic spacecraft flow.

Define the "as-is" process flow (including cycle times) from authorization to proceed through on-orbit customer selloff.

Determine high-leverage processes to investigate further. Develop a "should-be" overall process flow (including cycle times) applicable to a broad range of spacecrafts projects to: reduce cost and cycle time dramatically while maintaining or improving quality.

It proved to be equally important to develop a set of meeting rules and require strict adherence to them. We had a practice from the beginning of developing a written agenda for the next meeting as one of the last items of business in every meeting. That was useful, but what we found was that we tended to belabor the earlier items and never get through the entire agenda. When we began to set a time limit for each agenda item, the situation improved somewhat. Finally, when we rigidly enforced the time limits even to the point of interrupting conversations in mid-word, we achieved our highest meeting effectiveness scores. It seems that the stress caused by dictatorially ending discussion was more than offset by the sense of accomplishment achieved by addressing all of the agenda items.

Meeting effectiveness was measured for each meeting, then plotted and displayed in the meeting room. The measurement technique is simple and can be applied to any sort of meeting. At the end of the meeting, using a scale from 1 to 10, each member rates the Efficiency (how well the conduct of the meeting followed the rules) and the Importance (how important the meeting content is to him). All the E and I scores are averaged and multiplied together to produce an Effectiveness number. The Effectiveness can be dollarized to provide a measure of the "cost of lost opportunity" by subtracting the Effectiveness score from 1, then multiplying by the number of attendees, the length of the meeting, and an average cost per unit time for the attendees. It was interesting to note that the highest scores were achieved when the rules were most rigidly observed. It is therefore up to the leader to enforce the rules developed and adopted by the team. Demand excellence but realize that it can take many forms, and realize that schedule pressure to produce "something" offends the purist but results in helping to end "analysis paralysis."

Cultural Aspects

We discovered early on that we are event (schedule) oriented, not process oriented. Furthermore, the detailed examples usually given of a CI process are oriented toward short processes that repeat frequently, such as forms handling and high-rate manufacturing. It was difficult to relate these examples to the processes of requirements definition and detailed design. We ultimately settled upon a format for depicting our requirements and design processes in terms of a list of inputs, functions performed upon them, and a list of outputs. We are still inventing a way of viewing a lengthy spacecraft program in a process context.

The form, format, and conduct of the meeting are subtly critical to the outcome. There is a tendency for the meeting to become a project review where the leader, not the rest of the team, is presented with the pieces and expected to do the synthesis and make the final decision. We found this to be true after we launched the seven key teams mentioned above. Since all of the core team members could not attend every key team meeting, we added a "Key Team Leader Report" to the standing agenda. Each team leader was asked to share the progress of his team with the core team and was allocated a maximum of 5 minutes to do so. Within eight meetings, this agenda item became a de facto project review — with each team leader addressing the SCORE team leader, not the team, and feeling compelled to fill his time allocation whether or not he had anything to report. This behavior persisted even after I called attention to it numerous times. We solved the problem by eliminating the reporting agenda item and substituting one called "Issues." If a team leader had something to report to the team, he was required to write it on a white board before the meeting started. When we got to the issues item, we would vote on whether to address a given issue and set a time limit for its discussion.

While generating a process flow or map, there is a strong tendency to focus on fixing individual problems immediately and to lose focus on the bigger picture. Giving in to this tendency leads to a "tiger team" approach and the effort falters. Our solution was to set aside a wall area in the meeting room and label it the "Should-Be Parking Lot." As individual problems or non-value-added processes were found, they were listed on the parking lot to be addressed later when we progressed to the "should-be" development phase.

In analyzing the "as-is" and developing improvements, there was a general perception that most of the barriers to performance are external to one's own area. Forcing the teams to be cross-functional helped to mitigate that perception. It also helped overcome the fact that we have organized ourselves into such narrowly defined specialities that it's hard for an individual to identify how his or her actions affect the final product.

Having a few "nay-sayers" in the group improves the process by challenging the rest of the team. Nay-saying is often a way of talking out and defining a problem more clearly — or at least defining the barriers to solution.

A feeling of empowerment in the team members is developed by action and example, not by decree. It comes slowly and is the result of experiencing favorable response to success and tolerance of failure.

C.4. Implications of Multiple Levels (Key Teams and Subteams)

SCORE was unique in that it became a hierarchy of teams. The original concept was of a single team, but as we developed the Level 1 flow, it became apparent that more teams would be needed. With nearly 400 processes identified in the Level 1 flow, we formed seven key teams to study them in detail. The key team leaders were selected from the SCORE core team. Each of the teams was required to have cross-functional representation appropriate to its area of investigation. The task of the key teams was to validate the Level 1 flow developed by SCORE and define in more

detail the processes defined at Level 1. As the key teams formed and developed Level 2 process flows, they also found they had to create additional teams.

In all, 38 unit or Level 3 teams were formed. As with the key teams, each unit team was required to have cross-functional representation. The unit-level teams studied the lowest level of detail in a process, usually involving one work area, and provided a natural conduit for grass roots team results to be considered in the context of the entire enterprise.

The role of the core team changed as the additional teams were formed. We generated the Level 1 flow as a team then changed into essentially a steering committee for the lower level teams, then became a team again to synthesize the results of the other teams.

C.5. Tools and Techniques

As mentioned above, we tried a variety of tools and techniques with varying degrees of success. We set out to construct the Level 1 flow as a classic flow chart and failed twice. Then we tried to construct an N² chart and failed. On the fourth attempt, we divided the task vertically into time slices defined by major program events, and horizontally by discipline or where work is performed. This time we succeeded and defined nearly 400 processes for further study. Figure 2 shows an outline of the Level 1 flow. Within the horizontal lines, each team member constructed a flow of his work area as that discipline viewed it. Interfaces between disciplines were represented by connecting the source and destination points. Along the timeline, some events were put in quotation marks (e.g., "PDR") to signify our awareness that when the program conducts a formal Preliminary Design Review, not all disciplines have reached the same level of design maturity. We used "PDR" to indicate a state of completion consistent with the classic definition of PDR.

The Level 2 teams had difficulty with detailed flow charting as well. They developed a technique of defining a process in terms of inputs, operations performed on the inputs, and outputs. This method provided sufficient insight into the macro process to identify areas with the most leverage. The Electrical Design through Manufacturing key team discovered a significant benefit from this approach. When they began, they formed unit teams to study processes related to 16 different products. They were convinced that the products were unique and therefore the processes must be unique as well. When they reviewed the flows produced by the 16 unit teams, they discovered that the processes used to develop the 16 different products could be described by only seven different process flows!

C.6. Networking with Other CI Activities

We made a conscious effort to learn from the experiences of other CI teams. Several of the SCORE team were members of other teams in TRW Space & Technology Group and Electronic Systems Group and were able to bring "lessons learned" to our meetings. In spite of the good intentions of all concerned, however, we found that usually we didn't really understand until we had made the same mistake ourselves.

C.7. Follow-up: Acting on the Findings in a Continuous Improvement Environment

For 1992, SCORE has begun to implement the suggestions derived from the 1991 work. We are sponsoring 16 implementation initiatives that touch most of the work areas. The largest of these efforts is the Integrated Developed Process (IDP) team, whose task is to define an IDP in our work environment that will result in a high level of design maturity and a physical configuration freeze at PDR.

Our future plan is to implement new processes as opportunities occur and continue cause-effect analysis of additional processes. We will analyze the effect of the new or changed processes on the overall Level 1 flow and iterate until the goal is met.

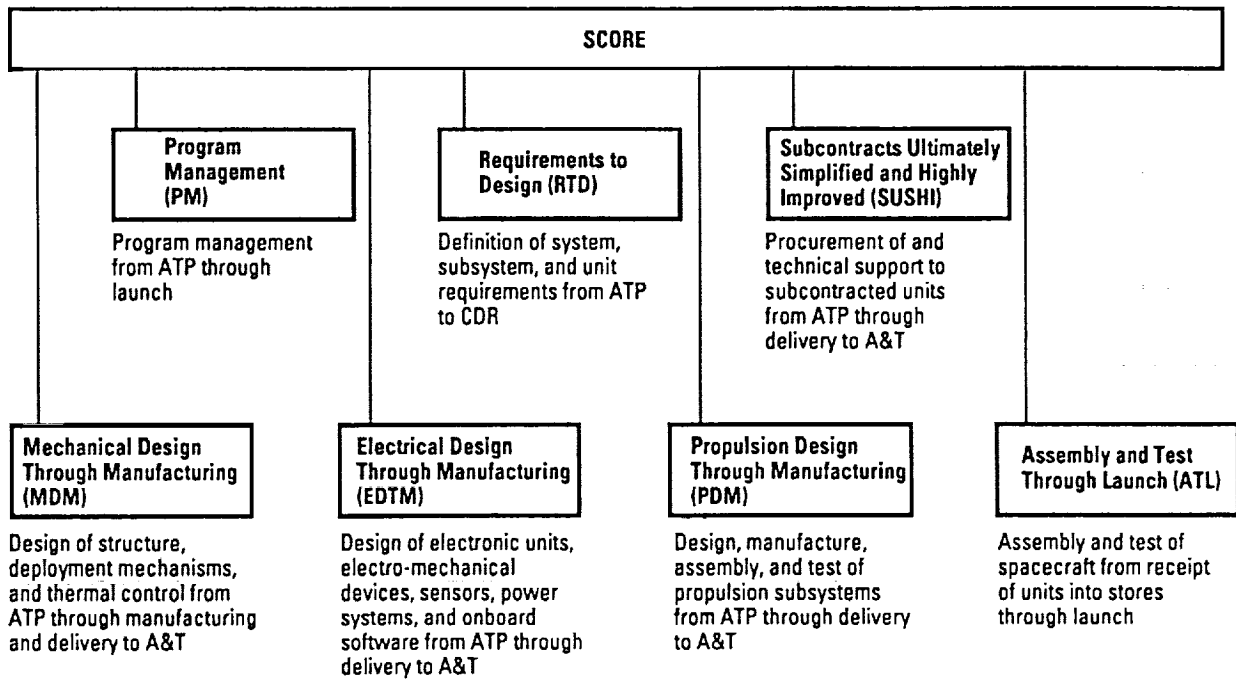


Figure 1. Seven Key Teams Addressed Level 2 Processes

Program Phase	ATP	"SRR"	"SDR"	"PDR"	"CDR"	"MRR"	Manufacturing	A&T	Launch
Work Area									
Subcontracts									
Utilities									
Propulsion									
Program Management									
Systems Management									
Mechanical Design									
Electrical Design									
Manufacturing									
Assembly & Test									
Ground Support Equipment									
Software									

Figure 2. Top-Level Process Flow Mapped Work Area Tasks Against Program Milestones