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TQM IN A TEST ENVIRONMENT

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ABSTRACT

In response to the changing aerospace economic climate, Martin Marietta Astronautics Group (MMAG) has adopted a Total Quality Management (TQM) philosophy to maintain a competitive edge. TQM emphasizes continuous improvement of processes, motivation to improve from within, cross-functional involvement, people empowerment, customer satisfaction, and modern process control techniques. The four major initiatives of TQM are Product Excellence, Manufacturing Resource Planning (MRP II), People Empowerment, and Subcontract Management. This paper focuses on the Defense Space and Communications (DS&C) Test Lab's definition and implementation of the MRP II and people empowerment initiatives within TQM.

The application of MRP II to environmental test planning and operations processes required a new and innovative approach. In an 18 month span, the test labs implemented MRP II and people empowerment and achieved a Class "A" operational status. This resulted in numerous benefits, both tangible and intangible, including significant cost savings and improved quality of life. The following is a detailed description of the implementation process and results.

INTRODUCTION

In recent years, MMAG recognized that there was a real threat of losing their competitive business base in the aerospace industry. This was the result of a number of factors including a shrinking defense budget and a changing world climate. In 1987, MMAG began to implement various initiatives in order to improve productivity with reduced cost. The Department of Defense (DOD) was also investigating TQM. In early 1989, the DOD released guidelines for the implementation of TQM. In response to the guidelines, MMAG published a TQM implementation plan in October, 1991. This paper describes how TQM was implemented into testing functions versus the traditional manufacturing process and the current operations of test laboratories within the TQM environment. It also includes lessons learned during the implementation and discusses the benefits of incorporating TQM philosophies into a test environment. This paper emphasizes implementation in the Space Simulation Lab (SSL) due to the authors' SSL background and the unique problems created by 24 hour per day, seven day per week operations in the lab.

DS&C TEST LABORATORIES

MMAG's Environmental Test Laboratories have a 25 year history of testing in state of the art facilities, performed by well educated, trained and empowered personnel. Laboratory employees are experienced in spacecraft testing at all levels, component to systems. Some examples are: Magellan Venus Radar Mapper, Tethered Satellite, Transfer Orbit Stage, Viking, Several Skylab Subsystems, and extensive support of our Titan Launch family. They are experts in numerous environmental disciplines including: Acoustics Testing, Antenna Design/Test, Data Acquisition/Digital Processing, EMI/EMC Testing, Modal Survey Testing, Pyro Shock Testing, Test Tooling Design/Build, Thermal Vacuum/Balance/Solar/Cycle Testing, and Vibration Testing.

TQM/MRP II

TQM emphasizes continuous improvement of processes, motivation for personal improvement, crossfunctional involvement, people empowerment and modern process control techniques. TQM is comprised of four primary initiatives: Product Excellence, People Empowerment, Subcontract Management, and Manufacturing Resource Planning (MRP II), Figure 1. The primary focus for the Defense Space and Communications (DS&C) Test Labs was people empowerment and MRPII.

MRP II was the lead initiative in the TQM implementation for MMAG. The following definition of Manufacturing Resource Planning (MRP II) is from Thomas E. Wallace's "MRP II: Making It Happen" (ref . 1)

A method for the effective planning of all resources of a manufacturing company. Ideally, it addresses operational planning in units, financial planning in dollars, and has a simulation capability to answer "what if" questions. It is made up of a variety of functions, each linked together: business planning, production planning, master production scheduling, material requirements planning, capacity requirements planning, and the execution support systems for capacity and material. Output from these systems would be integrated with financial reports such as the business plan, purchase commitment reports, shipping budget, inventory projections in dollars, etc. Manufacturing Resource Planning is a direct outgrowth and extension of closed loop MRP. MRP II has also been defined, validly, as a management system based on network scheduling. Also, and perhaps best, as organized common sense.

This definition specifically mentions a manufacturing company, but the theories apply to any company producing a product for a customer. MRP II philosophies are directly applicable to the aerospace industry. As shown in Figure 2, the DS&C Test Labs were able to take the manufacturing processes and apply them to a test environment. The only difference between the processes is that a manufacturing application produces hardware, where a test application produces a tested product.

HISTORY

MRP II began in the 1960's as Material Requirements Planning (ref. 1). Material Requirements planning used what Oliver Wight, hereafter referred to as the consultant, called the Universal Manufacturing Equation. This equation answers the questions "What are we going to make", "What does it take to make it", "What do we have" and "What do we need" (ref. 1). The equation then becomes:

$$MPS+BOM+IR=FR \quad (1)$$

where:
MPS = Master Production Schedule
BOM = Bill of Material
IR = Inventory Record
FR = Future Requirements

The original users of this tool soon found that its possibilities far exceeded what was originally intended. It not only was usable as a procurement tool in fabrication and assembly, but could also be used to schedule (ref. 2). MRP was then adapted to include capacity planning and converted to a closed loop process. This adaptation, with the additions of finance and simulation, resulted in MRP II as it is known today (ref. 1). MRP II is used to plan and control, two of the basic functions of management of any organization (ref. 3).

THE PROCESS

The current model for MRP II is illustrated in Figure 2 (ref. 4). This figure includes all aspects of the business and the ability for simulation. It is a feedback process with communication being essential. The process consists of eight steps. The first step is **Business Planning**. The Business Plan is the financial statement of projected business in terms of an income projection (ref. 3). This plan is used to develop and communicate the financial plans of the company. This plan should directly support the companies strategic plans (ref. 5). The next step, **Sales & Operations Planning,** is defined as "the function of setting the overall level of manufacturing output (production plan) and other activities to best satisfy the current planned levels of sales (sales plans and/or forecasts), while meeting general business objectives of profitability, productivity, competitive customer lead times, etc., as expressed in the overall business plan" (ref. 4). The Sales & Operations plan is essentially the tactical plans of the company and is developed concurrently with the Business Plan.

The next step in the process is **Master Production Scheduling**. The Master Production Schedule is essentially the build schedule (ref. 3). This plan drives material requirements planning and the capacity planning functions. **Material Requirements Planning** is used to determine the requirements for items. This step is the basis for closed loop MRP and is now thought of as a scheduling technique (ref. 3). This stage then leads into the **Capacity Requirements Planning**. This is defined as "the process of determining how much labor and/or machine resources are required to accomplish the tasks of production, and making plans to provide these resources" (ref. 3). This stage is obviously dependent on the Material Requirements Schedule.

The next stage of MRP II is the **Comparison Stage.** It forces the user to validate his plans. If the plans are not realistic, the user should go back to the Material Requirements Planning stage and repeat the process. If the plans are realistic, the user should begin executing the capacity and material plans. This is not the end of the process, it is the beginning. **Execution of the plans** needs to be graded on accepted performance measures and must be flexible enough to resolve problems, it is a separate process of feedback and control in itself. MRP II is an ongoing and adaptable process.

MRP II has four grades to determine how the organization is operating, Classes "A" through "D". At Class "D", MRP II is simply a scheduling system. At Class "A", MRP II becomes an overall business management system. DS&C Test Labs were given the goal of achieving Class "A" status within the recommended 18 month span. The Test Labs were the only true non-manufacturing area within MMAG to implement MRP II.

IMPLEMENTATION

Oliver Wight was selected as the professional guidance to be used by MMAG. The implementation process defined by the consultant is called the Proven Path (ref. 1). This process followed eleven steps required to achieve MRP II Class "A" status. The eleven steps of the proven path are as follows (ref. 1):

1. First cut education
2. Cost justification and commitment
3. User controlled project team
4. Assign full time project leader
5. Establish an Executive Steering Committee
6. Obtain professional guidance
7. Education of critical mass
8. Pilot approach to MPS/MRP
9. Close the loop
10. Include finance and simulation processes
11. Dedication to continuing improvement

The first step in the plan, first cut education, was completed by the executive staff and management of MMAG. They then completed a cost justification analysis that determined the implementation should continue. This resulted in a high level of commitment from top management to implement MRP II. The next step in the implementation was to form implementation teams for each of the areas, with full time project leaders. Space Systems company created six implementation teams, Figure 3, with an Executive Steering Committee in place to ensure success. As stated previously, professional guidance was provided by the Consultant.

The Test Laboratories MRP II Implementation team, Figure 3, was comprised of personnel from each functional area, supported by management leadership. The participants were engineers and planners who would use MRP II on a daily basis. Each team member was assigned a specific MRP II function and was challenged to become the team expert for that function. Functions were integrated planning, capacity planning, master test schedules, test readiness, systems/architecture, inventory/BOM, and design engineering.

The next step in the implementation was to educate all of the users in the labs. The Consultant recommended education of at least 80% of all affected personnel to ensure successful implementation. Implementation Team Members were extensively trained via consultant sponsored seminars and video tape sessions. They in turn, became the instructors for the weekly laboratory personnel training sessions. Leaders were tasked with tailoring the sessions to the lab environment and providing a question and answer period. All employees of the labs were required to complete the full video training over a four month period. This was approximately 40 hours of training per person. In addition to education, training on the computer system that was to be used was given to a limited number of personnel who were expected to use the system. The software tool chosen by MMAG was Mac-Pac/D by Arthur Andersen. This tool was integrated with current shop floor control, finance and purchasing systems. After the education had been completed, a pilot program was created to validate the MRP II process. MMAG first tested the software they had chosen using an Integrated Test Bed. A company wide team was formed which validated software performance and application across MMAG. After the 12 week validation process was completed, team members had gained the expertise required to train users in their respective areas. Pilot teams in each area then tested the software for functionality. At the completion of the pilot, the Test Lab's schedules were loaded onto Mac-Pac/D and a cutover to the new formal planning system was accomplished. This completed the close the loop step of the implementation.

The finance and simulation steps of the implementation integrated the financial and operational systems and initiated use of "what-if" capability. These steps were accomplished at the MMAG level with the Test Labs following the direction given. The final step of the implementation was a dedication to continuous improvement. Continuous improvement had been addressed by identifying problems caused by poor interface and communications between intercompany departments. High performance work teams (HPWT) were formed and challenged to work chronic problems not addressed through formal measurement systems. One team focused on the coordination of the DS&C Test Labs and the MMAG Facilities Department in regards to maintenance and repair of the labs, capital projects and utility outages. The Product Protection HPWT focused on protection of hardware during transportation, handling, and test activities. Test Planning teams were formed to ensure facility and customer readiness and to share lessons learned from similar testing experiences.

The Space Simulation Laboratory High Performance Work Team (HPWT) initiated two other important programs in 1990-1991 which reflect the continuous improvement and employee empowerment concepts which are the cornerstone of TQM. The first of these programs was targeted at improving the level of service provided by SSL. One means of measuring the level of quality provided is the number of testing incidents and anomalies resulting from lab operations. An incident is defined as a condition or event which resulted in injury to personnel or damage to test support or flight hardware. An anomaly is defined as a out-of-tolerance condition or event which did not involve hardware damage or personnel injury and was caused by a deviation from the controlling SSL environmental test procedure or a deviation from an accepted laboratory practice. The program began by analyzing contributory causes to incidents/anomalies caused by the laboratory. Contributory causes were grouped in the following categories: Follow-through, Laboratory Practices, Training, Procedures, Engineering, Supervision, Failure Modes Effects Analysis, Capital, Staffing, and Maintenance. Each incident/anomaly was analyzed to determine if a deficiency in one of these categories was responsible for the occurrence. Each category was also assigned a number from one to five to show its relative contribution to the incident/anomaly, a one being a minor contributor and a five being a major contributor. The incident/anomalies from 1990 were analyzed in this manner and overall leading causes for the year were determined by forming a matrix and adding individual scores. The two leading deficiencies, follow-through and laboratory practices, were targeted for improvement programs. A formal management program was established to achieve a reduction in incidents/anomalies caused by poor follow-through. Laboratory practices for test engineering, design and fabrication engineering, and operations engineering were developed and issued to all personnel. A metric was established to measure the rate of incidents/anomalies monthly.

The HPWT set two goals for 1991; reduce the number of incidents to zero and reduce the anomaly rate by 10% under the 1990 rate. Due to the implementation of these continuous improvement programs and an increased awareness of the impact of incidents/anomalies on test costs the goal of zero incidents was reached and the anomaly rate was reduced by 14% (one anomaly every 4,500 test "touch" hours). A goal of another 10%

reduction in the anomaly rate for 1992 was set. Through July of 1992, the anomaly rate has been reduced by 32%.

The second program developed by the HPWT was an innovative alternative work week for the Operations Group to solve some of the unique problems encountered by SSL. This idea was conceived by an operations supervisor, brought to fruition by the HPWT, and enthusiastically endorsed by laboratory management. Top management not only approved the plan but contributed as part of the HPWT to ensure its success. Several MMAG programs use the lab at any one time. The level of testing for each of these programs varies weekly, consequently, the laboratory's required capacity also varies. Laboratory capacity planning for manpower projection purposes strives to reach a compromise between limiting overtime during high capacity periods and staying within overhead budget limitations during low capacity periods. Thermal vacuum testing is inherently lengthy in practice. Component tests can run three to four weeks while systems tests can run up to two months. Stopping tests to allow personnel weekends off is not schedule or cost effective. Consequently, test personnel often work extensive overtime. In 1990, the average overtime for an SSL operations test technician was 920 man-hours. The average overtime for operations supervisors was 1320 man-hours.

The HPWT developed a work week system that changed this traditional approach, Figure 4. The objective of the work week was to provide 24 hours/day, 7 days/week test operations support while reducing overtime, test cost, and overhead spending during low capacity periods. The operations group was divided into four crews, designated as D1, D2, N1 and N2. Each crew works three 12 hour days and one six hour day, followed by three and one half days off. This equates to a 42 hour work week (40 during low capacity periods) resulting in two hours of paid overtime per week. The D1 crew schedule is Monday through Wednesday, 7 AM to 7 PM, and Thursday, 7 AM to 1 PM; the N1 crew schedule is Monday through Wednesday, 7 PM to 7 AM, and Thursday, 7 PM to 1 AM; the D2 crew schedule is Thursday, 1 PM to 7 PM, and Friday through Sunday, 7 AM to 7 PM; the N2 crew schedule is Friday, 1 AM to 7 AM, and Friday through Sunday, 7 PM to 7 AM. The crew rotation is set up such that each crew rotates to a different shift every four weeks. Each crew receives seven days off to make the adjustment from days to nights or from nights to days. This change occurs every eight weeks and has improved operator morale. Several metrics were devised to measure system performance. Employee days off doubled from one day off per week to two. Overtime was reduced by 60% and an estimated savings of $100,000 was realized from the conversion of overtime hours (paid at one and a half and double salary) to straight time hours. Employees also worked an average of 45 hours per week as opposed to the 1990 average of 57 hours per week. Periodic employee surveys rating the new system indicated a significant quality of work life improvement over the traditional system. Additional benefits realized were improved personnel scheduling flexibility and more efficient operations due to fewer shift turnovers

VALIDATION/QUALIFICATION

In order to validate the path the labs were taking for implementation, several design reviews were held. The reviews allowed the Executive Steering Committee and the consultant to evaluate adherence to the plan and review actions taken to attain Class "A" status. These reviews were held at approximately three month intervals during implementation.

The consultant graded the test labs using the ABCD checklist. This checklist is comprised of 35 overview/audit questions which allow the user and the consultant to measure the effectiveness of their MRP II operations. The checklist is comprised of four major areas, with four subsections for each area. The first area is Planning and Control. This section is comprised of Management, Demand, Supply and Product Development. It focuses on the planning and control processes of the business and the management of the continuous improvement process. This area requires strategic planning, business planning, sales and operations planning, financial planning, "what if" simulations, demand management, master production scheduling, supplier planning and control, material planning and control, shop floor control, capacity planning, and new product development processes to be established and maintained. These processes are the heart of MRP II. The second area is Data Management. This area is subdivided into Bills of Material, Routings, Inventory Records, and Change Control. This section verifies that processes are in place and ensures the data being used is correct. The third section is the Continuous Improvement process. It's divided into the areas of Education, Employee Involvement, One-Less-At-A-Time, and Partnerships. This section is aimed towards ensuring that the MRP II process is being continuously evaluated and improved. The final section is Performance Measurement. The subsections are Planning and Control, Management, Quality, Service and Cost, and Velocity. This is a verification that measurements of performance are in place for all critical processes and a correction plan is established where necessary. A company which can answer yes to all 35 questions is considered Class "A" and operating in a closed loop MRP II mode, and uses the formal process to develop the plans which the company lives to. The DS&C Test Labs were able to answer yes to all 35 questions over an 18 month period and were awarded Class "A" status in July, 1991.

CURRENT OPERATIONS

The Test Labs are currently operating as a Class "A" organization. The planning processes in place include Sales and Operations Planning (S&OP), Material Requirements Planning, and Capacity Planning/Shop Floor Control. Sales and Operations planning is defined as our ability to acquire and analyze the necessary data to accurately forecast manpower requirements. A current, accurate plan is crucial for effective resource allocation. The master production schedule provides forecasted contract work, referred to as direct charges, and in house projections for overhead expenditures, called indirect charges. All Independent Research and Development (IRADS), Capital funded facility modifications/upgrades and company funded engineering studies are considered direct charges. To convert schedules into manpower projections, the labs have been divided into work centers. A nominal charging rate is then assigned to each work center in man hour units. Summing work center man hours with planned overhead expenditures provides a comprehensive database for resource forecasting. The S&OP is updated monthly and spans five years. The first twelve months of the forecast are analyzed extensively. It is measured monthly with a goal of 80% -110% actual to plan.

Material Requirements Planning is being accomplished using Mac-Pac/D as the primary planning tool and various PC applications for detailed planning. The Master Schedule of all tests is maintained on Mac-Pac/D. This schedule is then broken into further detail depending on the complexity of the test. The ultimate goal is to perform all detailed planning on Mac-Pac/D. Due to software limitations, this is not currently feasible, and detailed planning is accomplished using PC packages such as MacProject II. The master schedule is updated on a weekly basis to reflect any changes or resolve any resource conflicts. Another area of material planning in the Test Labs is procurement of hardware. Mac-Pac/D is used to procure parts required for a specific test. Parts which are procured using overhead funds are processed using the manual system due to the inability of Mac-Pac/D to process overhead charge numbers.

Capacity planning, putting manpower and machine requirements against a task, is done using the master schedule from Mac-Pac/D, capacity reports from Mac-Pac/D, and assigning manpower requirements to the machine hours shown in the capacity reports. The coding in Mac-Pac/D has been arranged to output machine hours required to fulfill the master schedule. These hours are then converted to manhours by determining the number of people required and available for the test. There is a bi-weekly capacity meeting held between the operations lead, the master scheduler, and the individual test engineers to determine which tests will be running, capacity required for each test, and resolve capacity problems.

The actual execution phase of the process is recorded using a combination of systems. The technician will record the hours spent on a task using a timecard which is then input into an accounting database at the end of each week. This database allows the engineer to track budgets and maintain costs. When a test is completed, the responsible engineer closes out the order on Mac-Pac/D, produces a test summary, completes a budget analysis, and compiles all the pertinent information in a test folder.

Materiel control and inventory accuracy are critical to effective test planning. The laboratory inventory has been grouped into three general categories, test equipment, materiel required to fabricate test fixtures and test controls, and overhead supplies and spares. Test equipment is currently controlled with the company's Equipment Accountability System (EAS). This system schedules all equipment calibration and repair. The Test Engineer uses this automated system to ensure timely calibration and equipment availability. Materiel used to build test fixtures and controls (customer owned) is controlled using laboratory satellite stockrooms. These stockrooms are rigidly controlled, inventoried monthly, and must meet 95% accuracy standards. After fixtures have been fabricated, they are assigned a part number and controlled using the EAS system described above. Overhead supplies and spares are controlled with an in-house inventory system. Each test engineer utilizes these systems to ensure timely delivery and availability of test tools, fixtures and equipment.

The DS&C Test Labs currently take 28 performance measurements called metrics. These measurements range from schedule accuracy, fixture design accuracy, test bill of material accuracy, inventory accuracy and requirements received on time. These measures are used to identify problem areas. The Labs then meet with their customers and suppliers each month to work a resolution plan for problem areas. This allows open communication and encourages ownership of each process. Metrics are also reviewed on a regular basis to determine whether they are still measuring the right thing, and if not, to re-define the metric so that it is a valid measurement. It is critical that the metrics be changeable and valid.

CONCLUSION

In today's defense environment, a TQM philosophy is required to win contracts. The DS&C Test Labs have embraced the TQM philosophy and become Class "A" in MRP II. They have also formed numerous HPWTs and continue to investigate continuous improvement in all processes. Lessons learned for other test organizations who wish to implement a TQM philosophy focusing on MRP II and HPWTs include the following. Implementation team members must be laboratory experts, otherwise valuable time will be lost to educating unfamiliar participants. It is also important to ensure that all levels of the organization are committed. A key concept of people empowerment states that individuals must own their process and be involved in the decisions affecting their process.

Without integration of all customers and suppliers, islands of TQM are created. This results in each organization having different philosophies, tools, and language. When each organization's formal process is different, the company as a whole will suffer. The implementation should emphasize the importance of selecting software and tools which are compatible to all users.

The keys to success of TQM are integration, participation and empowerment. The organization must make a commitment to the success from the start and be open to the changes that are required. There is nothing harder than change, yet nothing is more critical in today's environment.

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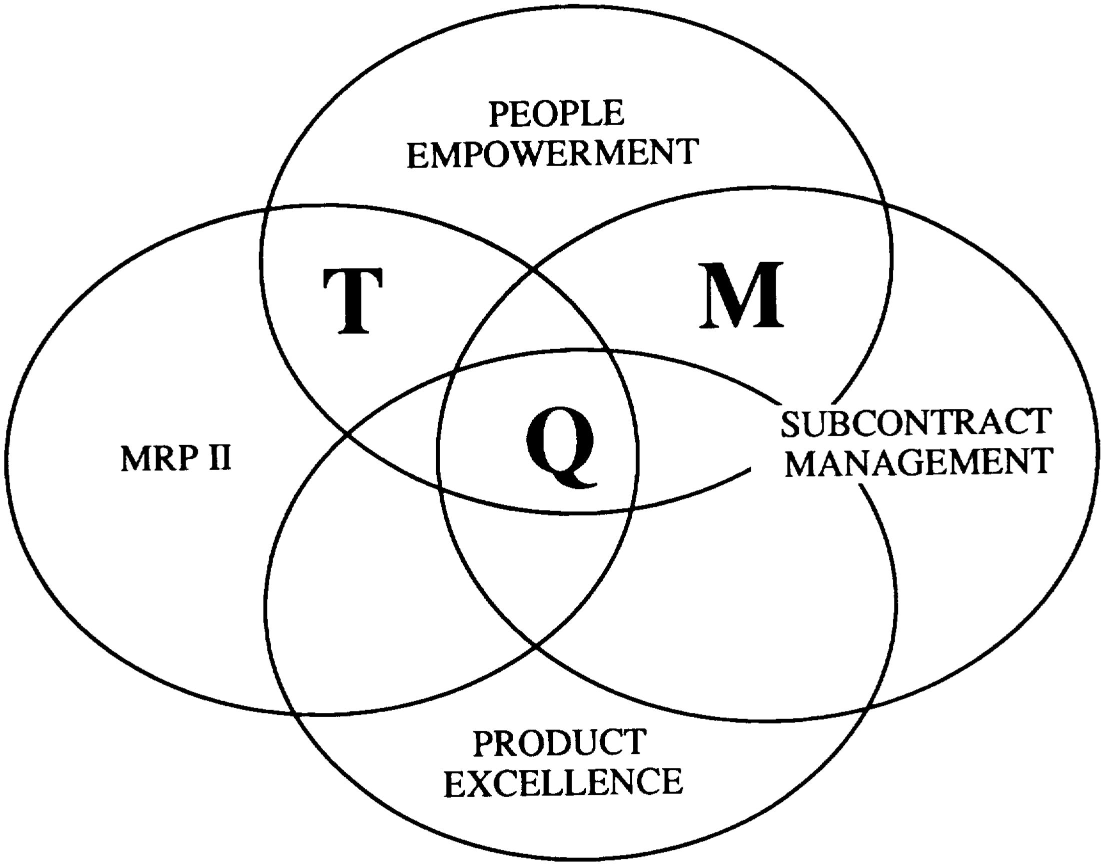

Figure 1 - TQM Primary Initiatives

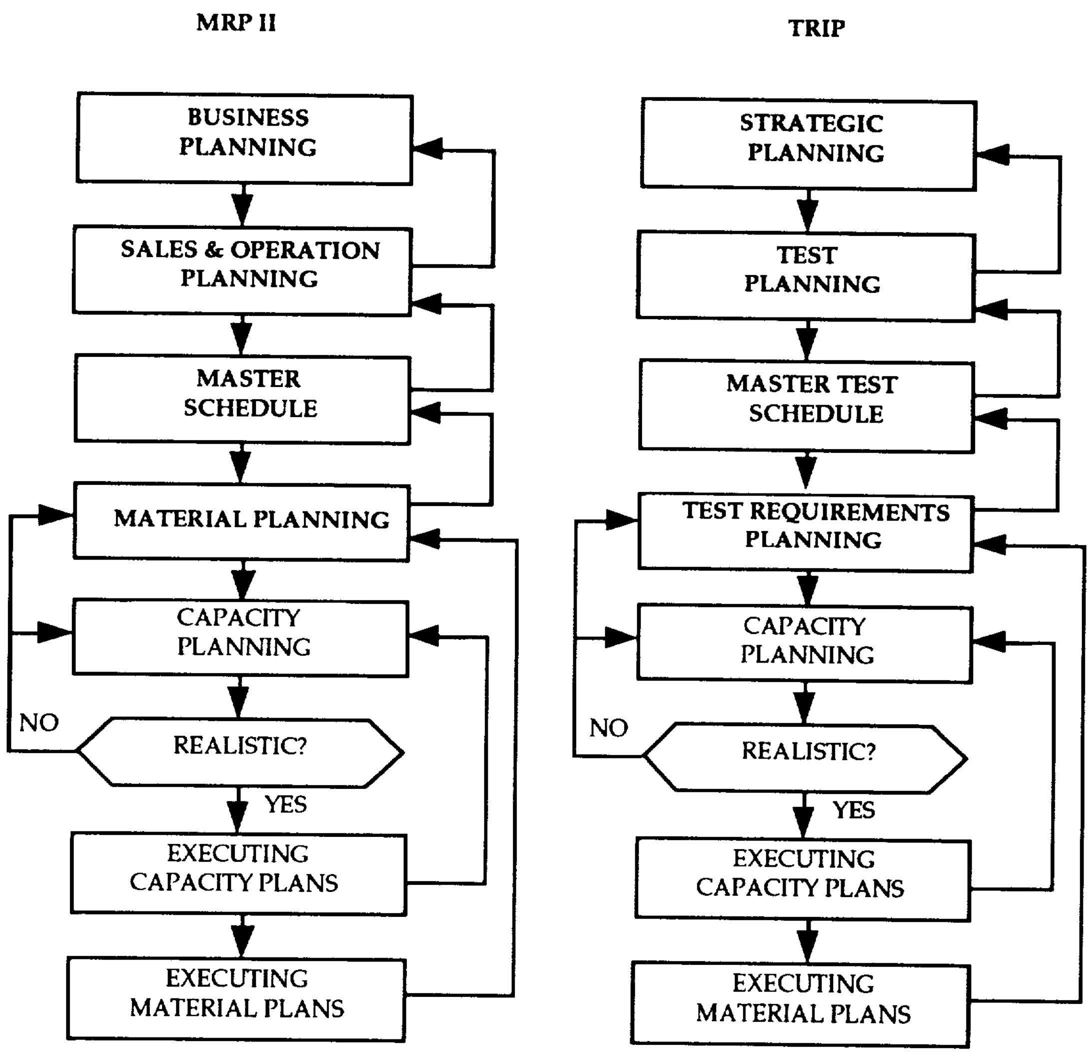

FIGURE 2 - MRPII VS. TEST RESOURCE INTEGRATED PLANNING (TRIP)

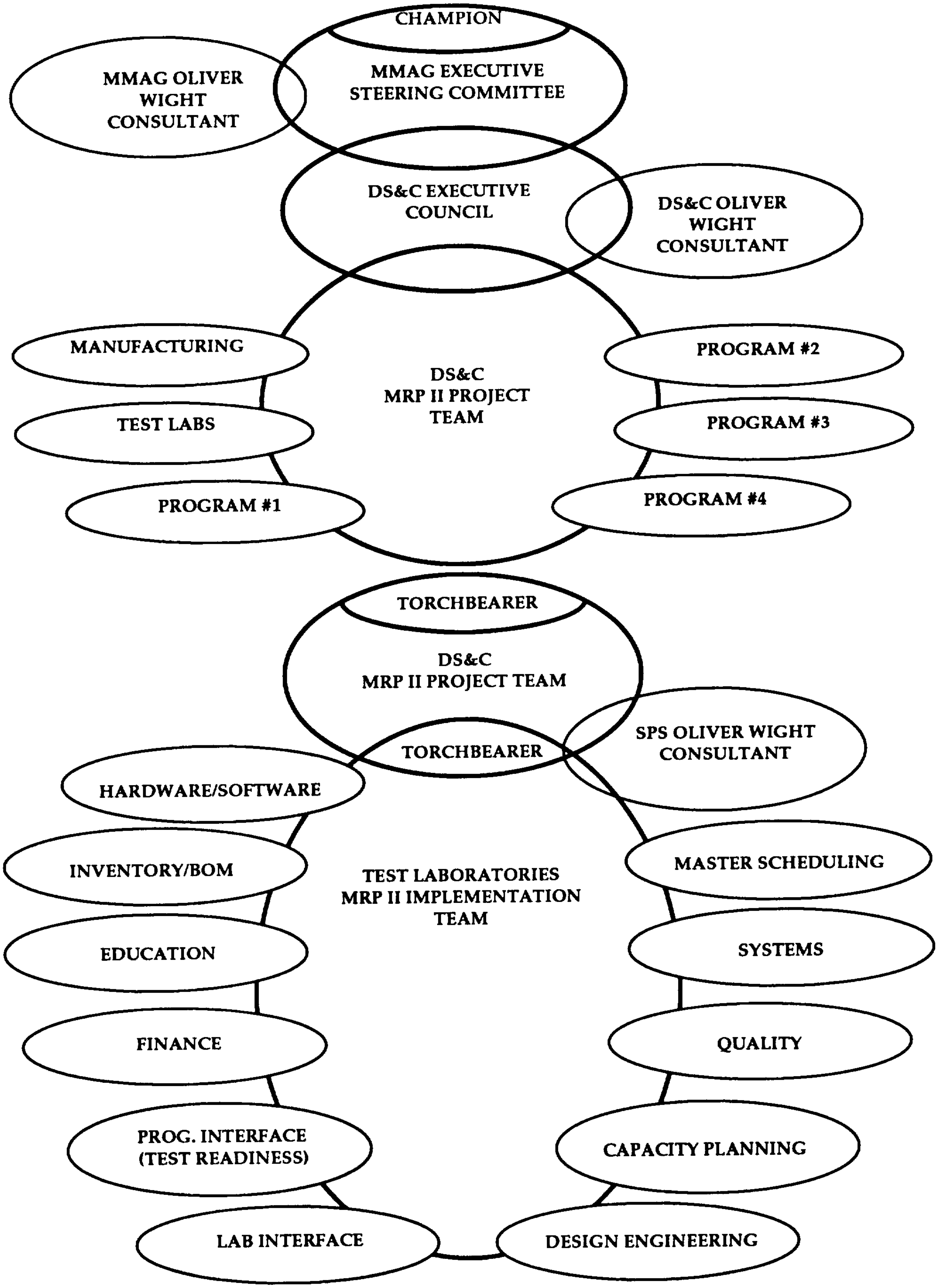

FIGURE 3 - SPACE SYSTEMS AND DS&C TEST LAB IMPLEMENTATION TEAMS

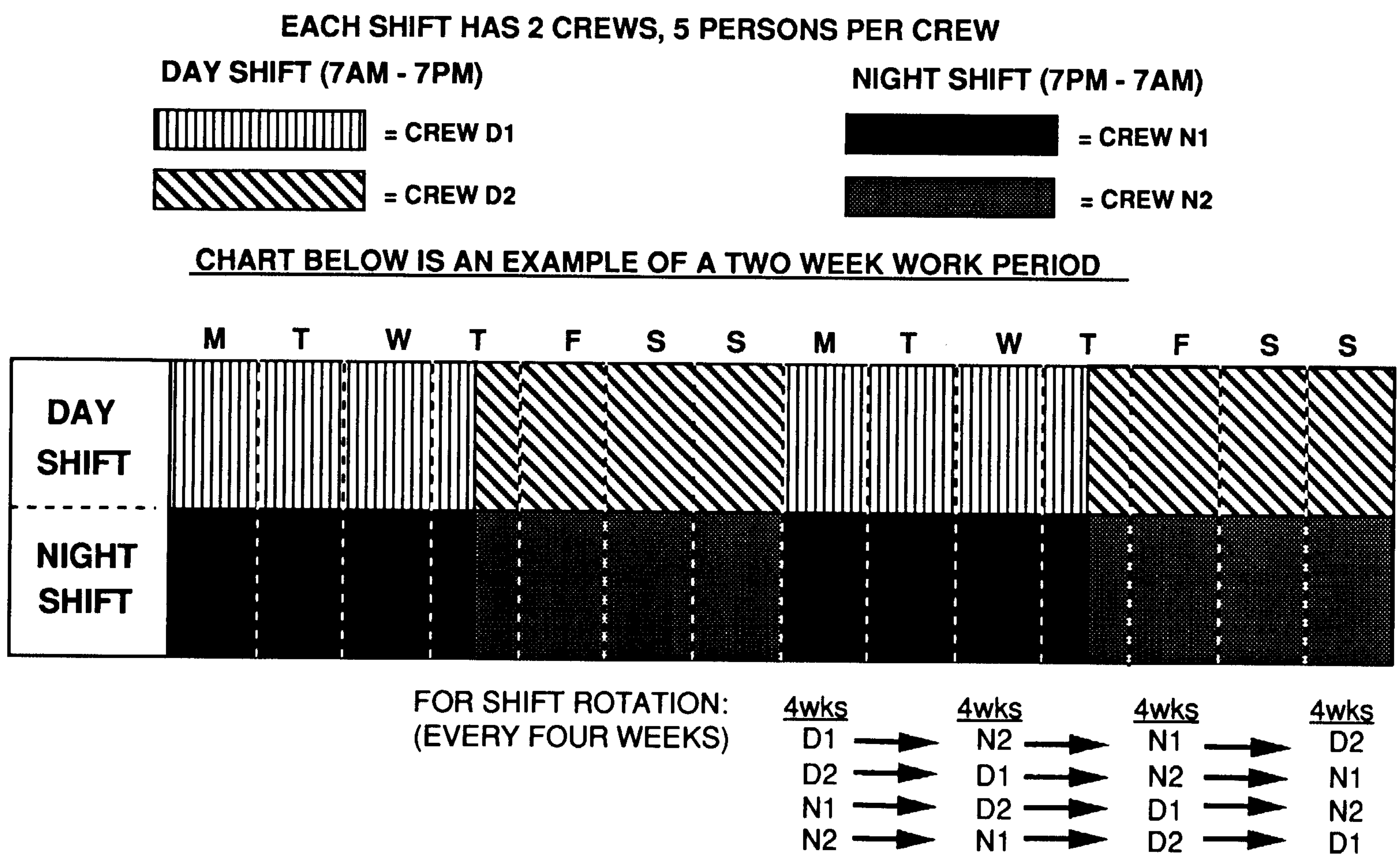

Figure 4 - 3.5 Day Workweek