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CROSS: A GDSS FOR THE EVALUATION AND PRIORITIZATION OF ENGINEERING SUPPORT REQUESTS AND ADVANCED TECHNOLOGY PROJECTS AT NASA

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ABSTRACT[1]

Objective evaluation and prioritization of Engineering Support Requests (ESRs) is a difficult task at the Kennedy Space Center (KSC) -- Shuttle Project Engineering Office. The difficulty arises from the complexities inherent in the evaluation process and the lack of structured information. The purpose of this project is to implement Consensus Ranking Organizational Support System (CROSS), a multiple criteria decision support system (DSS) developed at KSC, that captures the decision makers' beliefs through a series of sequential, rational, and analytical processes. CROSS utilizes Analytic Hierarchy Process (AHP), subjective probabilities, entropy concept, and Maximize Agreement Heuristic (MAH) to enhance the decision makers' intuition in evaluating ESRs. Some of the preliminary goals of the project are to:

- Revisit the Structure of the Ground Systems Working Team (GSWT) steering committee.
- Develop a template for ESR originators to provide more complete and consistent information about ESRs to the GSWT steering committee and stakeholders.
- Develop an objective and structured process for the initial screening of ESRs.
- Extensive training of the stakeholders and the GSWT steering committee members to eliminate the need for a facilitator.
- Automate the process as much as possible.
- Create an environment to compile Project Success Factor data on ESRs and move towards a disciplined system that could be used to address supportability threshold issues at the KSC.
- Investigate the possibility of an organization-wide implementation of CROSS.

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CROSS: A GDSS for the Evaluation and Prioritization of Engineering Support Requests and Advanced Technology Projects at NASA

Madjid Tavana

Introduction

Decreased availablity of funding and an increasing number of Engineering Support Requests (ESRs) has created more competition among the stakeholders at NASA - Kennedy Space Center. There is clearly a need to replace the current unstructured ESR evaluation and selection process. The current process lacks the accountability, ignores the participation, and limits the objectivity that can be achieved through Consensus Ranking Organizational Support System (CROSS). The more comprehensive and structured framework provided by CROSS promotes the participation and harmony among Management, The Ground System Working Team Steering Committee (GSWT-SC), ESR Originators, and Stakeholders.

A total of 30 ESRs as shown in Table 1 are being considered by the GSWT-SC for 1997 fiscal year.

Insert Table 1 Here

CROSS is a three-phase, eleven-step procedure which systematically assesses ESRs and provides a final ranking of these ESRs by calculating their Project Success Factor (PSF). The three phases of assessment as represented in Figure 1, include the *Interaction Phase*, *Integration Phase*, and *Interpretation Phase*. These phases along with their respective steps are described below:

Insert Figure 1 Here

I. Interaction Phase:

During this phase, Decision Makers (DMs) and stakeholders interact through a series of automated systems for the purpose of data gathering and processing. This phase includes the following steps:

1. DMs Identify stakeholder groups: In this step, DMs identify the stakeholders to participate in the evaluation process and obtain management approval. This identification is in line with the organizational mission, objectives, and management's fiscal year goals. Three groups of stakeholders are identified to evaluate fiscal year 1997 ESRs include: *Safety and Reliability*, *Supportability and Obsolescence*, and *Cost Benefit and Process Enhancement.*

2. DMs utilize AHP and EC to determine the importance weight of each stakeholder group (first round): AHP was introduced by Saaty (1972 and 1977a) to assist a DM in evaluating complex judgmental problems. AHP helps the DM assign numerical values to qualitative attributes by making trade-offs among them. The process which is described in Step 5, is confined to a series of pairwise comparisons. Saaty (1972) argues that a DM naturally finds it easier to compare two things than to compare all the items in a list. AHP also evaluates the consistency of the DM and allows for the revision of the responses. Because of the intuitive nature of the process and its power in resolving the complexity in a judgmental problem, AHP has been applied to many diverse decisions. A comprehensive list of the major applications of AHP, along with a description of the method and its axioms, can be found in Saaty (1972, 1977a, 1977b, 1980, and 1990), Weiss and Rao (1987) and Zahedi (1986). At the beginning of each evaluation cycle, DMs individually use EC software which is based on AHP to determine the importance weights of each stakeholder group. The results from the first round are presented in Table 2.

Insert Table 2 Here

3. DMs utilize AHP and EC to determine the importance weight of each stakeholder group (second round): DMs meet and review the first round anonymous feedback concerning individual and group weights. They are encouraged to share their viewpoints and perceptions during this feedback session. At the end of the meeting, DMs are given the opportunity to revise their weights with EC, given their new insight and understanding from other individuals. The second round results are presented in Table 2.

Insert Table 2 Here

4. Stakeholder groups identify their subcriteria: Each stakeholder group holds a separate meeting and develops their own set of subcriteria to be used in the evaluation of ESRs. A listing of all subcriteria fro all stakeholders along with their importance weights (which are described next) are presented in Figure 2 and Table 3.

Insert Figure 2 and Table 3 Here

5. Stakeholder groups utilize AHP and EC to determine the importance weight of their subcriteria: Members of different stakeholder groups use EC in brainstorming sessions and determine their group weight for each subcriterion identified earlier in step 4. Assuming that in the stakeholder i's mind, $c_1, c_2, \ldots, c_{N_i}$ are the N_i subcriteria that contribute to an ESR success. The stakeholder's goal is to assess the relative importance of these subcriteria. Saaty's Analytic Hierarchy Process (AHP) is a method of deriving a set of weights to be associated with each of the N_i subcriteria. Throughout the AHP, Stakeholder i is asked to compare each possible pair c_j, c_k of subcriteria and provide quantified judgments on which one of the subcriteria is more important and by how much. These judgments are represented by an N_i x N_i matrix:

$$A = (a_{jk}) \qquad (j,k=1, 2, \ldots, N_i)$$

If c_j is judged to be of equal importance as c_k, then $a_{jk}=1$
If c_j is judged to be more important than c_k, then $a_{jk}>1$
If c_j is judged to be less important than c_k, then $a_{jk}<1$

$$a_{jk} = 1/a_{kj} \qquad\qquad a_{jk} \neq 0$$

Thus, the matrix A is a reciprocal matrix (i.e., the entry a_{jk} is the inverse of the entry a_{kj}). a_{jk} reflects the relative importance of c_j compared with subcriteria c_k. For example, $a_{12}=1.25$ indicates that c_1 is 1.25 times as important as c_2.

Then, the vector w representing the relative weights of each of the N_i subcriteria can be found by computing the normalized eigenvector corresponding to the maximum eigenvalue of matrix A. An eigenvalue of A is defined as λ which satisfies the following matrix equation:

$$A\,w = \lambda\,w$$

where λ is a constant, called the eigenvalue, associated with the given eigenvector w. Saaty has shown that the best estimate of w is the one associated with the maximum eigenvalue (λ_{max}) of the matrix A. Since the sum of the weights should be equal to 1.00, the normalized eigenvector is used. Saaty's algorithm for obtaining this w is incorporated in the software Expert Choice.

One of the advantages of AHP is that it ensures that stakeholders are consistent in their pairwise comparisons. Saaty suggests a measure of consistency for the pairwise comparisons. When the judgments are perfectly consistent, the maximum eigenvalue, λ_{max}, should equal N_i, the number of subcriteria that are compared. In general, the responses are not perfectly consistent, and λ_{max} is greater than N_i. The larger the λ_{max}, the greater is the degree of inconsistency. Saaty defines the consistency index (CI) as $(\lambda_{max} - N_i) / (N_i - 1)$, and provides the following random index (RI) table for matrices of order 3 to 10. This RI is based on a simulation of a large number of randomly generated weights. Saaty recommends the calculation of a consistency ratio (CR), which is the ratio of CI to the RI for the same order matrix. A CR of 0.10 or less is considered acceptable. When the CR is unacceptable, the stakeholder is made aware that his or her pairwise comparisons are logically inconsistent, and he or she is encouraged to revise their judgment. These importance weights are presented in Figure 2 and Table 2.

n	3	4	5	6	7	8	9	10
RI	0.58	0.90	1.12	1.32	1.41	1.45	1.49	1.51

Insert Figure 2 and Table 3 Here

6. Stakeholder groups identify probabilities of occurrence of their subcriteria for the ESRs: Each stakeholder group receives a listing of all ESRs under consideration from the GSWT-SC. The stakeholder group will assign a probability to each subcriterion under each ESR. The assignment of probabilities is done by the group in a brainstorming session. This result is presented in Table 4.

II. Integration Phase:

In this phase all the data collected during the Interaction Phase are integrated and processed using a series of software programs including EXCEL, EC, ENTROSYS, and MAHS.

7. ENTROSYS is utilized to revise the importance weight of each stakeholder group determined in the second round: Entropy concepts will be used to revise the second round weights of the subcriteria based on the information provided by the stakeholders concerning the probabilities. Entropy Measurement Sub-System (ENTROSYS), an automated system will be used to perform all necessary calculations. Given that each subcriterion is an information source, the more information is revealed by a subcriterion, the more relevant it is. This intrinsic information will be used in parallel with the stakeholder group weights. The probabilities of occurrence are used to measure this average intrinsic information. The more different the probabilities of a subcriteria are for a set of ESRs, the larger is the contrast intensity of the subcriterion and the greater is the amount of information transmitted by that subcriterion. The model views decision making as an information processing task and a large amount of information about the ESRs is processed through their subcriteria. Given the fact that subcriteria are information sources, the more information is revealed by the *j-th* subcriteria and the *i-th* stakeholder, the more relevant is the subcriteria in the decision analysis. Zeleny (1982) argues that this intrinsic information must be used in parallel with the initial weight assigned to various subcriteria by the DM. In other words, the overall importance weight of a subcriteria, F_{ij}, is directly related to the intrinsic weight, f_{ij}, reflecting average intrinsic information developed by a set of ESRs, and the subjective weight, W_i, reflecting the subjective assessment of its importance rendered by the DM. The probabilities of occurrence are used to measure this average intrinsic information. The more different the probabilities of a subcriteria are for a set of ESRs, the larger is the contrast intensity of the subcriteria, and the greater is the amount of information transmitted by that subcriteria. In this section, all formulas necessary for calculating the overall importance weight of opportunities are presented. Assume that vector $p_{ij} = (p_{ij}^1, \ldots, p_{ij}^q)$ characterizes the set P in terms of the *j-th* subcriteria for the *i-th* stakeholder and define:

$$P_{ij} = \sum_{m=1}^{q} p_{ij}^m \qquad (i = 1, 2, \ldots, N_i \text{ and } j = 1, 2, \ldots, N_j)$$

Then, the entropy measure of the *j-th* subcriteria for the *i-th* stakeholder is:

$$e(p_{ij}) = -K\sum_{m=1}^{q} \frac{p_{ij}^m}{P_{ij}} \ln \frac{p_{ij}^m}{P_{ij}}$$

Where $K \rangle 0$, ln is the natural logarithm, $0 \le p_{ij}^m \le 1$, and $e(p_{ij}) \ge 0$. When all p_{ij}^m are equal for a given i and j, then $p_{ij}^m / P_{ij} = 1/q$, and $e(p_{ij})$ assumes its maximum value, which is $e_{\max} = \ln q$. By setting $K = 1/e_{\max}$, we achieve $0 \le e(p_{ij}) \le 1$. This normalization is necessary for meaningful comparisons. In addition, the total entropy is defined as:

$$E = \sum_{j=1}^{N_j} e(p_{ij})$$

The smaller $e(p_{ij})$ is, the more information is transmitted by the *j-th* subcriteria for the *i-th* stakeholder and the larger $e(p_{ij})$, the less information is transmitted. When $e(p_{ij}) = e_{\max} = \ln q$, the *j-th* subcriteria for the *i-th* stakeholder is not transmitting any useful information. Next, the intrinsic weight is calculated as:

$$f_{ij} = \frac{1}{N_i - E}\left[1 - e(p_{ij})\right]$$

Since f_{ij} is inversely related to $e(p_{ij})$, $1 - e(p_{ij})$ is used instead of $e(p_{ij})$ and normalized to make sure $0 \le f_{ij} \le 1$ and

$$\sum_{j=1}^{N_j} f_{ij} = 1$$

The more different the subjective probabilities, p_{ij}^m, are, the larger f_{ij}, and the more important the *j-th* subcriteria for the *i-th* stakeholder is. When all the subjective probabilities, p_{ij}^m, are equal, then $f_{ij} = 0$. In order to calculate the overall importance weight of the *j-th* subcriteria for the *i-th* stakeholder, F_{ij}, the intrinsic weight, f_{ij}, is multiplied by the subjective weight, w_{ij}, and then the product is normalized:

$$F_{ij} = \frac{f_{ij} . w_{ij}}{\sum_{j=1}^{N_j} f_{ij} . w_{ij}}$$

The revised importance weights along with the initial and intrinsic weights are presented in Table 5.

8. EXCEL is utilized to calculate PSFs and the committee ranking of ESRs: The model described next will integrate *importance weights of stakeholders* with the *weights for subcriteria* and the *probabilities of occurrence* to arrive at a set of PSFs. The higher the PSF, the more desirable an ESR is. These calculations are done using a simple model developed with Microsoft EXCEL.

9. EXCEL and MAHS are utilized to provide committee and consensus rankings of the ESRs enhanced with sensitivity analysis: Microsoft EXCEL and Maximize Agreement Heuristic System (MAHS) are used to provide a consensus ranking of the ESRs. Assume that each one of our d DMs has ranked q ESRs. Assuming further that the opinions of the d DMs are to be valued equally, the Maximize Agreement Heuristic (MAH) seeks to arrive at the consensus ranking of the ESRs for the group as a whole. According to Beck and Lin (1983), MAH defines an agreement matrix, A, where each element a_{mn} represents the number of DMs who have preferred ESR m to ESR n. Strict preference is important. If a DM is indifferent between m and n, he or she is not counted in a_{mn}. The sum of a_{mn} for each ESR m across all columns represents the positive preference vector, C, where

$$C_m = \sum_{n=1}^{q} a_{mn}, \qquad (m=1,2,...,q)$$

Similarly, the sum of a_{mn} for each ESR across all rows represents the negative preference vector, R, where

$$R_m = \sum_{n=1}^{q} a_{mn}, \qquad (m=1,2,...,q)$$

If for ESR m, $C_m=0$, implying that no DM prefers ESR m to any other ESR, ESR m is placed at the bottom [in subsequent iterations, at the next available position at the bottom] of the final consensus ranking. However, if for ESR m, $R_m=0$, implying that no DM prefers any other ESR over ESR m, ESR m is placed at the top [in subsequent iterations, at the next available position at the top] of the ranking.

When there are no zero values in either C or R, the difference in total decision maker agreement and disagreement ($C_m - R_m$) is calculated for each ESR, and ESR m with the largest absolute difference $|C_m - R_m|$ is considered. If ($C_m - R_m$) is positive, ESR m is placed in the next available position at top of the final consensus ranking, and if the difference is negative, ESR m is placed in the next available position at the bottom of the consensus ranking. Any ties are broken arbitrarily. Once an ESR is assigned a position in the final consensus ranking, that ESR is eliminated from further consideration. The remaining ESRs form a new matrix and the process is repeated until all ESRs are ranked. ESR rankings of the voting members of the GSWT-SC are presented in Tables 5 and 6 and Figure 3.

Insert Tables 5 and 6 and Figure 3 Here

III. Interpretation Phase:

During this phase all the synthesized data are presented to the GSWT-SC for the purpose of decision making.

10. DMs discuss the consensus and committee rankings and recommend a final ranking of ESRs to management: DMs meet and discuss the results of committee and consensus rankings. A final recommendation that includes a ranking of all ESRs will be forwarded to management for approval.

11. Management reviews the DMs' ranking of ESRs and makes the final decision: Management reviews the recommendation of the DMs and after considering various organizational implications, makes the final Selection.

The Model

To formulate an algebraic model , let us assume:

S^m	=	Project Success factor of the *m-th* ESR; ($m = 1, 2, ..., q$)
W_i	=	The importance weight of the *i-th* Stakeholder; ($i = 1, 2, ..., N_i$)
F_{ij}	=	The Overall Importance Weight of the *j-th* Subcriterion and the *i-th* Stakeholder; ($i = 1, 2, ..., N_i$ and $j = 1, 2, ..., N_j$)
P_{ij}^m	=	The *m-th* Probability of Occurrence of the *j-th* Subcriteria for the *i-th* Stakeholder;($m = 1, 2, ..., q; i = 1, 2, ..., N_i$; and $j = 1, 2, ..., N_j$)
N_i	=	Number of Stakeholders
N_j	=	Number of Subcriteria for the *i-th* Stakeholder

Given the above notations, the Project Success Factor for the *m-th* ESR is:

$$S^m = \sum_{i=1}^{N_i} W_i \left(\sum_{j=1}^{Nj} F_{ij} \left(P_{ij}^m \right) \right)$$

Where:

$1 \geq S^m \geq$

$$\sum_{i=1}^{N_i} W_i = 1$$

$$\sum_{j=1}^{Nj} F_{ij} = 1$$

and

$0 \leq P_{ij}^m \leq 1$

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Figure 1: Consensus Ranking Organizational Support System (CROSS)

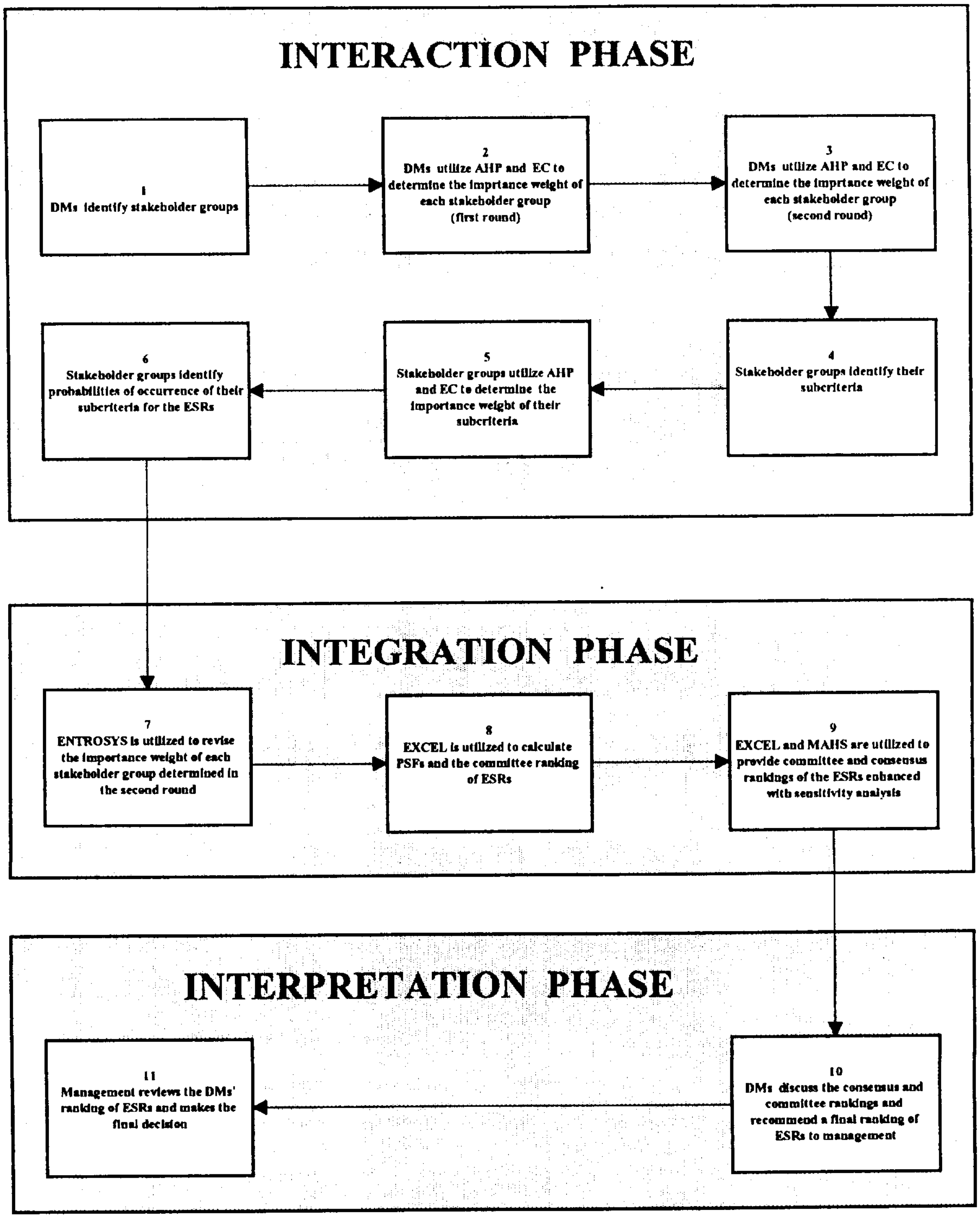

Figure 2: ESR Evaluation Subcriteria (Hierarchy and Relative Weights)

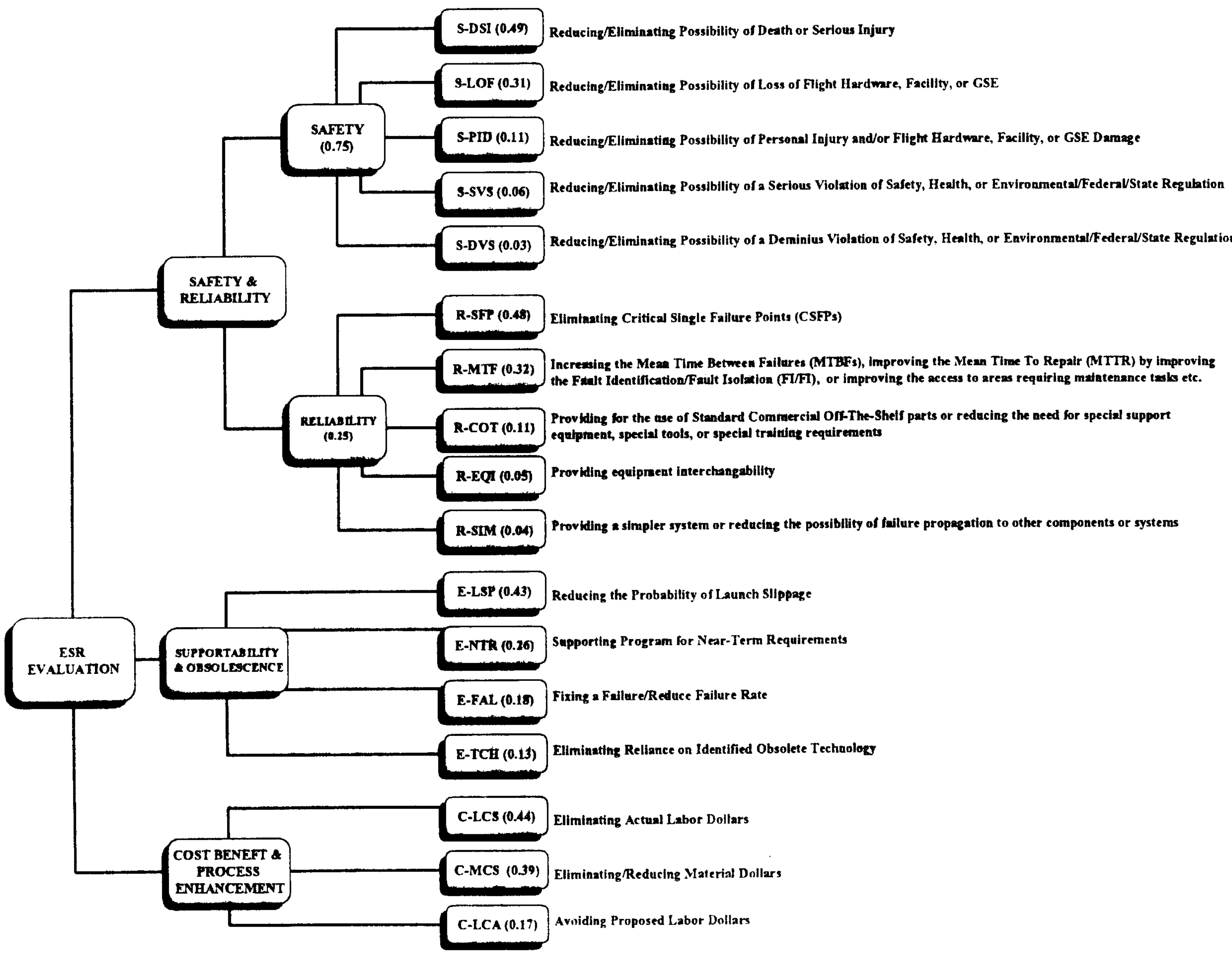

Figure 3: A Graphical View of the ESRs

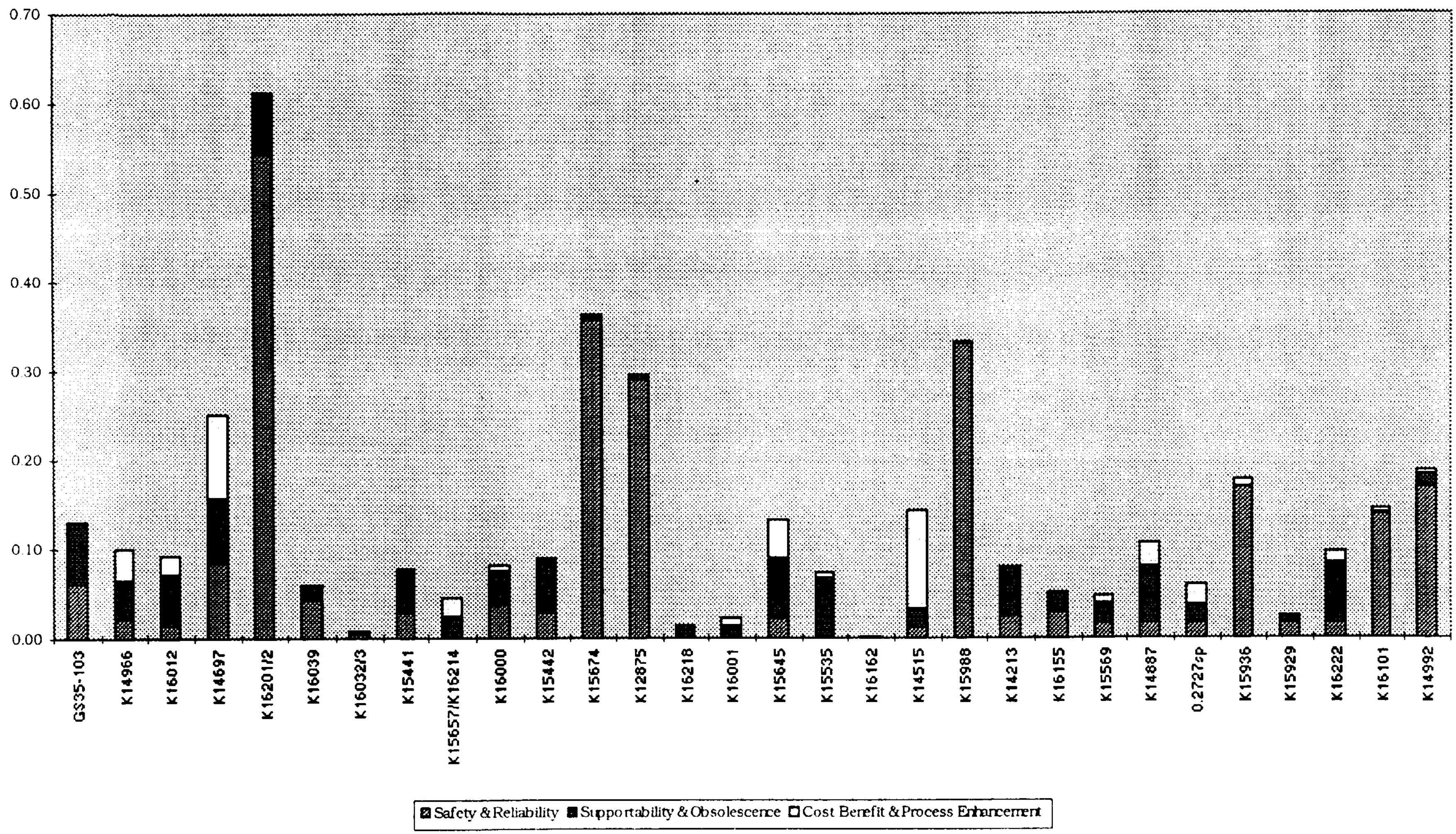

Table 1: Engineering Support Requests (Fiscal Year 1997)

Project No.	Organization	ESR No.	MOD
1	TE	GS35-103	$83,800
2	TE	K14966	$25,000
3	TE	K16012	$40,000
4	TE	K14697	$172,000
5	TE	K16201/2	$350,000
6	TE	K16039	$6,250
7	TE	K16032/3	$36,000
8	TE	K15441	$14,130
9	TE	K15657/K16214	$131,835
10	TE	K16000	$36,000
11	TE	K15442	$16,420
12	TE	K15674	$18,000
13	TE	K12875	$23,000
14	TE	K16218	$89,100
15	TE	K16001	$28,100
16	TV	K15645	$47,476
17	TV	K15535	$110,662
18	TV	K16162	$8,400
19	TV	K14515	$117,647
20	TV	K15988	$5,980
21	TV	K14213	$84,728
22	TV	K16155	$31,140
23	TV	K15569	$26,988
24	TV	K14887	$25,800
25	TV	0.2727sp	$37,000
26	TV	K15936	$29,000
27	TV	K15929	$13,938
28	TV	K16222	$20,000
29	TV	K16101	$4,200
30	TV	K14992	$2,856
		Total	$1,635,450

Table 2: Stakeholders' Relative Weights for the Voting Members of GSWT Steering Committee

Round 1

	Alexander	Allison	Kelley	Lee	Tootill	Normalized Mean
Safety & Reliability	0.71	0.65	0.76	0.76	0.63	0.71
Supportability & Obsolescence	0.16	0.28	0.15	0.15	0.28	0.20
Cost Benefit & Process Enhancement	0.13	0.07	0.09	0.09	0.09	0.09
Inconsistency Ratio	0.02	0.06	0.03	0.03	0.08	

Round 2

	Alexander	Allison	Kelley	Lee	Tootill	Normalized Mean
Safety & Reliability	0.60	0.57	0.76	0.63	0.53	0.62
Supportability & Obsolescence	0.25	0.33	0.15	0.26	0.33	0.26
Cost Benefit & Process Enhancement	0.15	0.10	0.09	0.11	0.14	0.12
Inconsistency Ratio	0.05	0.02	0.03	0.04	0.05	

Table 3: ESR Evaluation Subcriteria (Operational Definitions)

Code	Weight	Safety Subcriteria	Operational Definition
S-DSI	0.49	Reducing/Eliminating Possibility of Death or Serious Injury	Consequences of an action could be personal death or serious injury from potential safety and/or health hazard.
S-LOF	0.31	Reducing/Eliminating Possibility of Loss of Flight Hardware, Facility, or GSE	Consequences of an action could be loss of flight hardware, facility, or GSE from potential safety hazard.
S-PID	0.11	Reducing/Eliminating Possibility of Personal Injury and/or Flight Hardware, Facility, or GSE Damage	Consequences of an action could be personal injury and/or flight hardware, facility, or GSE damage from potential safety, health, and/or environmental hazard.
S-SVS	0.06	Reducing/Eliminating Possibility of a Serious Violation of Safety, Health, or Environmental/Federal/State Regulation	Consequences of an action could be a safety/federal citation and/or monthly fine arising from serious safety, health, and/or environmental standard violation.
S-DVS	0.03	Reducing/Eliminating Possibility of a Deminius Violation of Safety, Health, or Environmental/Federal/State Regulation	Consequences of an action could be a safety/federal citation arising from a deminius safety, health, and/or environmental standard violation.

Code	Weight	Reliability Subcriteria	Operational Definition
R-SFP	0.48	Eliminating Critical Single Failure Points (CSFPs)	Eliminates a component whose failure to perform its intended function could result in loss of life/vehicle, loss (damage) of a vehicle system, or loss of life/vehicle during the existence of a hazardous condition.
R-MTF	0.32	Increasing the Mean Time Between Failures (MTBFs), improving the Mean Time To Repair (MTTR) by improving the Fault Identification/Fault Isolation (FI/FI), or improving the access to areas requiring maintenance tasks etc.	Increases the average system operating time between failures of components of the system or of the entire system, reduces the average time it takes to repair an improperly functioning system by reducing the amount of time required to trouble-shoot and isolate a system problem, or improves the accessibility of maintenance personnel when their support is required.
R-COT	0.11	Providing for the use of Standard Commercial Off-The-Shelf parts or reducing the need for special support equipment, special tools, or special training requirements	Utilizes commercial, off-the-shelf components that have historical data available instead of unique, one-of-a-kind components or reduces the necessary support equipment, special tools, or unique training skills required to operate and maintain the system properly.
R-EQI	0.05	Providing equipment interchangability	Ensures that maintainability is not inhibited for all field units because of logistic problems associated with the special selection and storage of replacement components.
R-SIM	0.04	Providing a simpler system or reducing the possibility of failure propagation to other components or systems	Makes system success dependent on fewer items and thereby decreases the potential for failure of the system or reduces the chance that a component failure will propagate to another component within the system and/or to another system.

Code	Weight	Supportability & Obsolescence Subcriteria	Operational Definition
E-LSP	0.43	Reducing the Probability of Launch Slippage	Ability to reduce the probability of launch slippage.
E-NTR	0.26	Supporting Program for Near-Term Requirements	Ability to provide continuous support to launch and landing.
E-FAL	0.18	Fixing a Failure/Reduce Failure Rate	Ability of correcting an immediate (flow sensitive) failure.
E-TCH	0.13	Eliminating Reliance on Identified Obsolete Technology	Ability to eliminate identified and known obsolescence from occurring in systems and hardware.

Code	Weight	Cost Benefit & Process Enhancement Subcriteria	Operational Definition
C-LCS	0.44	Eliminating Actual Labor Dollars	Labor cost savings reflects actual labor dollars that are eliminated and are not available for other activities.
C-MCS	0.39	Eliminating/Reducing Material Dollars	Material cost savings reflect actual material dollars that are eliminated or reduced.
C-LCA	0.17	Avoiding Proposed Labor Dollars	Labor cost avoidance reflects proposed labor dollars that are avoided and are available for other activities.

Table 4: Stakeholders' Probability Judgments

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Safety and Reliability	S-DSI	0.10	0.00	0.00	0.00	1.00	0.10	0.00	0.00	0.00	0.00	0.00	1.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	S-LOF	0.10	0.00	0.00	0.20	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.80	0.00
	S-PID	0.10	0.00	0.00	0.40	0.50	0.10	0.10	0.00	0.00	0.00	0.00	1.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.90	0.00	0.00	0.00	0.90	0.00	0.00	0.90	1.00
	S-SVS	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	S-DVS	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	R-SFP	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
	R-MTF	0.00	1.00	0.50	1.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
	R-COT	0.50	0.50	0.50	1.00	1.00	0.00	0.00	1.00	0.00	0.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	R-EQI	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	R-SIM	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Supportability and Obsolescence	E-LSP	0.10	0.00	0.10	0.10	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.20	0.00	0.00
	E-NTR	0.50	0.70	0.50	0.20	0.60	0.50	0.20	0.50	0.40	0.00	0.60	0.40	0.30	0.30	0.10	0.70	0.50	0.10	0.50	0.10	0.80	0.20	0.10	0.80	0.30	0.00	0.50	0.50	0.10	0.70
	E-FAL	0.40	1.00	0.50	0.80	0.40	0.20	0.00	0.50	0.00	0.40	0.60	0.00	0.00	0.30	0.40	0.00	0.90	0.00	0.40	0.00	0.10	0.50	0.00	1.00	0.50	0.00	0.00	0.80	0.00	0.10
	E-TCH	0.80	0.00	0.40	0.70	0.80	0.00	0.00	0.60	0.00	0.70	0.80	0.00	0.00	0.00	0.00	1.00	0.80	0.00	0.00	0.00	1.00	0.00	0.10	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Cost Benefit and Process Enhancement	C-LCS	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00
	C-MCS	0.00	0.80	0.50	0.90	0.00	0.00	0.00	0.00	0.40	0.10	0.00	0.00	0.00	0.00	0.00	1.00	0.20	0.00	1.00	0.00	0.00	0.00	0.00	0.50	0.40	0.00	0.00	0.30	0.10	0.00
	C-LCA	0.00	0.70	0.50	0.00	0.00	0.00	0.10	0.10	0.70	0.10	0.10	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.90	0.00	0.00	0.30	0.10	0.90	0.80	0.20	0.00	0.20	0.10	0.30

Table 5: ESR Rankings of the Voting Members of the GSWT Steering Committee

	Project Number																													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Alexander	5	12	20	13	4	30	26	19	16	29	1	24	2	28	3	11	10	21	8	17	25	6	22	9	23	27	15	14	7	18
Allison	5	12	20	13	4	30	26	1	16	29	19	24	28	2	3	11	21	17	10	8	25	6	22	23	9	27	15	14	7	18
Kelley	5	12	20	13	4	30	26	29	1	19	16	2	24	10	11	28	3	8	21	6	22	25	17	23	9	27	15	14	7	18
Lee	5	12	20	13	4	30	26	29	19	1	16	24	2	28	3	11	10	21	8	17	6	25	22	23	9	27	15	14	7	18
Tootill	5	12	20	4	13	19	30	16	26	1	24	29	28	2	3	11	17	21	10	8	25	6	9	22	23	15	27	14	7	18
Consensus Ranking	**5**	**12**	**20**	**13**	**4**	**30**	**26**	**19**	**1**	**16**	**29**	**24**	**2**	**28**	**3**	**11**	**10**	**21**	**8**	**17**	**6**	**25**	**22**	**23**	**9**	**27**	**15**	**14**	**7**	**18**

Table 6: Consensus Ranking of the ESRs Using MAH

Rank	Project No.	Organization	ESR No.	MOD	CUM. MOD
1	5	TE	K16201/2	$350,000	$350,000
2	12	TE	K15674	$18,000	$368,000
3	20	TV	K15988	$5,980	$373,980
4	13	TE	K12875	$23,000	$396,980
5	4	TE	K14697	$172,000	$568,980
6	30	TV	K14992	$2,856	$571,836
7	26	TV	K15936	$29,000	$600,836
8	19	TV	K14515	$117,647	$718,483
9	1	TE	GS35-103	$83,800	$802,283
10	16	TV	K15645	$47,476	$849,759
11	29	TV	K16101	$4,200	$853,959
12	24	TV	K14887	$25,800	$879,759
13	2	TE	K14966	$25,000	$904,759
14	28	TV	K16222	$20,000	$924,759
15	3	TE	K16012	$40,000	$964,759
16	11	TE	K15442	$16,420	$981,179
17	10	TE	K16000	$36,000	$1,017,179
18	21	TV	K14213	$84,728	$1,101,907
19	8	TE	K15441	$14,130	$1,116,037
20	17	TV	K15535	$110,662	$1,226,699
21	6	TE	K16039	$6,250	$1,232,949
22	25	TV	0.2727sp	$37,000	$1,269,949
23	22	TV	K16155	$31,140	$1,301,089
24	23	TV	K15569	$26,988	$1,328,077
25	9	TE	K15657/K16214	$131,835	$1,459,912
26	27	TV	K15929	$13,938	$1,473,850
27	15	TE	K16001	$28,100	$1,501,950
28	14	TE	K16218	$89,100	$1,591,050
29	7	TE	K16032/3	$36,000	$1,627,050
30	18	TV	K16162	$8,400	$1,635,450