WORKERS AT THE EDGE; HAZARD RECOGNITION AND ACTION

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ABSTRACT

Supervisors and workers report they work in the danger zone where errors can have terrible consequences. Current best practice safety programs aim to train and motivate workers to avoid hazards. These programs attempt to counter pressure for improved efficiency and reduced effort but are only partly successful. A new approach has been proposed that aims to improve safety by increasing the ability of workers to work safely closer to the edge where control is lost and accidents occur (Howell, et al, 2002). In this paper we review and propose the implementation of an approach drawn from aviation. Airline safety has been improved by a system designed to alert pilots of hazards identified by anyone on the flight deck. Crew Resource Management (CRM) protocols establish a safe and emphatic way to alert the pilot that the safety of the flight is at risk. This system is designed to overcome the reluctance of junior members to make suggestions to more senior officers. Specific simple communication rules are established to assure the gravity and source of the concern is made apparent without disrupting normal roles and responsibilities. While flying a plane is different from working in a construction crew, we suspect that construction workers are reluctant, for a variety of reason to speak up when hazards are encountered. Taking risks is considered part of the job. This paper describes CRM, and proposes an experimental application in construction.

KEY WORDS

Construction safety, Crew Resource Management, Human Error, Error Management

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INTRODUCTION

The organizational pressure for productivity and the individual urge to minimize effort, push workers to work near the boundary of safe performance (Howell et al 2001, Rasmussen 1997). Safety programs create a counter pressure that aims to minimize exposure to hazards, and keep workers away from hazardous situations. In construction, worker training and motivation is assumed to be the key to preventing accidents. The most common practices that construction companies use to improve safety include:

- Training in safety requirements, safe use of tools, equipment operation, etc.
- Toolbox talks reviewing tool use, and project hazards.
- Pre-task hazard planning
- Inspections by safety and project management personnel.
- Safety performance incentives that reward for individuals or project teams.
- A citation program to recognize both good and bad behavior.
- Drug and alcohol screening
- Use of protective equipment to reduce the consequences of incidents.

However, the effectiveness of these strategies to prevent accidents is limited: The educational and motivational pressure to work safely is always at odds with the organizational imperative to increase productivity and the individual's urge to expend less effort. As a result, workers will often be working near the edge, where errors or normal variation in performance may cause workers to lose control. While errors will always occur in complex and dynamic situations, the consequences of errors increase as workers move closer to the boundary of safe performance. Dire consequences follow when workers approach the edge where even a minor error can lead to loss of control.

NEW APPROACH TO SAFETY

Rasmussen's model (1994, 1997) recognizes the pressures that push workers towards more risky behaviors. Based on Rasmussen's model (1994, 1997), Howell (2001) identified three zones of operations, illustrated in Figure 1: Safe zone, Hazard zone, and Loss of Control zone. Errors may occur in each zone. In a sense, the distance between the location of the work and the boundary where control is lost is the margin for error. Workers in the safe zone are only threatened by large and infrequent errors. Smaller errors do not propagate to injury or damage. Work becomes more sensitive to error as workers approach the edge where control is lost. In the Hazard Zone, even minor errors can quickly result in loss. Based on this model three strategies are proposed for improving safety:

1. IN THE SAFE ZONE: Enlarge the safe zone through planning the operation using First Run Studies to eliminate the opportunity for error and to protect from those that cannot be eliminated. Check the actual method against the plan.

2. AT THE EDGE: Make visible the boundary beyond which work is no longer safe because a hazard can be released by even a small error. Teach people how to recognize the boundary and how to detect and recover from errors at the edge of control.
3. OVER THE EDGE: Design ways to limit the effect of the hazard once control is lost.

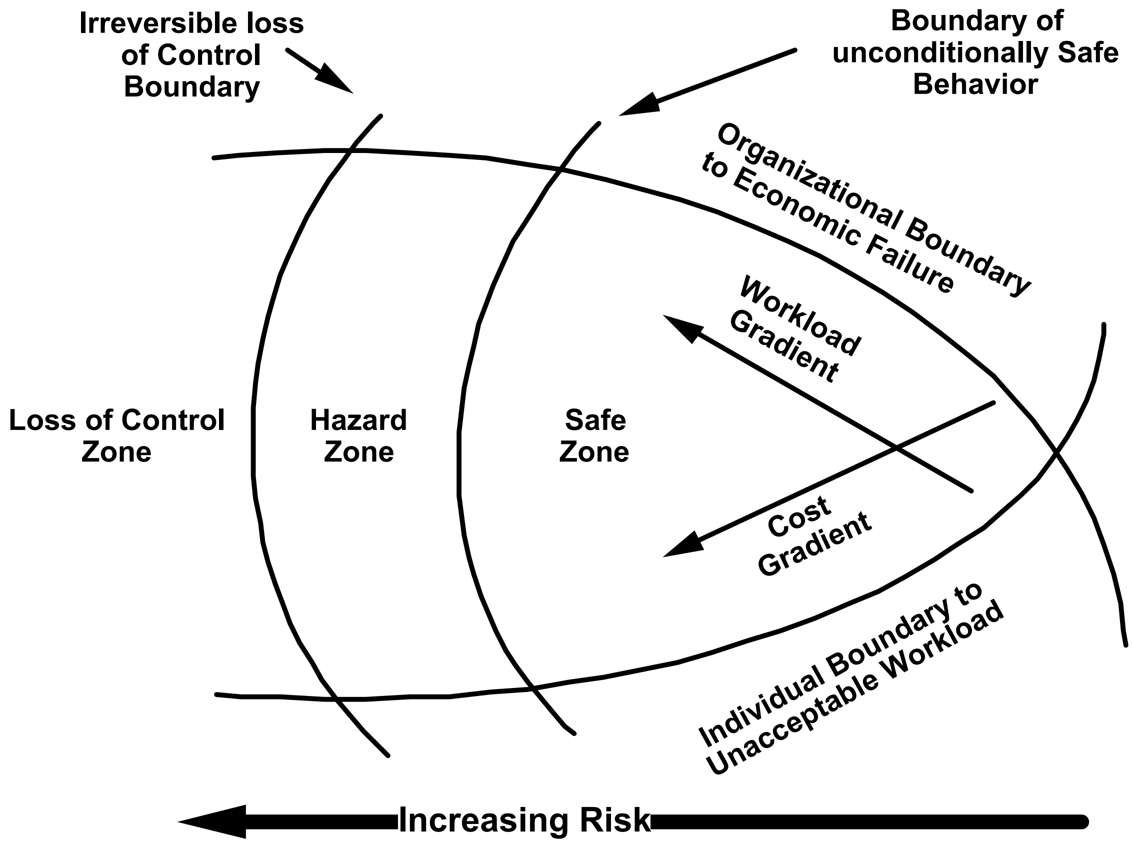

Figure 1: Three Zones of risk (Howell 2001)

Current best safety practices try to keep workers in the safe zone, by establishing rules of safe behavior and then training and motivating workers to comply with these rules. Behavior-based safety also trains workers to work in the safe zone, but it differs in the training approach, using on-the-job observations and positive feedback, and measurements of unsafe behaviors. The fundamental premise is that such compliance will result in the workers being in the "safe zone." Taking a more realistic and less 'moralistic' view, the new model acknowledges that workers move toward and eventually operate in the hazard zone where errors (or even normal variations in performance) can lead to the loss of control. This descriptive model does not give license to workers to willingly violate safety rules, but acknowledges that they will be in hazardous situations. Consequently, we need strategies to increase their ability to work safely in the hazard zone. Working near the edge requires increased awareness of the threats and potential errors, and effective error management to prevent loss of control.

The Crew Resource Management System, developed in aviation, focuses on threat recognition and error management within the crew. This paper reports on this approach, and proposes the investigation and implementation of a similar strategy to construction.

THE CREW RESOURCE MANAGEMENT SYSTEM

IMPORTANCE OF GROUP INTERACTION IN AVIATION

Airline accident investigation lead to the surprising conclusion that a high proportion of airline accidents occur because of "controlled flight into the ground." This means that the plane was under control but that pilot did not realize the danger. More disturbing, the investigations, often from cockpit tape recorders, show that someone in the crew knew the flight was at risk but was unable to get this message to the pilot. NASA researchers analyzed the causes of jet transport accidents and incidents between 1968 and 1976 (Cooper, White & Lauber, 1980; Murphy, 1980) and concluded that pilot error was more likely to reflect failures in team communication and coordination than deficiencies in technical proficiency. Human factors issues related to interpersonal communication have been implicated in between 70% and 80% of all accidents each year over the past twenty. Correspondingly, over 70% of the first 28,000 reports made to NASA's Aviation Safety Reporting System (which allows pilots to confidentially report aviation incidents) were found to be related to communication problems (Connell, 1995).

Communication is essential if crewmembers are to share a mental model, or common understanding of the nature of the situation and factors relevant to the flight safety and efficiency. This is not to say that effective communication can overcome inadequate technical flying proficiency, but rather the contrary, that good "stick & rudder" skills cannot overcome the adverse effects of poor communication (Sexton and Helmreich 2000). Ruffell Smith's (1979) landmark full-mission simulator study showed that crew performance was more closely associated with the quality of crew communication than with the technical proficiency of individual pilots or increased physiological arousal as a result of higher environmental workload. No differences were found between the severity of the errors made by effective and ineffective crews, rather, it was the ability of the effective crews to communicate that kept their errors from snowballing into undesirable outcomes. The accident analyses, simulator observations and pilot interviews confirmed the need for non-technical training, to improve pilot leadership, command, decision-making, communication and teamwork.

CREW RESOURCE MANAGEMENT SYSTEM

In response to this startling information, the Crew Resource Management (CRM) system was first developed in 1979, as an outgrowth of NASA research into the causes of air transport accidents. CRM is "an active process by crewmembers to identify significant threats to an operation, communicate them to the pilot and carry out a plan to avoid or mitigate each threat" (Helmreich et al. 1999a). When first developed, the term *Cockpit Resource Management* was used to describe the process of training crews to reduce "pilot error" by making better use of the human resources on the flight deck (Helmreich et al 1999b). CRM emphasizes the **key non-technical skills** that affect operational safety and includes concepts such as team building, briefing strategies, situation awareness, stress management, and flight deck communication and decision-making (Helmreich 1998).

The CRM methodology has several similarities with the Behavior Based Safety (BBS) methodology. Both establish critical behaviors, observe the individuals and measure the performance on these critical behaviors. However, they differ in their purpose and focus. BBS focuses on technical behaviors and trains workers to follow the prescribed safe behaviors. The identification of critical behaviors, can be considered as a way to identify boundaries. On the other hand, CRM focuses on critical non-technical aspects of the crew interaction that enable the crew to effectively recognize, analyze, and address threats, and manage errors.

ERROR MANAGEMENT

Airlines, indeed all organizations, face a variety of error inducing factors, including personal factors such as fatigue and workload and our limited ability to make sense of complex situations and take reasonable actions, flawed procedures, maintenance errors or inadequacies, air traffic control, equipment failures, and simple chance. Error management includes strategies to understand the causes of errors and take appropriate actions, including changing policy, procedures, and special training to reduce the incidence of error and to minimize the consequences of those that do occur.

Error management provides a set of error countermeasures with three lines of defense: (1) Error avoidance. (2) Error trapping to prevent it from propagating, (3) Error mitigation to reduce the consequences of those errors which occur and are not trapped. The following are examples of the types of error management and mismanagement recorded by a Line Safety Operations Audit (LOSA) team[4] (Helmreich and Merritt 2000) (The definition of the abbreviation is inserted in the quotation after the first use of each.)

ERROR AVOIDANCE

In this event, stopping a take off to verify information kept the crew from committing an error.

"FO (First Officer) confused about proper frequency approaching the T/O (Take Off) position. CA (Commander of the Aircraft or Captain) stopped A/C (Air Craft) and handled situation smoothly, as neither pilot knew if they were cleared for the runway."

ERROR TRAPPING

Here an error was committed, but effective cross-checking caught it before it became consequential.

"FO mis-set altimeter on the In Range Checklist. As the CA scanned the cockpit, he caught the error and corrected the FO's input."

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4 The LOSA (Line Operations Safety Audit) involves observation of crews under normal, non-jeopardy conditions for assessment of behaviors and safety performance. The observers account for the threats and errors during a flight and their management

ERROR MITIGATION

An inadvertent action by one crewmember was leading to an altitude violation. Cross-checking mitigated the consequences of the error.

"Autopilot disengaged unintentionally by FO, A/C lost 300' before CA caught error. Potential violation, ATC (Air Traffic Control) called them to check altitude."

When error management fails, actions by crewmembers can make things worse.

ERROR EXACERBATION

An error of omission by the FO was later denied. The failure to verify the ILS could have had extremely serious consequences, but luck intervened.

"CA specifically asked the FO if he identified the ILS (Instrument Landing System), FO said yes, when in fact he did not. This goes down as one of the most unprofessional acts I have been witness to in my aviation experience."

These examples demonstrate a range of errors and how the interaction within the crew and the air traffic control system can affect outcomes. These errors occur despite a large and continuous training effort to prevent them.

CRM AS ERROR MANAGEMENT STRATEGY

CRM improves the ability of the crew to work together to manage errors. The technique was developed because research identified several behavioral factors that affect a crew's response to errors, and subsequently the outcome of errors. A study that implemented CRM principles on medical operating teams, identified similar behavioral problems that increased risk to operations (Helmreich 2000):

1. **Communications**: Failure of team member to inform others of a problematic situation (existing information not communicated).
2. **Leadership**: Failure by leadership to establish an environment that encourages input from junior members.
3. **Interpersonal relations**: Frustration, conflict, hostility among the team members.
4. **Preparation, planning and awareness**: Failure to monitor situation/existing conditions or other team's activities, failure to plan for contingencies, failure to discuss alternative procedures.

The response to errors, and the importance of the above behavioral factors is strongly influenced by three cultures; the national culture surrounding the organization, the professional culture of aviators, and the company's organizational culture. Some aspects of national culture increase the probability of safe flight while others increase risk. Traditions of autocratic leadership, excessive individualism, and over-reliance on automation can lead to error. One of the negative aspects of the professional culture of pilots is the almost universal denial of vulnerability to stressors such as fatigue, danger, and personal problems (Helmreich 1998). Although all organizations value safety, organizational cultures differ in the extent to which they support safe practices. Norms of compliance with Standard Operateing

Procedures (SOPs), resources available for training and maintenance, and relations between management and flight crews all influence crew behaviors and, hence, the probability of safe flight. CRM training focuses on a set of behaviors that can improve error management. Early CRM training emphasized the pilot's managerial style and correcting deficiencies in individual behavior such as lack of assertiveness by juniors and authoritarian behavior by captains. It advocated general strategies of individual behavior without providing clear definitions of appropriate behavior in cockpit.

Later "generations" of CRM training dealt with more specific aviation concepts and included training in team building, briefing strategies, situation awareness, stress management, and effective decision making to break the chain of errors that can lead to accidents. Over time CRM became more integrated with the technical aspects of the operations—for example several airlines developed CRM modules to address potential problems due to increased cockpit automation, such as verification and acknowledgment of programming changes and switching to manual flight.

There is no universal CRM training program. The Federal Aviation Administration (FAA) allows air carriers to customize their CRM programs to address the needs of their organization. Although individual programs vary, the training includes courses in (a) Mission analysis/Briefing (b) Communications (c) Decision-making, (d) Assertiveness and (e) Stress and workload management. The content of CRM courses has been based on research findings from the aviation psychologists (such as NASA) and the expertise of experienced pilots.

CRM VALIDATION

According to Helmreich (1999), it is impossible to assess the direct effect of CRM in terms of reduced rates for accidents or near misses because the accident rate is very low, and many near misses are not always reported. The effect of CRM is evaluated in two ways:

1. **Changes of attitudes**. Attitudinal surveys (such as the Cockpit Management Attitudes Questionnaire) and peer performance rating questionnaires are used to evaluate the attitudes of crewmembers before and after CRM training. Results are intended to serve as a proxy for measuring crew process and performance.

2. **Changes of crew behaviors**. Behavior changes are assessed through the LOS Audits which observe and evaluate the crew behavior in actual and simulated flights. The LOS Checklist in Appendix I (Klampfer et al. 2001) is used to rate crew performance on critical behaviors during specific segments of flight (e.g., not rushing through briefing period, exhibiting high levels of vigilance in both high and low workload conditions, etc). Ratings on each behavioral element (ie, model for teamwork) range across 4 levels from poor to outstanding.

CREW RESOURCE MANAGEMENT IN CONSTRUCTION

With its origins in aviation, CRM has been implemented in several other sectors and operations that require effective group interaction in high risk environments, such as hospital operating teams, nuclear power operation centers, emergency response teams, and offshore oil platforms (Flin 1997). According to Helmreich (1998), successful error management places six requirements on organizations:

1. Trust
2. A non-punitive policy toward error
3. Commitment to taking action to reduce error-inducing conditions
4. Data that show the nature and types of errors occurring
5. Training in error avoidance and management strategies for crews
6. Training in evaluating and reinforcing error management for instructors and evaluators.

This paper proposes some experiments using a version of this approach in construction operations. These experiments will give us insight into the “normal” state of affairs by identifying moments or situations when workers are concerned for the safety of the operation.

IS CRM APPROPRIATE FOR CONSTRUCTION OPERATIONS?

CRM is used for operations in high-risk environment that require effective group interaction and coordinated decision-making and action. In most construction operations, the actions of the crew are less tightly coupled than the interdependence of the flight crew. Thus, small errors in construction may not propagate and lead to severe consequences. But beyond that, this approach is expected to increase situation awareness and crew communication. Further, this approach appears to be in line with lean principles, the Last Planner System™ and the ideas of Jens Rasmussen. CRM provides a way for people to take action in the face of a potential “defect.” Planning and execution are improved because every crewmember has a legitimate way to raise issues. In fact, they have the duty to speak up.

RESEARCH OBJECTIVE

The research will test these hypotheses;

1. Pre-task hazard planning is effective. Concerns for safety should be rare if the system is functioning.
2. People are aware that they are working in the hazard zone. Here, we can imagine that a worker might raise a concern when the crew is working at a hazardous rate, and we can imagine one worker might identify when another is cutting corners to avoid extra effort.
3. Genuine participation and empowerment will affect behavior.

In addition we expect to identify other important issues for further study.

RESEARCH PROTOCOL

The initial investigations will include the following activities:

Establish the Circumstance

The study will require an intact crew with a lead hand who will not be threatened by the system, a safety professional who will participate but will not take unusual steps during the experiment, a system to record the events, and a chance to brief the crew before and after the trial. We will approach the first application of the following protocol as a First Run Study by discussing the research and reviewing the protocol with the crew.

Preparation

We will gather information on the activity, the crew composition and the activity context (project context, production goals, surrounding conditions).

Before work

Crew training will be required to clarify the goals of the experiment, the participation required by the crew (that is, to raise any concerns regarding the safety of the operation), and to make such raising concerns for the safety of operations legitimate (as opposed to being evidence of cowardice).

Crew Briefing—similar to pre-task planning—will address work method, work plan, and safety risks and requirements. Taken a step further, the leader might ask the crew if anyone has a concern before beginning.

During work

The crewmembers will be required to speak up when they identify conditions that exceed their "comfort zone" in terms of ability to perform the work effectively and safely. Members can raise concerns about the work method, the conditions in the work area, the sequence of the work, the lack of safety measures and equipment, lack of appropriate equipment for the task, etc.

Anyone can raise a concern to the lead hand or foreman if that concern is grounded by a particular observation. The team leader can respond and address the issue. If the second statement of concern is ignored, the worker should then point out the specific cause for their concern.

We will also request that crewmembers to assign a "level of priority" to each issue/hazard identified, using a color code scheme (such as red for immediate threats, yellow for more distant, less immediate/severe threats). We are not proposing that any particular action be required, rather only that the protocol is followed.

Data Collection

We will document in a log the issues and any actions taken.

After the operation

We will debrief the crew. The discussion will review the hazardous situations identified, the hazards that could have been addressed in pre-task planning and what situations were found "on the ground" that could not have been predicted/addressed in planning. Moreover, we will ask the crew's feedback regarding the effects of the approach followed: Did this approach made the task safer, made them more alert to hazards? We also want to identify any negative effects that the method may create—such as disruptions that may have negative effect on other work aspect—production flow, foreman disruptions, etc.

Data analysis

We will analyze the data in different ways: the source of the hazards identified (resources, other crews, lack of safety measures, site conditions, etc.), the level of priority the crew assigned to the hazards (how do the crews assess the criticality of a hazard), the perception of hazards, and other elements that may emerge from the data.

Evaluate lessons learned

Were the Research Objectives achieved and what were the findings? It may not be possible from this initial action study, to make firm conclusions regarding worker attitudes or perception of hazards. Other opportunities might be revealed but the more important thing to do is to make a small test and then to see what it suggests.

RESEARCH LIMITATIONS AND POTENTIAL PROBLEMS

Workers may not identify hazardous situations

"Unsafe conditions" may not be identified as hazards, if the workers "comfort zone" is higher than the rule or safety policy. However, the goal is not to check compliance but increase situational awareness to perceived hazards.

Ergonomic hazards may not be identified as they are less visible threats than conditions, tools, and equipment. It will be interesting to see if workers identify hazards/threats (conditions, work methods, actions, etc.) that may lead to ergonomic injuries.

A following phase of the experiment may involve a safety expert as an LOSA observer to identify the "gaps" between what the worker and expert definition of hazard.

Worker assertiveness may be limited

Crewmembers may be reluctant to identify hazardous conditions—and particularly if the conditions are not immediately or necessarily hazardous because they:

- Do not want to question the foreman's or superintendent decisions/work plan.
- Do not want to criticize coworkers
- Fear speaking up.

It is essential to make clear that this approach is absolutely not punitive. Moreover, there must be confidence that the experiment will have no negative effect on the relationships of the crew after the experiment is done.

CONCLUSIONS

Construction work does not take place in a cockpit. The rigorous hierarchy and reliance on the skill of the senior person is less evident among crews. In the past, construction accidents have been understood mostly in terms of the result of unsafe conditions or unsafe acts. Crew Resource Management suggests that more effective error identification and management techniques can reduce accidents. This approach aligns nicely with the Rasmussen's work and offers the construction industry a practical new approach to improving safety. We are anxious to give it a try.

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APPENDIX I:
UNIVERSITY OF TEXAS BEHAVIORAL MARKERS RATING SCALE

The markers listed below are used in Line Operations Safety Audits, non-jeopardy observations of crews conducting normal line flights. Each of these markers has been validated as relating to either threat and error avoidance or management. With the exception of two global ratings, specific markers are rated (if observed) during particular phases of flight. Following is a list of currently used markers showing phase where rated, followed by the ratings for each phase of flight: P = Pre-departure/Taxi; T = Takeoff /Climb; D = Descent/Approach/Land; G = Global

SOP BRIEFING	The required briefing was interactive and operationally thorough	- Concise, not rushed, and met SOP requirements - Bottom lines were established	P-D
PLANS STATED	Operational plans and decisions were communicated and acknowledged	- Shared understanding about plans - “Everybody on the same page”	P-D
WORKLOAD ASSIGNMENT	Roles and responsibilities were defined for normal and non-normal situations	- Workload assignments were communicated and acknowledged	P-D
CONTINGENCY MANAGEMENT	Crewmembers developed effective strategies to manage threats to safety	- Threats and their consequences were anticipated - Used all available resources to manage threats	P-D
MONITOR / CROSSCHECK	Crewmembers actively monitored and crosschecked systems and other crewmembers	- Aircraft position, settings, and crew actions were verified	P-T-D
WORKLOAD MANAGEMENT	Operational tasks were prioritized and properly managed to handle primary flight duties	- Avoided task fixation - Did not allow work overload	P-T-D
VIGILANCE	Crewmembers remained alert of the environment and position of the aircraft	- Crewmembers maintained situational awareness	P-T-D
AUTOMATION MANAGENT	Automation was properly managed to balance situational and/or workload requirements	- Automation setup was briefed to other members - Effective recovery techniques from automation anomalies	P-T-D
EVALUATION OF PLANS	Existing plans were reviewed and modified when necessary	- Crew decisions and actions were openly analyzed to make sure the existing plan was the best plan	P-T
INQUIRY	Crewmembers asked questions to investigate and/or clarify current plans of action	- Crewmembers not afraid to express a lack of knowledge - “Nothing taken for granted” attitude	P-T
ASSERTIVNESS	Crewmembers stated critical information and/or solutions with appropriate persistence	- Crewmembers spoke up without hesitation	P-T
COMMUNICATION ENVIRONMENT	Environment for open communication was established and maintained	- Good cross talk – flow of information was fluid, clear, and direct	G
LEADERSHIP	Captain showed leadership and coordinated flight deck activities	- In command, decisive, and encouraged crew participation	G

1 = Poor	2 = Marginal	3 = Good	4 = Outstanding
Observed performance had safety implications	Observed performance was barely adequate	Observed performance was effective	Observed performance was truly noteworthy