ABSTRACT

Title of Dissertation:	ORGANIZATIONAL INTERFACES: CAUSES AND IMPACTS ON SYSTEM RISK
	Thiago Tinoco Pires, Doctor of Philosophy, 2017
Dissertation directed by:	Dr. Ali Mosleh, Mechanical Engineering

Organizational Interfaces exist when two or more organizations interact with each other in order to achieve objectives that would not be possible or feasible by operating independently. When organizations become interdependent an entire new class of vulnerabilities emerge, and understanding these is vital. Ideally, probabilistic risk assessments (PRAs) account for the reliability of hardware, software, humans and the interfaces among them. From a reliability and PRA disciplines perspective, very little is available in terms of methodologies for estimating the chances that OIs problems can contribute to risks. The objectives of this work are to address the following questions: 1) Are OIs important contributors to risks? 2) What are the ways/means of OI failures? 3) Can causal model of OI failures be developed? 4) Can improvements in the reliability discipline be made to incorporate the effects of OI failures? The importance of OIs as contributors to risks were confirmed through an investigation on past accidents in different industrial and service sectors and identifying the evidence on how OI failures played a role. A set of OIs characteristics that provide an understanding of how deficiencies and enhancements in such characteristics can lead to or mitigate/prevent OI failures were proposed. These are derived from insights gained from the accidents reviewed, and from a review on organizational behavior theories and models. The OI characterization was used to propose a Bayesian Belief Network causal model of OI failures for communication transfer. The model is built by means of a study conducted to gather empirical evidence on whether OI failures can be dependent on the OI characteristics. The evidence was gathered through a survey questionnaire to study causal factors of OI failures. The OI characterization was also used to develop OI Failure Mode and Effects Analysis (OI-FMEA) to be utilized as tool to incorporate the effects of OI failures in systems failure. The OI-FMEA was exercised to test if it provides enhancements on current Dynamic Position FMEA practices in the deepwater oil and gas well drilling industry. The exercise demonstrated that the OI-FMEA concepts were a powerful tool to identify serious risk scenario not realized previously.

ORGANIZATIONAL INTERFACES FAILURES: CAUSES AND IMPACTS ON SYSTEM RISK

by

Thiago Tinoco Pires

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Advisory Committee:
Professor Ali Mosleh, Chair
Professor Mohamed Modarres
Professor Gary Pertmer
Professor Monifa Vaughn-Cooke
Professor Mohamad Al-Sheikhly, Dean's Representative

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Chapter 1: Introduction

Apollo 13 was the seventh manned mission in the American Apollo space program and the third intended to land on the Moon. The craft was launched on April 11, 1970 but the landing was aborted after an oxygen tank exploded two days later, crippling critical systems. Astronauts Lovell, Swigert and Hage only survived safely thanks to the improvised use of the Lunar Landing Module as a "lifeboat" for their return voyage to Earth. The explosions were due to a monitoring breakdown and a communications gap. The tanks were damaged during a loading test, when a tank temperature gauge, built only to register temperatures up to the safety limit of 85 degrees Fahrenheit, did not show dangerous internal temperatures because of a defective safety switch. The safety switch's failure was the result of a communications lapse eight years earlier, when a subcontractor neglected to inform the safety switches supplier that the power specifications had been changed from 28 to 65 volts. As a result, during the test, when the temperature of the tanks rose to a level that was supposed to trigger the switch, the switch was instantly fused shut by the 65-volt current that exceeded its design limit.

Examination of any system, aerospace or otherwise, shows that two interfaces exist: the technological interface among the physical elements, and the organizational interface (OI) among the human elements. The technological interface must ensure that all subsystem performance is consonant with other subsystems and that each contributes as planned to total system performance. OIs must assure that all human elements coordinate, communicate and collaborate efficiently to insure technological interface reliability. The Apollo 13 accident portrays an OI failure between a NASA's subcontractor and a spacecraft parts supplier, causing the supplier to provide the wrong switch, and ending with the abortion of the mission.

OIs exist when two or more organizations interact with each other in order to achieve objectives that would not be possible or feasible by operating independently. The space exploration effort portrays a complex OI endeavor, where a number of different organizations are brought together for the purpose of producing, launching and operating space vehicles. The U.S. Air Force, the National Aeronautics and Space Administration (NASA), and hundreds of contractors and subcontractors work together in carrying out these different aerospace projects. For a particular project, the work is divided among various contractors and subcontractors; some are responsible for the propulsion, some for guidance, some for telemetry, some for data processing, some for the payload which will be carried, etc. Since each agency cannot possibly be expected to cover every nut and bolt and every possible contingency, an organizational system is needed to relate the human as well as the physical elements. Each agency has to coordinate, communicate and collaborate its efforts with every other agency, and this effort translates into the OIs among the agencies.

OI is not a new concept as it has increasingly been used in different contexts. The organizational theory field in particular contains various topics related to OIs. One essential question that has long been tackling is "*what is the best way to integrate and manage the activities and resources of an organization*"? In search for an answer to this question, various organizational management philosophies have been proposed to help companies in discerning the "best" way to integrate their resources and deal with the challenges of increasing global competition, increasing production and consume rate, increasing relevance given to process safety, increasing intolerance to disasters causing human fatalities or environmental impact, etc. Examples of such management philosophies are the interdependence models, boundary oriented approaches and social exchange theory (SET).

Interdependence models focus on the business nature of the relationship between work units (i.e., intra-organizational interfaces). Interdependence exists essentially when two or more work units have to work together to benefit from division of labor. For example, McCann and Ferry (1979) developed a model that allows measurement of the degree of interdependence between work units, by focusing on the transactions or exchanges between work units. They propose that interdependence is an additive function of the following features: number of resources exchanged; amount of each resource transacted per unit of time; frequency of transportation per unit of time; amount of time before loss of resource has an impact on the unit's outcomes; and the value of the resources to the unit. Drawbacks of this approach (and of interdependence models in general) is that it does not distinguish interfaces according to what is being exchanged at the interface (e.g., information, material, energy, etc.), and that it does not explicitly take into account that feelings are exchanged between agents, which influence the level of collaboration among agents and, thus, the functioning of the interface.

Differently from the interdependence models, which has an intra-organizational focus, boundary theorists target inter-organizational relationships, as their major concerns are the boundaries around entities (organizations or groups) and how these groups interact with other groups by managing the boundaries (or interfaces). The focus of this school of thought are the activities at the interface with other organizations or groups rather than the relationships between the various units within a single organization. For example, Evan (1966) proposes the term "*organization-set*"; *the "focal" organization is an organization to be studied within the network of its interactions with other organizations in its environment, i.e., its organization-set*. He suggests that interactions in the organization-set may be mapped by examining the "*boundary personnel*" or the people from the *focal organization* responsible for communicating, coordinating and collaborating with people from other organizations within the *focal organization's organization-set*.

Wren (1967) argues further that understanding of Evan's (1966) organization-set and the functions of boundary personnel needs to be enhanced by the use of the interface concept as a methodological tool. He adds that empirical evidence must be gathered and analyzed in the light of the interfacial relationships of the firm and its environment, as certain interfaces external to the business organization must be maintained (e.g., collaboration between a business and trade unions, government, community, and resource suppliers).

Aligned with the boundary theory, the Social Exchange Theory (SET) is another inter-organizational view on OI. According to Cropanzano and Mitchell (2005) SET provides a framework for explaining organizational behavior and its external environment. According to them, the foundational ideas of SET's explanatory power are: rules and norms of exchange, resources exchanged, and relationships that emerge.

One of the basic tenets of SET is that relationships evolve over time into trusting, loyal, and mutual commitments. To do so, parties must abide by certain "rules" of exchange, which form a "*normative definition of the situation that forms among or is adopted by the participants in an exchange relation*" (Emerson, 1976). In this way, rules and norms of exchange are "*the guidelines*" of exchange processes. Thus, the use of SET in models of organizational behavior is framed on the basis of exchange rules such as reciprocity and negotiated rules.

SET's second foundational idea is the type of resource exchanged, which addresses one of the drawbacks of the interdependence models (i.e., it does not account for what is being exchanged at the interface). Foa and Foa's (1974, 1980) resource theory (which is derived from SETs) for example presents four types of resources in exchange: information, money, goods, and services.

SET's last foundational idea is the type of relationships that emerge from exchanges, which also addresses another drawback of the interdependence models (i.e., it does not explicitly account for the feelings that are exchanged between agents). This idea stipulates that certain interaction characteristics lead to connections, referred to as social exchange relationships (Cropanzano, et al 2001). Social exchange relationships evolve when advantageous and fair transactions occur between parties (whether individuals or institutions), creating strong relationships that produce effective behavior and positive attitudes.

One common characteristic of the OI ideas discussed above have is that they were developed within the realm of organizational survival, work efficiency, cost reduction, etc. None of them address the fact (as it will be shown in the next Section) how weaknesses in OIs can lead to undesirable scenarios as illustrated in the Apollo 13 example, and how to estimate the likelihood of weaknesses in OIs contributing these scenarios.

As some of the theories above state, when two or more organizations interface, there is always a transfer of "*something*" from one organization to another, which can have many different forms, including knowledge/information, energy, material, and services. Depending on the nature of the interface, the resource exchange activity can easily turn into a complex coordination, communication and collaboration effort among the participating organizations. When the participating organizations are bonded by agreed upon interfacing structures, common values and mutual interest, strong interfaces arise. On the contrary, interfaces characterized by poor coordination practices and ineffective communication and collaboration among the participating organizations are potential ingredients for failures and even disasters.

Understanding OIs is important because it is omnipresent in today's world. There are many areas of activity that demand the involvement of many organizations acting together (usually because the activity is too big for one organization to handle by itself), which are characterized by numerous and complex interdependent actions. The air passenger transportation, power supply and medical care for example are heavily dependent on the interaction of a group of individual organizations, each one with its own culture, organizational design, level of dependency on external factors (e.g., economic, political, social, technological, etc.) and level of uncertainty regarding how changes in external factors (e.g., economic, political, social, technological, etc.) can impact performance.

When organizations become interdependent an entire new class of vulnerabilities emerge, and understanding these interdependence vulnerabilities is vital. Ideally, probabilistic risk assessments (PRAs) for any situation account for the reliability of hardware, software, humans and the interfaces among them. Unfortunately, OI failures are usually poorly accounted for, or even disregarded in such assessments. From a reliability and PRA disciplines perspective, very little is available in terms of methodologies and prediction tools to aid estimating the chances that OIs problems will trigger or initiate undesirable events. The objectives of this work are to address the following questions:

1. Are OIs important contributors to risks?
2. What are the ways and means of OI failures?
3. Can a simple causal model of OI failures be developed?
4. Can improvements in the current practices of reliability discipline be made to incorporate the effects of OI failures on systems failure?

These questions have been addressed to various degrees (consistent with a defied scope) in the rest of this dissertation. Section 2 presents the results of an investigation on past incidents and accidents in different industrial and service sectors (e.g., health care, product design, power generation and transmission, commercial air passenger transportation, etc.) focusing on identifying evidence on how OI failures played a role in contributing to the accidents/incidents (and, thus, demonstrate that OIs are important contributors to risk).

Section 3 elaborates on OI characteristics that provide an understanding of how deficiencies and enhancements in these characteristics can lead to or mitigate/prevent OI failures. These characteristics are derived in part from the insights from the incidents and accidents reviewed in the previous section. These characteristics are then used as the fundamental tools to propose OI failure modes and their potential causes/influencing factors.

In Section 4, the OI characterization offered in Section 3 is used to propose a causal model of OI failures. The model is built by means of a study conducted to gather empirical evidence on whether OI failures can be dependent on the OI characteristics.

In Section 5, the OI characteristics, failure modes, and potential causes/contributing factors are used to develop an OI Failure Mode and Effects Analysis (OI-FMEA) to be utilized as tool to incorporate the effects of OI failures in systems failure. The OI-FMEA proposed is then demonstrated in an application to offshore oil and gas well drilling industry.

The final section (Section 6), offers concluding remarks stressing the importance of scrutinizing OIs thoroughly when assessing systems risk. By not doing so, accidents that can be routed in OI weaknesses are a potential threat to system's reliability. The causal model proposed is discussed focusing on future work needed to achieve better levels of understanding regarding, for example, how different influencing factors effect different types of OI failure modes. Finally, the results of the application of the OI-FMEA proposed for deep water oil and gas well drilling applications is discussed.

Chapter 2: Historical Evidence on OI Failures

This section presents the result of a literature research on past accidents and incidents in different industries that draws the attention to how poor communication, collaboration and coordination among organizations can contribute to such events. It is important to note that these three concepts are not mutually exclusive when it comes to OIs in complex sociotechnical systems. The literature research found evidence on OI reliability influence in the oil and gas, commercial air passenger transportation industry, product design, energy supply, and health care sectors, and are examined next.

OI Failures in the civil air transportation industry

The civil air transportation industry is by its nature a multi-organizational endeavor that demands the coordination of various independent organizations involved in different operational aspects of transferring passengers (and their luggage) from one location to another. Within this inter-organizational scenario are complex air traffic control interfaces coordinating flights from hundreds of airlines and airports. In the US, for example, the Federal Aviation Administration (FAA) regulates air traffic within the US through thousands of volumes of procedural and safety guidelines and policies that must be followed by various airlines and airports to provide safe air transportation.

Most accidents in the commercial passenger air transportation industry occur during take-off and landing. Data from the National Transportation Safety Board (NTSB) indicates that between 1978 and 2001 26.8% of the accidents reported during this period occurred during take-off and 55.4% during approach/landing (Dismukes et al, 2007). Within the FAA, air traffic controllers have the ultimate responsibility of organizing the flow of aircraft in and out of airports. The activities performed in controlling air traffic involve exchange of information among air traffic controllers and the airline crew.

Despite the level of safety achieved by highly scripted operations, flight operation and air traffic control procedures represent an ideal in that, actual operations can involve unpredicted, complex situations not covered by the procedure (Loukopoulos et al 2003). In addition, the norms of actual operations sometimes diverge from the ideal because of sociocultural, professional and organizational factors (Helmreich and Merrit, 1998). A research on air passenger transportation accidents reveals that some of these accidents were rooted in OI weaknesses.

As it will be described, commercial air transportation involves OIs among airlines, airports and regulatory agencies. OI coordination among these entities are achieved by several regulatory procedures that govern, among several things, how aircraft should be maintained, communication protocol among ATC and aircraft crew, air traffic and ground traffic rules (e.g., under good/bad weather), aircraft landing and take-off rates, etc. Unfortunately, in many instances, these rules/procedures are not followed (e.g., not understood, forgotten, or not abode by due to lack of collaboration) and, when combined with poor airport design (e.g., lack of signals to indicate aircrafts where to turn, lack of lights at night, poor equipment for communication in fog conditions, etc.) are recipes for disasters.

Some of these disastrous events were the Tenerife airport disaster in 1977, the Ozark Air Lines Flight 650 accident in 1983, the Avianca Flight 52 accident in 1990, the Northwest Airlines Flight 1482 accident in 1990, the Continental Express Flight 2574 accident in 1991 and the Überlingen mid-air collision in 2002, which are discussed in detail next. Several other accidents can also be referenced as influenced by poor OI and are discussed briefly.

The Tenerife Airport Disaster

The Tenerife airport disaster was a fatal runway collision between Pan Am Flight 1736, a Boeing 747 named Clipper Victor and KLM Flight 4805, and another Boeing 747 named Rhine on March 27, 1977 at Los Rodeos Airport (now called Tenerife North Airport) on the Spanish island of Tenerife, one of the Canary Islands. The crash killed 583 people, making it the deadliest accident in aviation history. As a result of the complex interaction of organizational influences, environmental preconditions, and unsafe acts leading up to this aircraft mishap, the disaster at Tenerife has served as a textbook example for reviewing the processes and frameworks used in aviation mishap investigations and accident prevention.

Both flights had been routine until they approached Gran Canaria International Airport (their original destination). At 1:15 pm, a bomb exploded in the terminal of Gran Canaria International Airport. The civil aviation authorities had therefore closed the airport temporarily after the bomb detonated and diverted all of its incoming flights to Los Rodeos, including the two Boeing 747 aircraft involved in the disaster.

In all, five large aircraft were diverted to Los Rodeos, a regional airport that could not easily accommodate them. The airport had only one runway and one major taxiway parallel to it, with several small taxiways connecting the two (See Figure 1). While waiting for Gran Canaria airport to reopen, the diverted aircraft took up so much space that they were parked on the long taxiway, meaning that it could not be used for taxiing. Instead, departing aircraft had to taxi along the runway to position themselves for takeoff, a procedure known as a runway backtaxi.

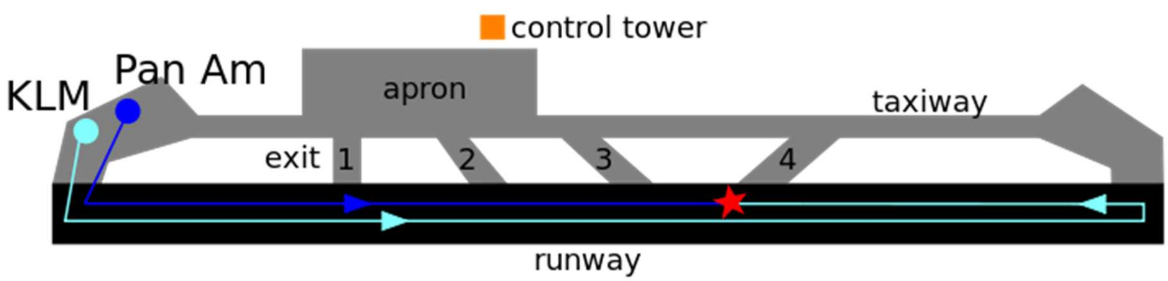

FIGURE 1 - SIMPLIFIED MAP OF RUNWAY, TAXIWAYS, AND AIRCRAFT. THE RED STAR INDICATES THE LOCATION OF IMPACT. NOT TO SCALE.

After the threat at Gran Canaria had been contained, authorities reopened that airport. Following the tower's instructions, the KLM was cleared to taxi the full length of the runway and make a 180° turn to get into takeoff position. While the KLM was backtaxiing on the runway, the controller asked the flight crew to report when it was ready to copy the ATC clearance. Because the flight crew was performing the before takeoff cockpit safety checklist, copying this clearance was postponed until the aircraft was in takeoff position.

Shortly afterward, the Pan Am was instructed to follow the KLM down the same runway, exit it by taking the third exit on their left and then use the parallel taxiway. The crew successfully identified the first two taxiways (C-1 and C-2), but their discussion in the cockpit never indicated that they had sighted the third taxiway (C-3), which they had been instructed to use. There were no markings or signs to identify the runway exits and they were in conditions of poor visibility due to heavy fog. The Pan Am crew appeared to remain unsure of their position on the runway until the collision, which occurred near the intersection with the fourth taxiway (C-4).

Immediately after lining up, the KLM pilot advanced the throttles and the aircraft started to move forward. The co-pilot, Klaas Meurs, advised the captain that ATC clearance had not yet been given, and Captain Veldhuyzen van Zanten responded, "*I know that. Go ahead, ask*." Meurs then radioed the tower that they were "*ready for takeoff*" and "*waiting for our ATC clearance*". The KLM crew then received instructions which specified the route that the aircraft was to follow after takeoff. The instructions used the word "*takeoff*," but did not include an explicit statement that they were cleared for takeoff. Meurs read the flight clearance back to the controller, completing the read back with the statement: "*We are now at takeoff.*" Captain Veldhuyzen van Zanten interrupted the co-pilot's read-back with the comment, "*We're going*."

The controller, who could not see the runway due to the fog, initially responded with "*OK*" (terminology which is nonstandard), which reinforced the KLM captain's misinterpretation that they had takeoff clearance. The controller's response of "*OK*" to the co-pilot's nonstandard statement that they were "*now at takeoff*" was likely due to his misinterpretation that they were in takeoff position and ready to begin the roll when takeoff clearance was received, but not in the process of taking off. The controller then immediately added "*stand by for takeoff, I will call you*," indicating that he had not intended the clearance to be interpreted as a takeoff clearance.

A simultaneous radio call from the Pan Am crew caused mutual interference on the radio frequency, which was audible in the KLM cockpit as a three second long whistling sound. This caused the KLM crew to miss the crucial latter portion of the tower's response. The Pan Am crew's transmission was "*We're still taxiing down the runway, the Clipper 1736!*". This message was also blocked by the interference and inaudible to the KLM crew.

Due to the fog, neither crew was able to see the other plane on the runway ahead of them. In addition, neither of the aircraft could be seen from the control tower, and the airport was not equipped with ground radar. After the KLM plane had started its takeoff roll, the tower instructed the Pan Am crew to "r*eport when runway clear.*" The Pan Am crew replied: "*OK, we'll report when we're clear*." On hearing this, the KLM flight engineer expressed his concern about the Pan Am not being clear of the runway by asking the pilots in his own cockpit, "*Is he not clear, that Pan American?*" Veldhuyzen van Zanten emphatically replied "*Oh, yes*" and continued with the takeoff.

According to the CVR, the Pan Am pilot said, "*There he is!*" when he spotted the KLM's landing lights through the fog just as his plane approached exit C-4. The Pan Am crew applied full power to the throttles and took a sharp left turn towards the grass in an attempt to avoid a collision. By the time the KLM pilots saw the Pan Am, they were already traveling too fast to stop.

This OI failure was influenced by ineffective coordination at the Tenerife airport facilities, which was not designed to handle the increased amount of air traffic caused by an unplanned incident at the Gran Canaria International Airport. This ineffective coordination was exacerbated by the poor visibility at the time due to fog and less than adequate communication protocol used among the airlines and ATC, which prevented the airlines to acknowledge their locations and permission for takeoff.

The Ozark Air Lines Flight 650 accident, 1983

Ozark Air Lines Flight 650 (OZ650) was a regularly scheduled flight between Sioux Gateway Airport in Sioux City, Iowa, and Sioux Falls Regional Airport in Sioux Falls, South Dakota. While landing on runway 3 in a snow storm and very low visibility on December 20, 1983, it struck a snow plow on the runway.

During the winter months at most airports in the north, runways, taxiways and the air carrier ramp areas of the airports are cleared of snow while they are being used by landing, taxiing and parking aircraft. All vehicles operating on, or adjacent to, usable runways or taxiways are required to be equipped with two-way radios and must be in contact with the tower or be escorted by a vehicle with a two-way radio in contact with the tower. All the communications between such vehicles and the tower are on the ground control frequency.

At the time of the accident, runway sweeping was necessary and was in progress. The sweeper was a commercial Snowblast vehicle call sign Sweeper7 and was equipped with two-way radio, standard vehicular lights and a 10-inch, 360 degrees amber rotating beacon on top of the cab roof. On the day of the accident, a shift turn over for air traffic control took place. Upon assuming control responsibilities the new controller received normal position briefing from the controller he was relieving and was advised that OZ650 was approaching for landing on runway 3 and that Sweeper 7 was on that runway. He also stated that operations were normal and Sweeper 7 was being directed on and off the runway between arriving and departing traffic.

The transcript of tower communications shows that neither the approach controller, nor the local controller advised OZ650 of snow removal operations. Also the local Controller did not communicate with Sweeper 7 after he took the hand off of OZ650. The transcript showed that in the 12 minutes preceding the accident, the controller had six communications with Sweeper 7, involving position reports by the sweeper operator, clearance to cross on intersecting runway, and clearance off the runway for a landing airplane, then back on the runway. The last communication between the controller and Sweeper 7 occurred about 6 minutes before the accident.

Investigators questioned the controller as to when he last recalled seeing Sweeper 7. He stated that he knew that it had crossed runway 33 southwest bound toward the approach end of Runway 3 and that he had lost sight of it at that time. When the controller was questioned as to where Sweeper 7 was when he issued the landing clearance to OZ650, he stated he did not know where it was.

This accident portrays an example of an OI. The fact that the controller issued landing clearance to OZ650 without ascertaining the runway was clear off the Sweeper 7 reveals, at a minimum, poor coordination of snow removal operations. In fact, the NTSB investigation (1985) concluded that the snow removal operations were inadequately supervised by the tower, as the Ozark 650 crew stated that no information was transmitted to them either by approach control or local control concerning snow removal operations. This condition was exacerbated by the poor visibility conditions that prevented OZ650 to visualize the maintenance truck.

The Avianca Flight 52 accident, 1990

On January 25, 1990, Avianca Flight 52 (AVA052) was much delayed in approaching its destination due to congestion and bad weather. It had been in a holding pattern off the coast near New York for over one hour due to fog and wind interfering with smooth arrivals and departures into JFK International Airport. During this hold the aircraft was exhausting its reserve fuel supply, which would have allowed it to divert to its alternate, Boston, in case of an emergency or other critical situation.

Seventy-seven minutes after entering the hold, New York air traffic control (ATC) asked the crew how long they could continue to hold, to which the first officer replied, "*About five minutes*." The first officer then stated that their alternate was Boston, but since they had been holding for so long they would not be able to make it there anymore. Even though AVA052 had fuel issues, the controller handling the flight passed it to another person, presumably unaware there was any urgency to landing this airplane. The new controller then cleared the aircraft for an approach to runway 22L and informed the flight of wind shear at 460 m.

As AVA052 approached, they encountered wind shear and was forced to abandon the landing, even though they knew the plane did not have enough fuel to turn around for another attempt. The crew alerted the controller that they were low on fuel, and in a subsequent transmission stated, "*We're running out of fuel, sir.*" The controller then asked the crew to climb, to which the first officer replied, "*No, sir, we're running out of fuel*." Moments later, with no engine thrust, the plane lost height and plunged into the small village of Cove Neck on northern Long Island killing 73 passengers and crew.

The investigation report on the incident (NTSB, 1991a) pointed out several issues regarding the flight planning, flight crew communications, communications with controllers, communications between pilot and ATC and traffic management and coordination that contributed to the accident.

The Safety Board found several deficiencies in the quality of to the flight plan issued to and used by the flight crew of AVA052: it did not reflect the most current upper air data, or the actual gross weight of the airplane upon departure from Medellin;

the reserve fuel stipulated in the flight plan out of Medellin did not account for the possibility of extensive en route and landing delays at JFK or at the alternate because of not anticipated challenging weather and air traffic conditions.

Avianca's General Operations Policy Manual required the captain and the dispatcher to establish communication with each other for "*messages related to operational development or occurrences that are different than the original flight plan, such as weather conditions at the terminal or en route, availability of facility or services at the terminal or en route, a significant change of the flight plan, a deviation, or an emergency notification*." Communication could have been established through the use of the high frequency (HF) radio on board the airplane or through the Dispatch Services dispatcher in Miami with which Avianca Airlines had a contract.

The Safety Board was unable to determine why the flight crew and the dispatcher did not communicate with each other when they were clearly able to do so. This failure is especially serious because of the multiple holds that the flight encountered before its fuel state became critical. Intra cockpit conversations suggest that the flight crew assumed that ATC was giving them priority handling, as they believed ATC was aware of their critical situation. At one moment the captain advised the first officer to "t*ell them we are in emergency*." However, the first officer acknowledged an ATC altitude and heading instruction to the JFK tower controller, adding, "*...we're running out of fuel*." He did not use the word "*emergency*," as instructed by the captain, and therefore did not communicate the urgency of the situation. Thus, the controller was not alerted to the severity of the problem.

These intracockpit conversations indicated a total breakdown in communications by the flight crew in its attempts to relay the situation to ATC. The accident may have been inevitable at that point, because the engines began to flame out only about 7 minutes later. However, the first officer failed to convey the message that the captain intended. The evidence strongly suggests that the captain was unaware, at times, of the content of the first officer's transmissions and that he did not hear or understand the ATC communications. The Safety Board believes his limited command of the English language prevented him from effectively monitoring the content of the transmission.

Much of the flight crew's failure to communicate effectively resulted from limitations in their knowledge of standard ATC terminology. None of the controllers involved in the handling of AVA052 considered the request for "*priority*," (issued to ATC prior to the crash) or the comments about running out of fuel, to be significant or an emergency request by AVA052. The controllers believed that the transmission from AVA052 about only being able to hold for 5 more minutes meant that the flight could only hold 5 minutes and would then have to divert to its alternate. Both controllers believed that the intent of the request for priority was to depart the holding pattern within 5 minutes, either for JFK or Boston, the alternate.

The word "*priority*" was used in procedures' manuals provided by the Boeing Company to the airlines. A captain from Avianca Airlines testified that the use by the first officer of the word "*priority*," rather than "*emergency*," may have resulted from training at Boeing. He stated that these personnel received the impression from the training that the words priority and emergency conveyed the same meaning to air traffic control. Boeing training addressing operations with low fuel quantity indications, state that, "*during any operation with very low fuel quantity, priority handling from ATC should be requested*." "*Priority*" is defined in the ATC Handbook as "*precedence, established by order of urgency or importance*." This is a clear evidence of poor coordination between FAA and Boeing as to the meaning of the word "*priority*".

Another aspect that greatly influenced the accident was the inadequate airport acceptance rate (AAR) (i.e., the number of arrivals per hour) for that day developed by JFK's Central Flow Control Facility (CFCF), which was set at 33 arrivals per hour. Unfortunately, this AAR was compromised as weather deteriorated, missed approaches began (i.e., safe landing cannot be accomplished for any reason and, thus, must be discontinued) and the numbers of airplanes that ended up in holding patterns (i.e., delaying landing) waiting for the weather conditions to improve started to increase.

As revealed by the NTSB investigation, this situation was exacerbated as the National Weather Service (NWS) personnel did not inform JFK's traffic management personnel of the severe wind conditions that were causing the missed approaches. Traffic management personnel informed the Safety Board that if they had known about the wind conditions, the AAR would have been implemented at a lower airport acceptance rate, thereby reducing the airborne inventory of airplanes arriving at JFK during each hour of the traffic management program. The Safety Board believes that the NWS personnel failed to communicate this information to the CFCF traffic management specialists.

Northwest Airlines Flight 1482 accident, 1990

This accident involved the collision of two Northwest Airlines planes in dense fog at Detroit Metropolitan Wayne County Airport on December 3, 1990. It occurred when Flight 1482, a scheduled Douglas DC-9-14 operating from Detroit to Pittsburgh International Airport, taxied onto an active runway by mistake in dense fog and was hit by a departing Boeing 727 operating as Flight 299 to Memphis International Airport. One crew and seven occupants of the DC-9 were killed.

Moments before the accident, Northwest 1482 was cleared from the gate towards Runway 03C, but it missed turning onto taxiway Oscar 6 and instead entered the Outer taxiway. To correct the error they were instructed to turn right onto Taxiway Xray but they turned onto the active runway 03C. They realized the mistake and contacted air traffic for instructions who told them to leave the runway immediately, five seconds later the crew saw a Boeing 727 that had just been cleared for take-off heading towards them. The 727 wing hit the right-hand side of the DC-9 and cut through the fuselage just below the windows until it cut off one of the DC-9s engines. The DC-9 caught fire and was destroyed; the 727 just had a damaged wing and was later repaired.

The accident was investigated by the National Transportation Safety Board (NTSB, 1991), which determined the probable cause of the accident to be a lack of proper crew coordination, including a virtual reversal of command roles by the DC-9 pilots (i.e., the captain became overly reliant on the first officer leadership on the situation), which led to their failure to stop taxiing their airplane and alert the ground controller of their positional uncertainty in a timely manner before and after intruding onto the active runway.

This example shows a poor airport coordination in poor visibility conditions exacerbated by deficient communication among the relevant individuals. As the investigation report mentions, contributing to accident were deficiencies in the air traffic control services provided by the Detroit tower, including failure of the ground controller to take timely action to alert the local controller to the possible runway incursion, inadequate visibility observations, failure to use progressive taxi instructions in low-visibility conditions, and use of inappropriate and confusing taxi instructions. Other important influencing factors revealed by the investigation report included deficiencies in the airport's surface markings, signage, and lighting, which definitely contributed to the Northwest 1482 to enter the wrong taxiways twice.

Continental Express Flight 2574 accident, 1991

Continental Express Flight 2574 was a scheduled domestic passenger airline flight operated by Britt Airways from Laredo International Airport in Laredo, Texas to Bush Intercontinental Airport in Houston, Texas. On September 11, 1991, the flight crashed as it was approaching the runway for landing, killing all 14 people on board.

The National Transportation Safety Board investigation (NTSB, 1992) revealed that bolts had been removed from a critical component during unfinished maintenance work the night before the accident and, following a shift change, the screws were not replaced. The plane crashed on its second flight of the day.

The National Transportation Safety Board determines the probable cause(s) of this accident as failure of Continental Express maintenance and inspection personnel to adhere to proper maintenance and quality assurance procedures. Contributing to the cause of the accident was the failure of the Continental Express management to ensure compliance with the approved maintenance procedures, and the failure of FAA surveillance to detect and verify compliance with approved procedures.

As the NTSB report states, this is a very strong evidence of: 1) poor OI between maintenance and inspection personnel due to the incoming shift personnel not being communicated of the incomplete work, 2) poor OI between Continental Express management and Continental Express maintenance and inspection personnel due to poor surveillance and control regarding adherence to maintenance and quality assurance procedures and 3) poor OI between the FAA and Continental Express management due to poor surveillance and enforcement of compliance with approved procedures.

Überlingen mid-air collision, 2002

Bashkirian Airlines Flight 2937 was a Tupolev Tu-154M passenger jet going from Moscow to Barcelona. DHL Flight 611, was a Boeing 757-23APF cargo jet flying from Bergamo, Italy, to Brussels, Belgium, which collided on air during their courses. Despite being over Germany, the airspace was controlled from Zürich, Switzerland by the private Swiss airspace control company Skyguide.

The only air traffic controller handling the airspace, Peter Nielsen, was working two workstations at the same time. He did not realize the close proximity in time and thus failed to keep the aircraft at a safe distance from each other. Only less than a minute before the accident did he realize the danger and contacted Flight 2937, instructing the pilot to descend by a thousand feet to avoid collision with crossing traffic (Flight 611). Seconds after, the Russian crew initiated the descent, however, their Traffic Collision Avoidance System (TCAS) instructed them to climb, while at about the same time the TCAS on Flight 611 instructed the pilots of that aircraft to descend.

Flight 611's pilots followed the TCAS instructions and initiated a descent, but could not immediately inform Nielsen due to the fact that Nielsen was dealing with Flight 2937. About eight seconds before the collision, Flight 611's descent rate was about 12 meters per second, not as rapid as the 13 to 15 m/s range advised by TCAS. The Russian pilot on the Tupolev disregarded the TCAS instruction to climb and instead began to descend, as instructed by the controller, thus both planes were now descending.

Unaware of the TCAS-issued alerts, Nielsen repeated his instruction to Flight 2937 to descend, giving the Tupolev crew incorrect information as to the position of the DHL plane. Maintenance work was being carried out on the main radar system, which meant that the controllers were forced to use a slower system.

The aircraft collided at almost a right angle with the Boeing's slicing completely through Flight 2937's fuselage just ahead of the Tupolev's wings. The Tupolev exploded and broke into several pieces, scattering wreckage over a wide area. The nose section of the aircraft fell vertically, while the tail section with the engines continued, stalled, and fell. As the nose section of the Tupolev fell at such speed, the flight deck crew soon lost consciousness. The crippled Boeing struggled for a further seven kilometres before crashing into a wooded area at a 70 degree downward angle. All 69 people on the Tupolev, and the two on board the Boeing, died (German Federal Bureau of Aircraft Accidents Investigation, 2004).

This accident portrays a case of poor coordination among ATC and the two flights crew, due to poor surveillance of the air traffic as there was only one individual (Peter Nielsen) working two workstations at a time (which caused Nielsen's to miss the information regarding Flight 611's TCAS instructions) and low performance equipment being used due to maintenance work being done on the main radar system.

Other commercial air transportation OI failures

The research conducted in the commercial air transportation accidents influenced by poor OI has found several other examples, which, for simplicity, are summarized below by listing the airline flight number and year, and a brief explanation of the OI contributing factor to the accident:

1. <u>Pan Am Flight 845, 1971</u>: Wrong information provided to flight crew due to two copies of the same document indicating length of runway containing two different values. Flight crew received the one containing wrong information and caused the flight crew to believe the available takeoff length was 9,500 feet (a thousand feet longer than actually existed) (NTSB, 1971). Aircraft

struck approach lighting system structures located past the end of the runway, seriously injuring two passengers and sustaining significant damage.

2. Texas International Airlines Flight 655, 1973: The crew did not discuss the details of their intended route with Flight Service or activate the instrument flight rules flight plan forwarded from the airline dispatch to Flight Service. According to the report, this is a violation of Federal Aviation Regulation (FAR) rules FAR 121.533, which gives the pilot-in-command and the aircraft dispatcher joint responsibility for the preflight planning, delay, and dispatch release of a flight (NTSB, 1973). The plane crashed into Black Fork Mountain, Arkansas, and the eight passengers and three crewmembers on board were killed.
3. National Airlines Flight 193, 1978: The lack of crew communication resulted in false awareness of altitude and descent rate on the part of all involved (NTSB, 1981). During the descent into Pensacola Regional Airport it impacted Escambia Bay, sinking in 3.7 m of water and killing 3 passengers.
4. Pacific Southwest Airlines (PSA) 182, 1978: failure of the PSA flight crew to follow proper air traffic control (ATC) procedures caused Flight 182's crew to lose sight of another aircraft along the same traffic, in contravention of the ATC's instructions to "*keep visual separation from that traffic*", and not alerting ATC that they had lost sight of it (NTSB, 1979). The airplanes crashed killing a total of 144 people.
5. United Airlines Flight 173, 1978: the NTSB believes that this accident exemplifies a recurring problem of cockpit management and teamwork breakdown. The NTSB determined probable a causes was failure of flight crewmembers to successfully communicate their concern to the captain that led the aircraft to run out of fuel and crash in a suburban Portland neighborhood, killing 10 of the 181 passengers (NTSB, 1979).
6. Independent Air Flight 1851, 1989: The Board of Inquiry determined the accident was due to non-observance by the crew of established operating procedures. Other contributing factors reported include bad communications techniques on the part of the co-pilot and controller, including the non-adherence to standard phraseology in some of the ground communication; neglecting aerodrome control tower procedures in not requesting a readback of the descent clearance (Duke, 1995). The flight struck Pico Alto while on approach to Santa Maria Airport killing all 144 onboard.
7. USAir Flight 5050, 1989: The NTSB found numerous "*crew coordination problems*" during its investigation, including the captain's failure to provide an extended briefing, or an emergency briefing, before the takeoffs at BWI and LGA or at any time during the 9 hours the crewmembers spent together before the accident; the decision of the captain to execute the takeoff at with autobrakes disengaged, on a wet and short runway, contrary to company and manufacturer recommendations; and the failure of the captain to transfer control back to the first officer in a smooth and professional manner, with the

result of confusion as to who was in control (NTSB, 1989). The plane crashed during takeoff and killed 2 of the 63 people onboard.

8. <u>USAir Flight 1493, 1991</u>: The NTSB determines that the probable cause of the accident was the failure of the FAA Air Traffic Service to provide adequate policy direction and oversight to its air traffic control facility managers, which created an environment in the LA ATC tower that ultimately led to the failure of the local controller to maintain an awareness of the traffic situation, culminating in the inappropriate clearances and the subsequent collision of the USAir and Skywest aircraft (NTSB, 1991). The flight crashed with another one upon landing killing 35 people onboard.
9. <u>Thai Airways International Flight 311, 1992</u>: frustrating and misleading communications (due partly to language problems of the air traffic controller) ensued between air traffic control and the pilots regarding Flight 311's altitude and distance from the airport. Only after numerous extremely frustrating exchanges with ATC was the captain able to obtain adequate weather information for the airport, but by that time he had overflown Kathmandu and the aircraft was headed towards the Himalayas (Job, 1998). The aircraft crashed into the side of a mountain killing all of the 113 people inside.
10. <u>US Airways Flight 1016, 1994</u>: The tower controller issued a wind shear warning to all aircraft, but it was on a different radio frequency than Flight 1016, which, ultimately did not receive the critical piece of information (NTSB, 1991). The flight crashed into heavy trees in a private residence near the airport, killing 37 people.
11. <u>Vnukovo Airlines Flight 2801, 1996</u>: Communication between air traffic control and the crew was problematic, since the crew lacked sufficient English skills. After the crew decided to carry out the approach to Runway 28, a new approach briefing was not accomplished. The aircraft overshot the approach centerline (The Aircraft Accident Investigation Board/Norway, 1996). All 141 people inside died.
12. <u>United Express Flight 5925, 1996</u>: Aircraft collision on runway involving 2 aircraft due to lack of awareness of aircraft locations. Flight 5925 was approaching to land on Quincy airport at the same time as two aircraft at Quincy were ready for departure (i.e., Beechcraft King Air and a Piper Cherokee). As Quincy is a non-towered airport, all three aircraft were operating on the same Common Traffic Advisory Frequency. On approach, the 5925 inquired as to whether the King Air would hold short of the runway, or depart before their arrival. 5925 received a reply from the Cherokee stating they were holding short. However, the 5925 pilot's misunderstood the transmission believing it was from the King Air's and believed it would not take off until after 5925 had cleared the runway, leading to their collision.
13. <u>Avjet Aspen crash, 2001</u>: Aircraft crashed into terrain due to: FAA unclear wording of the March 27, 2001 Notice to Airmen regarding the nighttime restriction for the approach to the airport, the FAA's failure to communicate this restriction to the Aspen's Airport tower; the inability of the flight crew to

adequately see the mountainous terrain because of the darkness and the weather conditions (NTSB, 2003). The plane crashed into the ground killing all 18 people inside.

14. Crossair Flight 3597, 2001: The investigation concluded that the accident was a controlled flight into terrain caused by Captain deliberately descending below the minimum descent altitude without having the required visual contact with either the approach lights or the runway. Also, the pilot had failed to perform correct navigation and landing procedures before, but no action had been taken by the airline. Other contributing factors include the fact that the range of hills the plane crashed into was not marked in the approach chart used by the crew (Swiss Aircraft Accident Investigation Bureau, 2001). The plane crashed into a wooded range of hills and exploded, killing 24 of the 33 people on board.
15. TAROM Flight 3107, 2007: due to poor communication between ATC and airport maintenance workers and poor visibility due to fog, flight 3107 was cleared for takeoff on the runway where maintenance workers where performing maintenance work on the runway's center lights. Moreover, the maintenance worker's car was not signalized and had no beacons lit contrary to airport procedures, culminating in the airplane crashing on it (ZRH, 2008). Fortunately, no fatalities happened.
16. Airblue Flight 202, 2010: lack of professionalism in the cockpit crew along with poor weather conditions as primary factors in the crash. In particular, the captain ignored or did not properly respond to a multitude of Air Traffic Control directives and automated cabin warning systems (Pakistan Safety Investigation Board, 2011). The flight crashed in the Margalla Hills north of Islamabad killing all 146 passengers and six crew on board.

OI failures in healthcare systems

The inter-organizational nature of healthcare systems was appropriately addressed by Mohr et al (2004). According to them, healthcare organizations are conglomerates of smaller systems. A clinical microsystem for example is a group of clinicians and staff working together with a shared clinical purpose to provide care for a population of patients. The clinical purpose and its setting defines the essential components of the microsystem. These include the clinicians and support staff, information and technology, the specific care processes, and the behaviors that are required to provide care to its patients. The outcomes from the complex activities developed by this clinical microsystem depend on the harmony among individuals, teams, and technical, and organizational factors (Vicent et al, 1993; Bogner, 1994).

Examples of clinical microsystems include a cardiovascular surgical care team, a community based outpatient care center, or a neonatal intensive care unit. Each of them has in common core elements: a focused type of care, clinicians and staff with the skills and training needed to engage in the required care processes, a defined patient population, and a certain level of information and technology to support their work. What often differs across microsystems is the ability of individual caregivers to recognize their efforts as part of a microsystem as well as the microsystem's level of functioning. Given the complexity of these systems, the actions of individuals are interconnected so that the actions of one provider changes the context for all of the other providers (Plsek and Greenhalgh, 2001; Plsek and Wilson, 2001).

According to Awad et al (2005), healthcare organizations are often complex, disorganized, and opaque systems to their users and their patients. This disorganization often leads to patient discomfort and harm. Inadvertent errors in the delivery of medical care are recognized as a leading cause of inpatient morbidity and mortality. Estimates from the Institute of Medicine's report in 1999 suggest that medical error is the eighth leading cause of death in the United States and results in up to 100,000 deaths annually (Kohn et al, 2000). This has been brought to the public's attention secondary to recent media reports that have put a spotlight on the increasing number of medical errors occurring in U.S. health care institutions (Etchells, 2003). Very common health care system errors events categories reported in the literature include wrong-patient/wrong procedure, wrong-site/wrong-side, and wrong-drug/wrong-dose events.

According to Chassin and Becher (2002), among all types of medical errors, cases in which the wrong patient undergoes an invasive procedure are sufficiently distressing to warrant special attention. Their work examines the case of a patient who was mistakenly taken for another patient's invasive electrophysiology procedure. The case is described below:

- *In a large teaching hospital, an elderly woman ("Joan Morris") is waiting to be discharged after a successful neurosurgical procedure. A floor away, another woman with a similar last name ("Jane Morrison") is scheduled to receive the day's first cardiac electrophysiology study (EPS), a procedure that starts and stops the heart repetitively to find the cause of a potentially fatal heart rhythm disturbance. The EPS laboratory calls the floor to send "Morrison" down, but the clerk hears "Morris" and tells that patient's nurse that the lab is ready for her patient. Luckily, the procedure, which was finally aborted when the neurosurgery attending came to discharge his patient and learned she was in EPS laboratory, caused no lasting harm.*

The incident above is displays an OI failure case where the wrong patient (i.e., the wrong "transaction object" as it will be presented in Section 3) was selected to be transferred to the EPS laboratory, which was clearly caused by communication failure between the laboratory and the clerck's office. This is evidence of what will also be defined in Section 3 as poor "transaction control process", or measures (e.g., mechanisms, trainings, etc.) that assure the right patient is selected and sent to the right location, that invasive surgeries are administered at the right body location in patients and that the right medication (or medication dose) are given to patients.

Unfortunately, the importance of "transaction control process" are not acknowledged by unwary healthcare facilities exposing patients to these kinds of failures. Therefore, not different from wrong-patient type of error, wrong-site surgery had received little attention and had been considered a random, infrequent event (Meinberg and Stern, 2003). One example of this event is shown below (Watcher, 2008):

- *In 1995, Willie King, a 51-year-old diabetic man with severe peripheral vascular disease, checked into a hospital in Tampa, Florida for amputation of gangrenous right leg. The admitting clerk mistakenly entered into the computer system that Mr. King was there for left below-the-knee amputation. An alert floor nurse caught the error after seeing a printout of the day's operating room (OR) schedule; she called the OR to correct the mistake. A nurse made a handwritten correction to the printed schedule, but the computer schedule was not changed. Since this computer schedule was the source of subsequent printed copies, copies of the incorrect schedule were distributed around the OR and hospital. King's surgeon entered the OR, read the wrong procedure off one of the printed schedules, prepped the wrong leg, and then began to amputate it. The error was discovered partway through the surgery, too late to save the left leg. Of course, the gangrenous right leg still needed to be removed.*

In an effort to prevent wrong-site surgery, in 1997, the American Academy of Orthopedic Surgeons (AAOS) Task Force on Wrong-Site Surgery was formed to determine the incidence of wrong-site surgery and to initiate the "*Sign Your Site*" campaign. The campaign urged surgeons to sign the location where a procedure is supposed to be performed hours before the procedure is executed, which is definitely a "transaction control process" initiative. Meinberg and Stern (2003) study aimed to evaluate the effectiveness of the AAOS "Sign Your Site" campaign. Seventy percent of the responding orthopedic surgeons were aware of the "Sign Your Site" campaign, and 45% had changed their practice habits as a result.

The last common types of error are wrong drug and wrong drug dose, also called Adverse Drug Events or ADE. These events occur when a patient is administered the wrong medication or the right medication with a wrong dose (overdoses being the most dangerous cases). Examples of wrong drug event and wrong drug dose are shown below (Watcher, 2008):

- <u>Wrong drug event</u>: *Mr. S, a 74-year-old man, is admitted to the hospital with severe substernal chest pain. The cardiologist, Dr. G, orders a dose of metoprolol. Dr. G's handwriting is difficult to read, but the pharmacist is reluctant to page the doctor, who is known for his "difficult personality". So the pharmacist takes his best guess at the prescription and dispenses a dose of metformin, a medicine for diabetes. Ultimately the mistake is recognized and the correct medicine is administered as the patient is wheeled up for his angioplasty.*
- <u>Wrong dose case 1</u>: *In June 1995, a middle-aged man named Ramon Vasquez went to see his physician in Odessa, Texas to investigate his chest pain. His physician, suspecting angina, prescribed 120 tablets of Isordil, as its typical dose of 20 milligrams by mouth every six hours. Unfortunately, the unclear handwriting in the prescription caused Ramon Vasquez's pharmacist to read Plendil, and instructed the patient to take a 30 milligram pill every six hours. However, the usual starting dose of Plendil is 10 milligrams a day, making this an eightfold overdose. A day later, Mr. Vaquez was critically ill from low blood pressure and heart failure. He died within the week.*

- Wrong dose case 2: *Etsy Lehman was hospitalized for recurrent breast cancer at Dana-Farber Cancer Institute in 1994. Her experimental protocol called for her to receive an unusual high dose of cyclophosphamide (a chemotherapy agent), followed by bone marrow transplant. The ordering physicians wrote a prescription: "cyclophosphamide 4g/sq m over four days," intending that she receives a total of four grams per square meter of body surface area spread out over four days. Instead, the nurses administered the total dose of 4g/sq m on each of the four days. A fourfold overdose. She died within a month.*

The wrong drug event exhibits an OI failure that was influenced by poor collaboration between interfacing parties (the doctor and the pharmacist). The doctor's difficult personality prevented the pharmacist to ascertain with the doctor the right drug is prepared and sent to the patient. Differently, the wrong dose events were caused by communication breakdown between doctor and pharmacists, and doctor and nurses. As it will be discussed in Section 3, communication challenges are common causal factors in healthcare OI failures and a number of studies deliberated on this topic.

Electric Power Grid OI Failure

Power pooling is a complex inter-organizational system, which is used to balance electrical load over a larger electrical grid network. It is a mechanism for interchange of power between two and more utilities, which provide or generate electricity.

From an operational standpoint, the power pooling systems have developed because of two factors: one, the need for operating efficiencies in the generation and transmission of electric power; and two, technical advancements in high voltage lines and dynamos which enable generation and transmission of power over long distances. In a study of the New England region, it was found that the high cost of electricity was due to the structure of the electrical industry (Shipman, 1962). The region is served by many small companies, each having plants of limited scale and serving limited markets. This proliferation of small firms, having high productive costs because of the large investment and high operating and administrative costs, resulted in diseconomies of scale. Between 25% and 50% of the price of electricity in New England was attributed, directly or indirectly, to these structural arrangements. Therefore, consolidation and integration of these power resources could result in economies of operation. Technological advancements have made the interconnection of these small systems possible. The result is the development of power pools to share and exchange power resources.

With technical integration possible and desired, the need arises to arrange the systems organizationally. According to Bary (1963), electrical grid interconnection is "*the physical tying in together of two or more independently owned and managed electric supply systems at their bulk supply levels*". These interconnections tie together autonomous companies into pools to realize economies of scale and to share and switch power as the need arises. Through these interconnections, companies also realize economies by reducing their "*spinning reserve*", which is the capacity in excess of current demand necessary to offset emergency outages or sudden increases in demand.

By pooling this spinning reserve, companies can build capacity lower than otherwise because they can call on other systems for emergency assistance.

As these interconnecting systems developed, they took on two forms which differed in their degree of coordination: fully integrated (or coordinated) and unintegrated pools. In unintegrated systems, there is a low degree of coordination where each participating company deals with others as the occasion arises, prices for power are negotiated on the spot, and informal agreements establish switching procedures to meet unexpected outages or peak needs.

Fully integrated pools are those in which companies operate as if they were a single company covering an entire area. Coordination of such a pool is based on formal agreements between participants as to the price of exchanged power and the operating procedures pertaining to the load dispatching. In integrated pools, dispatching is centralized and the system is planned and designed so that each subsystem (company) is fully integrated into the total system. Integration of these pools depends upon a high degree of interfirm coordination. In some cases, the power pool, formed by the utilities, has a control dispatch office from where the pool is administered. All the tasks regarding interchange of power and the settlement of disputes are assigned to the pool administrator.

As the size of unintegrated pools expands, organizational interfaces problems arise the potential for opposition of pool members to give up their rights to engage in independent transactions outside the pool (i.e., collaboration challenges) among others exists. Failure to work oppositions over could potentially have disastrous consequences as it is illustrated by the Northeastern USA Blackout in 1965. The great blackout of 1965 occurred in a power pool called CANUSE (Canadian-United States Eastern Interconnection). CANUSE would be properly termed as an unintegrated pool, although parts of the system are integrated. This great power loop running through the northeast is composed of 83 separate utilities loosely bound together by a series of both formal and informal agreements (i.e., there is no formal transaction control process). Their system linkage was facilitated by high speed computers that sensed power needs, located the best source as to cost and availability, and, in many cases, switched power where it was needed. The failure of this technical system was something that "*couldn't happen*" according to most observers (Wren, 1967).

Days before the blackout, maintenance personnel incorrectly set a protective relay on one of the transmission lines leaving Sir Adam Beck Station (part of Ontario Hydro on Figure 2). The safety relay, which was to trip if the current exceeded the capacity of the transmission line, was set too low.

As was common on a cold November evening, power for heating, lighting and cooking was pushing the electrical system to near its peak capacity. Transmission lines heading into Southern Ontario were heavily loaded. At 5:16 p.m. Eastern Time a small surge of power coming from the Robert Moses generating plant in Lewiston, New York (part of Niagara-Mohawk Power Co.) caused the improperly set relay to trip at far below the line's rated capacity, disabling a main power line heading into Southern Ontario. Instantly, the power that was flowing on the tripped line transferred to the other lines, causing them to become overloaded. Their own protective relays, which are designed to protect the line from overload, tripped, isolating Sir Adam Beck Station from all of Southern Ontario.

With no place else to go, the excess power from Beck Station then switched direction and headed east over the interconnected lines into New York State, overloading them as well and isolating the power generated in the Niagara region from the rest of the interconnected grid. The Beck generators, with no outlet for their power, were automatically shut down to prevent damage. The Robert Moses Niagara Power Plant continued to generate power, which supplied Niagara Mohawk Power Corporation customers in the metropolitan areas of Buffalo and Niagara Falls, NY. These areas ended up being isolated from the rest of the Northeast power grid and remained powered up. The Niagara Mohawk Western NY Huntley (Buffalo) and Dunkirk steam plants were knocked offline. Within five minutes, the power distribution system in the Northeast was in chaos as the effects of overloads and loss of generating capacity cascaded through the network, breaking it up into "islands." Station after station experienced load imbalances and automatically shut down.

Figure 2 shows CANUSE, its related systems, and the interface points. Certain autonomous systems have been designated as integrated, as, for example, Convex. The Convex system is composed of three Connecticut power companies and a company in western Massachusetts. It is fully coordinated as defined previously. Some other systems are also integrated, but as a whole, CANUSE is unintegrated.

It is this unintegrated feature which illustrates the failure of the inter-organizational system to parallel the development of the technological system. Technologically the systems were related for operating economies; but organizationally, they were not. There were no, or few, provisions for linking the autonomous, yet interdependent, systems together. The parts of CANUSE were autonomous organizations which have been brought together to serve a larger system. The organizations were mutually dependent in that they must work together to achieve total system goals and subsystem goals, which were twofold: 1) to serve a given area of electric consumers and 2) support the total system upon demand.

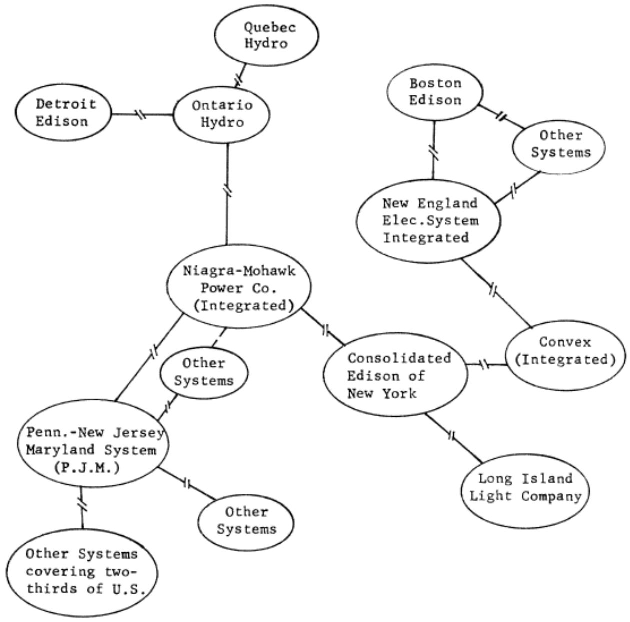

FIGURE 2 - CANUSE OI SYSTEM (WREN, 1967)

OI Failure in the Oil and Gas Industry - Piper Alpha 1983

Piper Alpha was an offshore oil and gas platform located at the North Sea and was owned and operated by Occidental Petroleum. It made part of a very complex oil and gas extraction, processing and transfer network of offshore platforms owned and operated by different shareholders from the UK and Norway. It was situated within the network in a configuration that it not only received oil and gas perforated and extracted by its own, but it also received gas from two other platforms (i.e., Claymore and Tartan). Piper Alpha's operations were carried out not only by Occidental Petroleum's personnel, but also by various contractors and subcontractors, usually for maintenance work.

At 10:00 p.m. on July 6th 1988, a massive explosion and subsequent fire led to the destruction of the platform causing the death of 167 people. Piper Alpha contributed to about 10% of the oil production from the U.K. sector of the North Sea at the time of the disaster, and became the worst offshore oil disaster in terms of lives lost and financial impact. The sequence of events leading up to the accident is complex and is described in Cullen (1990). Two condensate pumps, designated A and B, displaced the platform's condensate (i.e., natural gas liquids/NGL) for transport to MCP-01 (another interconnected platform). On the morning of July 6, Pump A's pressure safety valve was removed for routine maintenance by contractor personnel. The pump's overhaul was planned but had not started and the open condensate pipe was temporarily sealed with a blind flange (flat metal disc). Because the work could not be completed by the end of that day's shift, the blind flange remained in place. The on-duty contractor engineer filled out a work permit stating that Pump A was not ready and must not be started under any circumstances. After the day shift ended and the night shift started, the day shift contractor engineer neglected to inform the incoming shift of the condition of Pump A, assuming one would come across the work permit sheet he had prepared.

Later that night, Condensate Pump B stopped suddenly and could not be restarted. As the entire power supply depended on this pump, the manager had only a few minutes to bring the pump back online, otherwise the power supply would fail completely. A search was made through the work-permit documents to determine whether Condensate Pump A could be started. The work permit stating that it must not be started under any circumstances was not found. The manager then assumed that it would be safe to start Pump A.

Soon after, Condensate Pump A was turned on. Gas flowed into the pump, causing an overpressure that the blind flange did not withstand. Gas leaked out at high pressure through the flange, triggered six gas alarms, ignited and exploded before anything could be done to prevent it. The explosions also ruptured the pipelines that fed Piper Alpha with the material from Tartan and Claymore, which fed the fire with a lot more fuel. Claymore continued pumping material to Piper until the second explosion was heard. Also, the connecting pipeline to Tartan continued to pump, as its manager had been directed by his superior, as it would have taken several days to restart production after a stop, with substantial financial consequences.

One interesting aspect in the Piper Alpha accident was the maintenance work at the platform, which was supposed to be performed under the control of a work-permit system. It was a system of paperwork where workers had to fill out a form, which would then be submitted to a manager who would approve and track it until the work was completed. Unfortunately, the work-permit system at Piper Alpha became vulnerable to uncooperative workers, who did not apply the system as it was intended.

Employees relied on too many informal communications, such as merely leaving the form on a manger's desk instead of personally giving to him, which caused many permits to be lost. This, coupled with a poor monitoring of such permits from the leadership was the perfect combination for a failure. In reality, it was not uncommon that leadership did not know which work permits are in effect, or have been suspended, or what equipment had been isolated for maintenance purposes (Pate-Cornell, 1993).

Another unfortunate OI aspect in the Piper Alpha accident was that gas flow among the platforms was very critical in that interruptions would translate into unacceptable loss of revenue. According to Pate-Cornell (1993) the network had grown in an unplanned manner as systems were modified over time to accommodate new needs, production parameters, and regulatory requirements. The gas transfer among the platforms was characterized by strong vulnerability to corporate pressure to keep production at all cost and production could not be stopped at Piper Alpha's will alone; it also depended on decision-making in the other connected platforms.

Shockingly, when Tartan and Claymore realized that there was a problem on Piper, they simply assumed that Piper would take care of it. They did not shut off the flow of gas that they had been pumping onto Piper for over an hour, effectively tripling or more the available fuel supply. Claymore, assuming Piper Alpha would be capable of containing the situation, maintained pipeline pressure and continued production until an hour later, after a fourth violent explosion and the rupture of the Claymore riser.

Tartan personnel, though, soon realized the severity of the situation on Piper Alpha and ordered production to stop (Cullen, 1990).

<u>Product design OI failures</u>

Product design, depending on the complexity of the product, can involve a large team of designers and support personnel that must communicate critical information (e.g., product requirements) in order to achieve a successful product development (i.e., what was required by the client). Unfortunately, communication errors are not uncommon during product design. Below, two examples are discussed: the loss of the NASA Mars climate orbiter and the Tokyo Disneyland Space Mountain derailment.

The loss of the NASA Mars climate orbiter

The Mars Climate Orbiter (MCO, formerly the Mars Global Surveyor MGS) was a robotic space probe launched by NASA on December 11, 1998 to study the Martian climate, Martian atmosphere, and surface changes and to act as the communications relay in the Mars Surveyor '98 program. However, on September 23, 1999, communication with the spacecraft was lost as the spacecraft went into orbital insertion. The spacecraft encountered Mars on a trajectory that brought it too close to the planet, causing it to pass through the upper atmosphere and disintegrate.

On November 10, 1999, the Mars Climate Orbiter Mishap Investigation Board released a Phase I report (Stephenson et al., 1999), detailing the suspected issues encountered with the loss of the spacecraft. As stated in the report, on September 8, 1999, Trajectory Correction Maneuver-4 (TCM-4) was computed and then executed on September 15, 1999, which was intended to place the spacecraft at an optimal position for an orbital insertion maneuver that would bring the spacecraft around Mars at an altitude of 226 km on September 23, 1999. However, during the week between TCM-4 and the orbital insertion maneuver, the navigation team indicated the altitude may be much lower than intended at 150 to 170 km. Twenty-four hours prior to orbital insertion, calculations placed the orbiter at an altitude of 110 kilometers (80 kilometers is the minimum altitude that Mars Climate Orbiter was thought to be capable of surviving during this maneuver). Post-failure calculations showed that the spacecraft was on a trajectory that would have taken the orbiter within 57 kilometers of the surface, where the spacecraft likely disintegrated because of atmospheric stresses.

The primary reported cause of this discrepancy was that one piece of ground software supplied by Lockheed Martin produced results in a United States customary unit, contrary to its Software Interface Specification (SIS), while a second system, supplied by NASA, expected those results to be in SI units, in accordance with the SIS. Specifically, software that calculated the total impulse produced by thruster firings calculated results in pound-seconds. The trajectory calculation software then used these results - expected to be in newton-seconds - to update the predicted position of the spacecraft.

This portrays an unfortunate weak OI among Lockheed Martin and NASA, leading to Lockheed Martin providing NASA with wrong information (i.e., impulse produced by thruster firings). In fact, one of the problems observed by the Board on

MCO was that the systems engineering process did not adequately transition from development to operations. There were a number of opportunities for the systems engineering organization to identify the unit's problem leading to mission loss. The lack of an adequate systems engineering function contributed to the lack of understanding on the part of the navigation team of essential spacecraft design characteristics and the spacecraft team understanding of the navigation challenge. It also resulted in inadequate contingency preparation process to address unpredicted performance during operations, a lack of understanding of several critical operations tradeoffs, and it exacerbated the communications difficulties between the subsystem engineers.

The board found evidence of inadequate communications between the project elements, including the development and operations teams, the operations navigation and operations teams, the project management and technical teams, and the project and technical line management. For example, the operations navigation team did not communicate their trajectory concerns effectively to the spacecraft operations team or project management. In addition, the spacecraft operations team did not understand the concerns of the operations navigation team. The Board found the operations navigation team supporting MCO to be somewhat isolated from the MCO development and operations teams, as well as from its own line organization, by inadequate communication.

One contributing factor to this lack of communication may have been the operations navigation team's assumption that MCO had Mars Global Surveyor (MGS) heritage and the resulting expectation that much of the MCO hardware and software was similar to that on MGS. This apparently caused the operations navigation team to acquire insufficient technical knowledge of the spacecraft, its operation, and its potential impact to navigation computations. For example, the operations navigation team did not know until long after launch that the spacecraft routinely calculated, and transmitted to Earth, velocity change data for the angular momentum desaturation events. An early comparison of these spacecraft-generated data with the tracking data might have uncovered the unit's problem that ultimately led to the loss of the spacecraft. When conflicts in the data were uncovered, the team relied on e-mail to solve problems, instead of formal problem resolution processes such as the Incident, Surprise, and Anomaly (ISA) reporting procedure.

Tokyo Disneyland Space Mountain derailment

(http://www.mouseinfo.com/forums/tokyo-disney-resort/13134-olc-space-mountain-accident-report-released.html)

On January 26, 2004 at Tokyo Disneyland's Space Mountain, an axle broke on a roller coaster train mid-ride, causing it to derail. Detailed analysis and investigation were conducted focusing on the cause of the breakage, which determined that the gap between the axle which broke and its bearing exceeded the design specification. This wider-than-specified gap resulted in excess play between the axle and its bearing and caused more vibration than normal during the operation of the vehicle, placing excessive stress on the installation screw nut at the tip of the axle. This fatigue fracture of the axle was the direct cause of the breakage.

While the design specifies that the gap between axle and its bearing should be about 0.2 mm, the actual gap in this case was over 1 mm. The axle that broke was one of 30 axles received in October 2002. All 30 axles were thinner than the design specification, which resulted in the gap between the axles and their bearings to be greater than the specified width. This abnormal situation occurred due the design specifications for the size of the axle bearing for Space Mountain vehicles being changed from inches to the metric scale back in 1995.

Accordingly, the axle diameter was changed, in this case from 44.14mm to 45.00mm. However, appropriate action to revise and maintain the design drawings was neglected. Consequently, two different drawings existed within the company after the changes were made and the old drawing showing the 44.14 mm diameter was used to order the axles that were delivered in 2002. It was also confirmed that other axles ordered and delivered between 1995 and 2002 were all of the required size (45.00mm).

This incident shows how poor OIs caused the underdesign of an important product subcomponent due to wrong design drawings (i.e, wrong information) being used to order the subcomponent. After this incident, countermeasure implemented aimed at improving the flow of critical design information by establishing a control and management group (called the Ride Control Group) to be responsible for a unified system of ordering, inspection upon delivery and quality control of important ride vehicle parts as well as maintenance of design drawings.

Commercial Nuclear Power Plant OI failures

Nuclear power generation plants can be considered as very complex socio-technical systems where several human beings interact with each other and the complex nuclear generation system to maintain and ensure a high level of performance in operations, which is achieved through the effective implementation and control of operations (and maintenance) activities among the actors involved. According to the IAEA (2008) effective implementation and control is achieved by assuring and maintaining optimum OI among the actors.

OI effectiveness in nuclear power plants is achieved by adequate communication and collaboration among plant personnel and adequate coordination of activities. This is particularly important in a nuclear power plant setting due to its 24 hours/ day - 7 days/ week operations nature, which require shift operations structure. It is critical to maintain prime OIs among the plant shift crew (including control room and field operators), the technical support group and maintenance groups, including contractors. For example, after completing work, the shift crew, technical support group and maintenance groups should ensure that structures, systems and components affected by the work are tested and returned to their original state or to a satisfactory operational state that complies with the operational limits and conditions.

Adequate OIs between the operations department and the maintenance department is critical in particular for all aspects of outage activity, to ensure that risk from an outage is managed properly and the effectiveness of an outage is maximized.

This can be achieved by means of thorough planning and scheduling, effective coordination and implementation and the timely return of systems and components to safe operational status.

In order for adequate OIs to be present, nuclear power plants develop several measures including: 1) planning the overall activities and work of the operations department in cooperation with other departments at the plant, to develop an integrated program for plant operations; 2) monitoring and controlling the plant systems in accordance with relevant rules, operating procedures, established operational limits and conditions and administrative procedures; 3) development of operating procedures and instructions and coordination of their preparation; 4) development and implementation of work management processes to ensure that shift personnel are cognizant of the work in the plant and maintain the correct plant configuration; just to name a few.

Despite all the measures taken to maintain adequate OIs and safe nuclear power plant operations, weaknesses in these measures are strong contributing factors for unsafe events, which are very common. The United States Nuclear Regulatory Commission (USNRC) has required nuclear power plants to submit Licensee Event Reports (LERs) when conditions occur in a nuclear power plant that are beyond its technical specifications (i.e., those conditions approved for the plant to operate). For example, if a required safety barrier was discovered to not function properly, this would trigger the need for an LER. The USNRC has been receiving LERs since 1980, and about 52,000 of these reports have been submitted since then. An analysis of some of these LERs was performed and it was found that several of these events have reported root cause on OI weaknesses. Some of these events are listed below:

LER #: 87-005-0 (Title: Personnel Error Resulting In Technical Specification Violation, 1986)

This event involved the violation of a technical procedure of the Big Rock Point nuclear plant. The procedure required that when removing a control rod drive (Rod Driv) from the reactor vessel (RCT) that the reactor be in the shutdown condition and the mode switch (HS) be locked in the "shutdown" position.

Contrary to the above, on February 22, 1987, a control rod drive change out commenced with the mode switch in the "Refuel" position. Upon discovery, the Shift Supervisor stopped the activity, locked the mode switch in the "shutdown" position and then permitted completion of the change out.

The primary cause reported for this event is attributed to a failure of the maintenance personnel to follow their procedure and insure that each step is signed off when completed. Poor communication between the maintenance crew and the control room concerning the evolution of the situation coupled with a shift change complicated matters. Control room personnel should have known when the control rod drive was going to be removed and insured plant conditions were appropriate for the activity.

LER #: 86-006-00, (Title: Inadequate procedure causing untimely initiation of fire watch patrol, 1986)

In this event, a particular Technical Specification required that, when one or more fire barriers protecting safety-related areas are non-functional and the area of the affected barrier(s) is monitored by operable fire detection instrumentation, fire watch patrol be established within one hour and inspect the affected area(s) at least once per hour.

Contrary to this requirement, on October 8, 1985 following performance of surveillance test, TR-69 (Fire System Inspection), fire barrier was determined to be non-functional, however, the fire watch patrol was not established within one hour. This deviation was discovered during Quality Assurance audit of the Fire Protection Program and documented to Plant Management on August 25, 1986. The cause of the event was concluded to be procedural inadequacy in not providing a description of what constituted non-functional barrier. The Shift Supervisors did not realize that the minor deficiencies found during the test constituted non-functional fire barrier. A change to TR-69 has been initiated to provide improved definition/guidance to avoid recurrence.

LER #: 89-019-00 (Title: Manual reactor trip following a loss of feedwater to one steam generator as a result of miscommunication, 1989)

On July 24, 1989, at 12:16 while at 76% power, Unit 1 was manually tripped due to a loss of feedwater flow to Steam Generator (SG) "A" and resultant low level. The loss of feedwater flow occurred during performance of a test of the SG "A" high level alarm. At 12:15, operators authorized maintenance technicians to perform testing of the SG "A" high level alarm and Steam Flow/Feed Flow Mismatch Reactor Trip alarm. During the high level alarm portion of the test, the SG "A" high level alarm annunciated as anticipated. The high level alarm was promptly followed by the SG "A" Steam/Feed Mismatch alarm, which was not anticipated at this point in the test sequence. After observing that SG "A" levels were rapidly decreasing and the SG "A" main feedwater Flow Control Valve (FCV) had tripped closed, operators unsuccessfully attempted to open the FCV and, in accordance with procedures, manually tripped the reactor. SG "A" may have dried out for a brief period shortly after the reactor had been tripped until the auxiliary feedwater system actuated at 12:17. All required systems functioned normally.

As an intermediate cause of this event, the effects of a recent design change on the FCV circuitry were not recognized to result in a loss of feedwater flow and were, therefore, not transferred into station procedures or operator training. Consequently: (1) the issue of how the high SG level alarm test could be performed with the unit at power was not addressed nor was the test procedure revised; and (2) the ability to control an affected SG FCV was not addressed in operator training or in the SG low level operating instruction.

The cause of this failure was a miscommunication of design change information from the design organization to the station organizations who must recognize and use the change information. The miscommunication resulted from a mismatch in the expectations of the two types of organizations about the type and identification of design change information which may impact the station organizations. Additionally, there is no training or formal guidance which would enhance the ability of non-engineering PFC reviewers to identify design change impacts within their area of responsibility.

LER #: 86-044-00 (Title: Automatic Reactor Trip Due to Personnel Error During Maintenance, 1986)

On November 30 at 16:26 hours with the plant operating in mode 1 at 100 percent power, the feedwater control valve for loop 3 failed in the closed position. An automatic reactor trip was generated within 15 seconds due to low steam generator level coincident with steamflow/feedflow mismatch. Investigation into the incident revealed that the trip had been caused by an Instrumentation and Controls technician who had inadvertently grounded both normal and backup power to the feedwater control system during troubleshooting.

The root cause of this event has been determined to be personnel error and inadequate control over repair activities. The personnel error went undetected until it was too late due to inadequate work control. Specifically, the Shift Supervisor was not kept adequately abreast of work in progress, and the potential plant impact that could result. This incident has identified that there is a need for a more formal vehicle to ensure adequate communication takes place during work of this nature. Corrective action to prevent recurrence includes: improved job planning in the Instrumentation and Controls Department, and increased involvement of the Shift Supervisor in the control of troubleshooting and repair activities.

LER #: 87-008-00 (Title: Reactor Scram Due to Personnel Error While Installing Jumper, 1987)

During the performance of DOS 6600-5 procedure a full scram occurred while Electrical Maintenance personnel were placing jumpers around bypass relays in the Reactor Protection System (RPS) condenser low vacuum (SH) and main steam line isolation valve closure bypass relays (590-112A, 590-112B, 590-112C and 590-112D). Installation of the jumpers was necessary to prevent a full reactor scram during performance of DOS 6600-5. By design, a full reactor scram will occur when one train of electrical power is lost when the reactor pressure is less than 600 psig and the relays are not jumpered. The Electricians informed the Station Control Room Engineer (SCRE) of their intent to install the jumpers via Work Request (WR) #D62532. The SCRE told the Electricians to proceed with the installation after informing the Nuclear Station Operator (NSO). The NSO and the licensed Senior Reactor Operator (SRO) in charge of the test conferred and told the Electricians to install the jumpers at the positions indicated by DOS 6600-5 rather than as indicated by the work instructions listed in WR #D62532.

Both DOS 6600-5 and WR #D62532 provided instructions concerning jumpering of the relays. However, the method used to jumper the relays in DOS 6600-5 and WR #D66532 were different. Each instruction was correct. DOS 6600-5 required the jumpers to be placed on the terminal strips of the relay cabinet. Circuit continuity is interrupted when the relay lead is lifted to install the jumper. The interruption causes one of the RPS relays to de-energize, resulting in a half scram of the affected channel. The work instructions in WR #D62532 specified that the jumpers were to be placed on the contacts themselves which would eliminate the half scram possibility. At the instructions of the SRO in charge, the Electricians followed instructions in DOS 6600-5 and lifted the first lead which resulted in a half scram. The SCRE believed the Electricians were following WR #D62532 instructions and was not aware that a half scram would occur. He instructed the Electricians to return the circuit to its original condition. The half scram was then reset. The SCRE conferred with the SRO in charge of the test and they reviewed the work request, the procedure, and the electrical schematics. The cause of the half scram was determined and the decision was made to install the jumpers per DOS 6600-5 at the terminal strips. The SCRE explained the half scram to the Electricians and informed them to wait before installing the second jumper so the half scram could be reset, thus preventing a full scram. The Electricians, who had not heard the instruction to wait, proceeded with the jumper installation. The first lead was lifted and the half scram occurred as expected. Before the NSO reset the half scram a lead was lifted to install the second jumper which de-energized a scram relay in the other RPS channel resulting in the full scram. The Electrician's work was stopped again by the SCRE and the scram was reset. The Electricians were instructed to inform the NSO at his desk after each jumper was installed. The remaining jumpers were installed without further incident.

The root cause of the event has been attributed to personnel error. The SCRE, NSO and the Electricians failed to establish an adequate line of communication as required by Operating Order #16-87, "*Required Communications Prior to Complex Plant Evolutions*". A contributing factor was that the procedure does not note that half or full scrams will result when leads are lifted. Also, the procedure did not provide the optimum method of jumpering the relays.

LER #: 95-027-00 (Title: Non-Compliance with Technical Specification for Containment Integrity While Draining Feedwater, 1995)

On November 13, 1995, it was discovered that the Secondary Containment was potentially breached for almost one hour, while the plant was in the REFUEL MODE. It was determined that plant operators while draining the High Pressure Heaters in the Heater Bay, had inadvertently drained the Feedwater headers through two 1-inch valves into the Steam Tunnel. The opening of the simultaneous drain paths created a potential flow path from secondary containment to the atmosphere. Technical Specifications required that Secondary Containment integrity be maintained at the time of the event.

The condition was discovered by personnel in the Steam Tunnel, who noted water draining onto the Steam Tunnel floor. The drain valves in the Steam Tunnel had been throttled open one turn as a result of Local Leak Rate Testing, completed the previous shift.

The event was caused by personnel error due to a communication breakdown. The brief held between the Work Control Senior Reactor Operator and the Licensed Plant Equipment Operator being sent into the field to verify valve positions was inadequate, as no formal two way communication was demonstrated during the brief. Also, no system prints were referenced or cross checked with existing boundary tags. The action to prevent recurrence include: personnel counseling and training incorporating two way communication, proper boundary verification, including prints and specific repeatback communications.

Observations on Historical Evidence

The accidents and incidents above show evidence of how poor coordination, communication and collaboration among interfacing organizations can escalate to disasters. Putt differently, successful OIs are achieved by the successful exercise of three different functions: coordination, communication and collaboration. The following Section develops an OI characterization that is necessary to understand what the three functions entail (i.e., what needs to be communicated, how transactions need to be coordinated, and how levels of collaboration must be controlled). This characterization will then be used as a basis to propose OI failure modes and potential causes or influencing factors.

Chapter 3: Organizational Interface Characterization

In order to prevent OI failures it is fundamental to understand and analyze OI characteristics so as to understand how deficiencies and enhancements in these characteristics can lead to or prevent failures respectively. The following sections propose definitions of OI characteristics as instruments to understand OIs, OI failures modes, and OI failures contributing factors.

OI Characteristics

The starting point to analyze OI success (and failure) is understanding what the objective(s) of the OI is(are). For example, the air commercial passenger transportation industry involves the interaction of different organizations (e.g., airlines and airports) and regulatory agencies (e.g., USFAA, etc.) that aims to provide air transportation services to passengers and tangible goods within a given level of quality and reliability. Quality and reliability in the air transportation service can mean several things including: the transportation process does not compromise the physical and psychological integrity of the human beings involved; accuracy in departure and arrival times; comfortable levels of the airport/airplane structures; courtesy of staff; accurate (i.e., at the correct destination) and timely luggage delivery; etc.

Urgency, complexity, ambiguity, confusion, and disjointed directions that may exists among the airport, airlines and regulatory agencies form the recipe for failure to achieve the OI objectives. Successful OIs are achieved by implementing three integrated functions: communication, collaboration and coordination. Communication is the foundation for collaboration, which in turn is the foundation for coordination. Effective communication leads to collaboration, which leads to coordination, which leads to OI harmony and OI objective(s) achievement. Before implementing these three functions, it is necessary to define OI characteristics that are used as the building blocks of the OI functions.

At a higher level, OIs involve the transfer of Interface Objects (IOb) from one location to another. Therefore, OIs can be condensed into two important elements that must be clearly defined and understood in order to analyze OI reliability: IOb and IOb transaction. IOb is defined as the element of transaction, which can be characterized by it tangibility, desired properties, origin and destination:

IOb Tangibility (IObTng)

IObTng refers to whether the IOb is tangible (e.g., people and consumable matter in general) or intangible (e.g., electronic form of information, service, natural gas and energy).

IOb Properties (IObPrp)

IObPrp refers to the features that the IOb must maintain during the transaction process and depends on the IObTng. A few examples follow:

- when people are transported, safety and wellbeing is a property of utmost importance (i.e., people want to arrive at their destination free of physical harm);

- when perishable food is transported from a distribution center to supermarkets, it must arrive at the supermarket in sellable conditions (e.g., not perished);
- when natural gas is transported from a well to a processing facility, it must maintain sand levels below pre-defined threshold;
- when an orthopedic surgeon performs a leg amputation on a diabetic patient (i.e., IOb here is a service being performed in a patient), the surgeon is expected to assure the patient's integrity and deliver the surgery procedure successfully (e.g., in the right leg, the IOb Destination/IObDt discussed below).

IOb Origin (IObOr)

IObOr refers to the original location where the IOb is situated before the transaction is initiated. This is intuitive for most IObTng, with the exception of when the IOb is "service", in which case the IObOr are the elements that will carry out the action. For example, when a surgeon performs an operation on a patient, the IObOr is the surgeon (and his/her assistants, if this is the case). When a mechanic performs corrective maintenance on a car, the IObOr is the mechanic (and his/her assistants, if this is the case).

IOb Destination (IObDt)

IObDt refers to the final location where the IOb is situated after the transaction is completed. This is intuitive for most IObTng, with the exception of when the IOb is "service", in which case the IObOr are the elements that will be affected by the action. For example, when a surgeon performs an operation on a patient, the IObDt is the patient's body part(s) affected by the surgeon's actions (e.g., left foot, heart, right lung, etc). When a mechanic performs corrective maintenance on a car, the IObDt is the car's component(s) affected by the mechanic's actions.

IOb transaction is defined as the process of transferring IOb(s) from one location to another. IOb transactions can be characterized by its transaction rate, transaction vehicle quality, number and quality of transaction routes, transaction planning quality, transaction surveillance and control process, transaction actors and transaction failure modes. These are elaborated in the following paragraphs.

Transaction rate and timing (TrR&T)

TrR&T refers to frequency of IOb transactions and the time at which the IOb must be at its destination. The rate can take the form of a discrete (i.e., an integer) or continuous value.

For example, when passengers are transferred from one airport to another, the frequency of this transfer can be measured by the number of passengers (or airplanes) that depart a given airport. The time at which an airplane lands on a runway, or the time at which passenger are at a concourse after leaving the airplane can be used as desirable transaction timing measure.

In the other hand, when water is transferred from the water supply company to the end consumer, the amount of water that is transferred is a continuous value (e.g., 400 gallons per month). The uninterruptable availability of water at the end consumer location can be used as a desirable transaction timing measure.

Recalling the accidents discussed in the historical perspective (Section 2), TrR&T can be seen as playing a role in the Avianca Flight 52 accident, 1990 (i.e., poorly estimated airport acceptance rate (AAR) turned out to be higher than the airport could handle contributed); the CANUSA power outage (i.e., the disabling of one main power line caused an overload of other lines in the system which cascaded down into the majority of the pool); and Piper Alpha explosion (i.e., continued hydrocarbon supply over an hour after the first explosions occurred);

Transaction vehicle quality (TrVhQ)

TrVhQ it is the instrument that carries the IOb from its origin to its destination. In general, tangible IObs can share common Transaction Vehicles. For example, airplanes, cars, boats, etc. transport people, food, construction material, etc.

Liquids and gases are transported in pipelines and any chemically stable substance can be sent through a pipeline. Pipelines exist for the transport of crude and refined petroleum, fuels - such as oil, natural gas and biofuels - and other fluids including sewage, slurry, water, and beer. Pipelines are useful for transporting water for drinking or irrigation over long distances when it needs to move over hills, or where canals or channels are poor choices due to considerations of evaporation, pollution, or environmental impact.

Information can be “transported” through different transaction vehicles including the human voice (through face-to-face, telephone, recorded voice message, etc.), paper, telex, fax, and electronic media (e-mail). Electric power can be transported through power lines (recent experiments suggests that it is feasible to transfer electric power using microwave technology).

Service is a more elusive intangible IOb and is defined as the action of helping or doing work for someone or something. The action is performed by one or more individuals (e.g., a doctor examining a patient, a car mechanics fixing a car, a group of technicians servicing a nuclear reactor, etc.) that may or may not using tools/equipment and other material to perform the service, and, therefore, service’s transaction vehicles are the resources (e.g., people, tools, materials, etc.) used to effect the service.

Recalling the accidents discussed in the historical perspective, TrV&Q can be seen as playing a role in the Continental Express Flight 2574 accident, 1991 (i.e., missing critical aircraft component - bolts removed during maintenance and not put back after shift change) and the Tokyo Disneyland Space Mountain derailment (i.e., rail car built with gap between axle and bearing much higher that it should have been).

Number and quality of transaction routes (TrNQRt)

TrNQRt refers to the quantity and quality of routes available for the transaction vehicles to transport the IOb from its origin to its destination. The number of transaction routs is an important characteristic as it relates to the redundancy available for the transaction process. Moreover, each particular transaction rout has traits related to its quality that can have positive or negative impact to the success of the transaction. For example, the rout selected for an airline to go from one airport to another can start experiencing strong turbulence or bad weather, which could potentially force the pilot to opt for an alternative rout (e.g., reduce or increase altitude to get out of the disturbance).

Pipelines conveying flammable or explosive material, such as natural gas or oil, pose special safety concerns as they can be the target of vandalism, sabotage, or even terrorist attacks. In some countries where poverty is a social problem, and above ground natural gas pipeline routing is the only option, the pipeline system is routed to avoid areas of high poverty (e.g., slums) due to people in these areas being inclined to steal the natural gas by incurring damage to the pipe. The routs chosen for pipeline systems are carefully studied not only to prevent these unwanted acts but also to protect the pipes from impact, abrasion, and corrosion.

Recalling the accidents discussed in the historical perspective, TrNQRt can be seen as playing a role in several of the accidents: Tenerife airport disaster, 1977 (i.e., fog reduced visibility; no markings or signs to identify the runway exits); Ozark Air Lines Flight 650 accident, 1983 (low visibility due to snow storm); Avianca Flight 52 accident, 1990 (i.e., bad weather condition); US Airways Flight 1016, 1994 (i.e., challenging wind shear conditions); Avjet Aspen crash, 2001 (i.e., darkness and the weather conditions); TAROM Flight 3107, 2007 (i.e., poor visibility due to fog); Airblue Flight 202, 2010 (i.e., poor weather conditions); and CANUSA (i.e., protective relay incorrectly set too low).

Transaction surveillance and control process (TrS&C)

TrS&C refers to the existence of efforts to monitor the status of the transaction characteristics and IOb characteristics during the entire transaction process and the mechanism that starts and stops the transaction (i.e., automatic versus human). The main purpose of TrS&C efforts is to provide a measure of how well the transaction objectives are being achieved.

A good example of TrS&C is the supervisory control and data acquisition (SCADA) system. The SCADA is a system that operates with coded signals over communication channels so as to provide control of remote equipment. The control system may be combined with a data acquisition system by adding the use of coded signals over communication channels to acquire information about the status of the remote equipment for display or for recording functions. It is a type of industrial control system (ICS), which are computer-based systems that monitor and control industrial processes that exist in the physical world. The SCADA systems distinguish themselves from ICS systems by monitoring and controlling inter-organizational processes that can include multiple sites, and large distances. Examples of such processes include infrastructure process like water treatment and distribution, wastewater collection and treatment, oil and gas pipelines, electrical power transmission and distribution, wind farms, civil defense siren systems, and large communication systems.

Other very common TrS&C systems are found in the transportation industry. In the commercial passenger air transportation industry, the air traffic control (ATC) is a service provided by ground-based controllers who direct aircraft on the ground and through controlled airspace, and can provide advisory services to aircraft in non-controlled airspace. The primary purpose of ATC worldwide is to prevent collisions, organize and expedite the flow of traffic, and provide information and other support for pilots.

The health care system unfortunately still has a lot to improve when it comes to this OI characteristic. The Joint Commission on Accreditation of Healthcare Organizations (JCAHO, 2001) attributes the types of failure discussed in the previous Section due to several factors that boil down to the essence of TrS&C, including breakdown in communication between surgical team members and the patient and family, a lack of policies and procedures in the operating room to verify that the correct patient is being operated on and that the planned procedure is being performed, a lack of a uniform method of marking surgical site, a lack of a preoperative standardized checklist, a lack of available pertinent information in the operating room, and cultural or language barriers.

For example, the Joan Morris case discussed in Chassin and Becher (2002) portrays an OI failure example where the IOb (i.e., the patient) is sent to the wrong destination (IObDt) due to poor transaction surveillance and control process. The poor TrS&C was evidenced by the authors after discovering absent or misused protocols for patient identification, systematically faulty exchange of information among caregivers, and poorly functioning teams. Their findings are consistent with Seiden and Barach (2006) view that "*wrong-patient*" errors often share a root error pathology related to ambiguous and imprecise identification, rooted in communication breakdowns.

Similarly, Willie King's Case also shows an example of poor TrS&C. The amputation procedure (which is the IOb), was administered at the wrong leg (i.e., wrong IOb destination/IObDt) due to King's surgeon reading the wrong procedure off one of the printed schedules that should have been correct in the computer system times before the surgery, which is the signature of poor TrS&C. The "sign your site" campaign initiated by the American Academy of Orthopedic Surgeons (AAOS) Task Force on Wrong-Site Surgery was a way to improve the TrS&C.

As it was discussed in the power pooling example, fully integrated pools have a "*control dispatch office*" from where the pool is administered and all the tasks regarding interchange of power and the settlement of disputes are assigned to the pool administrator, which constitutes the TrS&C. The CANUSE blackout, was highly influenced by a very poor TrS&C among 83 separate utilities loosely bound together by a series of both formal and informal agreements.

In this particular incident, the interfacing organizations had no means to cope with the unanticipated event that culminated the blackout. When confronted with a system failure, there was no way in which the organizations involved could react quickly enough to prevent their own downfall. This failure to react promptly indicates an OI deficiency in obtaining information in order to effect changes (i.e., poor TrS&C). If information had been available to provide what would be an acceptable range of tolerance for a power drain, employees, or a computer program, could have sensed the deviation, compared it with the tolerance range, and "kicked" the subsystem out of the total system.

Finally, in the Piper Alpha accident, work permit system constitutes a TrS&C tool to assure that services (i.e., the IOb) are performed successfully at the right time and frequency (i.e., right Transaction rate and timing/TrR&T), using the right tools/ parts and right qualified personnel (i.e., right transaction vehicle quality/TrVhQ).

Unfortunately Piper Alpha was characterized by a poor TrS&C, as the employees relied on too many informal communications, such as merely leaving the form on a manger's desk instead of personally giving personally (causing permits to be lost) and the leadership's lack of ownership in monitoring these permits.

In addition, there was no criteria to stop the inter platform transfer of gas. Gas flow into Piper Alpha's depended on decision-making in the other connected platforms, which caused delay in halting the gas flow into Piper Alpha, and continued to fuel the inferno the culminated in several deaths and the destruction of the entire structure.

Transaction characteristics alteration (TrCA)

TrCA refers to whether the characteristics of the transaction are dynamic (i.e., change over time) or static (i.e., do not change over time). It is natural to discern that during any IOb transaction, the TrS&C, TrR&T, TrAc, TrVhQ and TrNQRt can change during the process. Airplanes can change their routs or altitudes during a flight in order to avoid bad weather, even pilots can be replaced before a flight initiates in case the original pilot is not available (e.g., becomes sick); the destination airport of a flight maybe diverted due to dangerous landing conditions; the ATC crew that performs flight control and surveillance changes periodically, etc.

The same can be said in Power Pooling systems as it is the very reason they were created. Increases in electric power demand from consumers (a transaction characteristic alteration/TrCA) may cause a company participating in the pool to supply power at level it cannot sustain, a situation in which another company that has the extra capacity to act upon this change.

Recalling the accidents discussed in the historical perspective, TrCA can be seen as playing a role in the several accidents:

- Tenerife airport disaster, 1977 (i.e., unplanned incident at the Gran Canaria International Airport causing increased number of flights);
- Ozark Air Lines Flight 650 accident, 1983 (i.e., shift turn over for air traffic control);
- Continental Express Flight 2574 accident, 1991 (i.e., maintenance crew shift change);
- CANUSA power outage (i.e., small surge of power coming from one generating plant caused the improperly set relay to trip at far below the line's rated capacity, disabling a main power line);
- Piper Alpha 1983 (i.e., maintenance shift turn over; network had grown in an unplanned manner as systems were modified over time to accommodate new needs, production parameters, and regulatory requirements);
- Tokyo Disneyland Space Mountain derailment (i.e., design specifications for the size of the axle bearing for Space Mountain vehicles changed from inches to the metric scale);
- LER #: 87-005-0 (i.e., shift change);
- LER #: 89-019-00 (i.e., design change on the FCV circuitry were not recognized to result in a loss of feedwater flow and therefore not transferred to procedures).

Transaction planning quality (TrPlQ)

TrPlQ reflects to the amount of effort and resources devoted to plan the IOb transaction, which can have several degrees of adequacy (the worst case being no planning whatsoever). Planned transactions are those premeditated and designed with specific IOb transaction characteristics (i.e., TrS&C, TrR&T, TrAc, TrVhQ and TrNQRt). Reliable OIs are those that use special tools and techniques to foresee and risk assess transaction characteristics alteration/TrCA that could potentially prevent the objectives of the OI transaction from happening.

Unplanned transactions occur when unforeseen/ad hoc situations emerge and compel organizations to interface amongst each other with the aim of contending with the circumstances. In these cases, in general, the interface is depicted by IOb transaction characteristics arising out of unpreparedness. This could be the case of the Tenerife airport disaster. Due to a transaction characteristics alteration/TrCA, the KLM and Pan Am flights and the Tenerife airport were at the mercy of an unplanned situation that may have been trained for or not.

In the case of the power pooling system, unintegrated system have very week transaction planning quality/TrPlQ as it relied on informal agreements and no provisions were made for subsystems to link at interface points. In its report on the CANUSA blackout, the Federal Power Commission (FPC, 1967) pointed out the need for system planning to meet change. For example, there were no standing procedures set forth by CANUSE specifying "*under what circumstances particular interconnections should be severed or ... temporarily disconnected in order to save the remainder”*.

Other incidents that TrPl&Q played a role include:

- Avianca Flight 52 accident, 1990 (i.e., flight plan issued did not reflect the most current upper air data; the actual gross weight of the airplane; the reserve fuel stipulated did not account for possible en route/landing delays);
- Texas International Airlines Flight 655, 1973 (i.e., crew did not discuss the details of their intended route with Flight Service);
- USAir Flight 5050, 1989 (i.e., captain's failure to provide an extended briefing, or an emergency briefing, before the takeoffs at BWI and LGA or at any time during the 9 hours the crewmembers spent together before the accident);
- Vnukovo Airlines Flight 2801, 1996 (i.e., new approach briefing was not accomplished);
- Piper Alpha 1983 (i.e., Claymore assumed Piper Alpha would be capable of containing the situation and continued production - and feeding fuel into the fire);
- LER #: 95-027-00 (i.e., brief held between the Work Control Senior Reactor Operator and the Licensed Plant Equipment Operator being sent into the field was inadequate).

Transaction actors (TrAc)

TrAc refers to the human elements involved in the transaction process. Humans are the agents of all the essential actions for the inter-organizational transaction success. Human beings plan the OI transaction design (see TrPlQ above) by determining reliable transaction vehicles suitable for specific transaction routs, and by selecting reliable transaction surveillance and control methods, so that targeted transaction rate and timing can be attained and that desired interface object properties are maintained.

The OI characteristics described here lay the foundation to understand the three fundamental functions necessary for IOb transaction success: communication, collaboration and coordination. In order to achieve a successful IOb transaction, the transaction planning quality (TrPlQ) must address these three functions, which are elaborated further in the next Sections.

Communication

Effective communication is key to IOb transaction success. Without a common basis for communication OI efforts may be bound to fail. Communication is the primary basis for acquiring knowledge about OI related tasks at hand and, thus, is the basis for OI performance. Good communication is affected when what is implied is perceived as intended. An optimum transaction planning quality (TrPlQ) involves developing critical information that needs to be communicated and understood by all TrAc. A list of such critical OI information includes, but is not limited to:

- The objectives of the IOb transaction in terms of: desired IOb properties (IObPrp) at the end of transaction, the rate or timing (i.e., delivery date and time) at which the transaction must be finalized (TrR&T);
- The roles and responsibilities of the TrAc involved in the entire transaction process. Responsibilities include:
    - preparation of the IOb and its origin (IObOr), where IOb preparation means all the arrangements necessary for the IOb to maintain its desired properties during the transaction period until the delivery at its destination (IObDt)
    - selection and operation of the transaction vehicle, as well as determining the necessary quality of transaction routs and selection of transaction routs (TrNQRt) that meet quality requirements
    - monitoring the transaction process (TrS&C)
- Criteria for controlling IOb motion (e.g., when to pause/continue, when to initiate/terminate the transaction)
- IOb transaction characteristics that must be monitored (e.g., TrNQRt, IObPrp, TrAc, etc.), how they must be monitored (i.e., frequency and methodology) and how they must be informed to the relevant TrAc that are directly or indirectly impacted (frequency and methodology).
- Criteria for determining when IOb transaction characteristics must be changed;
- Criteria for how to communicate all of the information listed above (i.e., procedures, verbal protocol, etc.)

The list of critical information above contains topics that are essential to the IOb transaction success. One great challenge that OIs face regarding the communication function involves monitoring its effectiveness and determining whether a comfortable degree of understanding has been achieved among TrAcs. Within these lines, the study of communication is complex and measuring its effectiveness has been the subject of extensive study.

Two important factors are the communication mode and communication media. Badiru (2008) discusses three types of communication modes: simplex communication, half-duplex communication and full-duplex communication.

Simplex communication is a unidirectional communication arrangement in which one entity initiates communication to another entity or individual. The entity addressed in the communication does not have the mechanism or capability for responding to the communication.

Half-duplex communication is a bidirectional communication arrangement whereby one project entity can communicate with another entity and receives a response within a certain time lag. Both entities can communicate with each other, but not at the same time.

Full-duplex communication involves a communication arrangement that permits a dialogue between the communicating entities. Both individuals and entities can communicate with each other at the same time or face-to-face. As long as there is no clash of words, this appears to be the most receptive communication mode.

One natural question is which communication media is best suited for specific situations. The Media Richness Theory (MRT) of media choice in organizations claims to explain which communication mean is best suited for specific situations. The MRT suggests that organizational communication is influenced by two forces: uncertainty and equivocality.

Uncertainty can be defined as the absence of information. Communication media appropriate for uncertainty reduction are those that facilitate the exchange of large amounts of accurate, objective, or numerical data. Equivocality, on the other hand, refers to ambiguity and multiple, conflicting interpretations of situations. Media appropriate for equivocality reduction need to promote the ability to clarify and explain. Richness is defined as the media's ability to reduce equivocality. Richness is a function of four factors: feedback capability, cues (voice or tone inflection), personalization (transmission of personal feelings), and language variety. Communication media are proposed to vary in their capacity to process rich information along a one-dimensional continuum that includes, in order of decreasing richness: face-to-face discussion, phone calls, written addressed communication and written unaddressed communication.

Several studies have found empirical support for MRT's ability to account for differences in the ways individuals choose among traditional media and between traditional and new media (Daft, Lengel and Trevino, 1987). However, it appears that MRT is unable to account for individuals' choice among new media. In a study comparing individuals' choice between email and voice mail El-Shinnawy and Markus (1992) found, contrary to the predictions of MRT, that not voice mail but rather email was the preferred medium in equivocal communication (i.e., susceptible to two or more interpretations) situations. Voice mail, although obviously the richer medium, was preferred for short, spontaneous messages, rather than for typical equivocal communication which tends to be lengthy and ongoing. The results of the study indicated, however, that, in accordance with MRT, email was preferred over voice mail for the exchange of information to reduce uncertainty. The results of this study suggest that MRT may not be general enough to account for the choice among computer mediated technologies.

One attempt to cope with this diverging finding has been the development of a contrasting model for newer communication media. The Social Influence Model of Technology Use (FulkSchmitz and Steinfield, 1990) begins with the alternative assumption that perceptions of electronic media vary across individuals in systematic ways where media perceptions and media choice are in part socially constructed through social influence (e.g., through direct statements of co-workers). The prediction of the model is that media use within groups will follow similar patterns, while across groups differing patterns will be found. Despite there is some evidence to support this model (Rice and Shook, 1989; Ryu and Fulk, 1991), the challenge of modeling communication effectiveness remains as there are myriad elements that can influence it.

Badiru (2008) lists several important factors that impact communication effectiveness. Some of them are:

- Personal perception: Each person perceives events on the basis of personal psychological, social, cultural, and experimental background. As a result, no two people can interpret a given event the same way. The nature of events is not always the critical aspect of a problem situation. Rather, the problem is often the different perceptions of the different people involved.
- Psychological profile: The psychological makeup of each person determines personal reactions to events or words. Thus, individual needs and level of thinking will dictate how a message is interpreted.
- Social Environment: Communication problems sometimes arise because people have been conditioned by their prevailing social environment to interpret certain things in unique ways. Vocabulary, idioms, organizational status, social stereotypes, and economic situation are among the social factors that can thwart effective communication.
- Cultural background: Cultural differences are among the most pervasive barriers to project communications, especially in today's multinational organizations. Language and cultural idiosyncrasies often determine how communication is approached and interpreted.
- Organizational structure: The way that an organization is structured may have a direct influence on the flow of information and, consequently, on the effectiveness of communication. Organization hierarchy may determine how different personnel levels perceive a given communication.
- Communication media. The method of transmitting a message may also affect the value ascribed to the message and, consequently, how it is interpreted or used. The common barriers to communications are: inattentiveness, lack of organization, outstanding grudges, preconceived notions, ambiguous presentation, emotions/sentiments, lack of communication feedback, sloppy/unprofessional presentation, lack of confidence in the communicator, low credibility of the communicator, unnecessary technical jargon, too many

people involved, untimely communication, arrogance/imposition, and lack of focus.

Ineffective communication was a strong influencing factor in the Tenerife airport disaster. There was poor communication among ATC and the two airlines. According to the Air Line Pilot Association (ALPA) report on the accident (1977), facts showed that there had been misinterpretations and false assumptions. Analysis of the CVR transcript showed that the KLM pilot was convinced that he had been cleared for takeoff, while the Tenerife control tower was certain that the KLM 747 was stationary at the end of the runway and awaiting takeoff clearance. It appears KLM's co-pilot was not as certain about take-off clearance as the captain. This was exacerbated by use of ambiguous non-standard phrases by the KLM co-pilot ("*We're at take off*") and the Tenerife control tower ("*OK*").

Also, the accident showed poor coordination of the airlines locations due to lack of knowledge of the name of the Pan Am airplane (one of the TrAcs). According to the ALPA report, the KLM crew did not realize that the transmission "*Papa Alpha one seven three six, report when runway clear*" from ATC was directed at the Pan Am because this was the first and only time the Pan Am was referred to by that name (before that, the Pan Am was called Clipper one seven three six).

Finally, there was also poor radio transmission coordination among ATC and the airlines, as interference from simultaneous radio transmissions resulted in important messages not being delivered. Radio communications allows for only one transmission at a time. The fact that the ATC and the airlines transmitted simultaneously indicates a lack of awareness of the importance of coordinating the flow of radio transmission.

Poor communication was also evident in the wrong-dose cases discussed in the previous Section. In reality, poor communication is heavily referenced in the medical literature as strong root cause of medical errors (e.g., Lingard et al, 2004). There is a growing literature on the critical relationship between teamwork and safety in health care (Firth-Cozens and Mowbray, 2001). The trend in this literature is towards studying teamwork as a cluster of behaviors including coordination, situational awareness and communication (e.g., Carthey et al, 2003). In these studies for example, communication patterns were observed to be variable from case to case and team to team in operating rooms (OR). Critical information was often transferred in an ad hoc reactive manner and tension levels were frequently high. Interviewed team members varied in their perceptions of team roles and motivations underlying communication events, while they agreed that communicative tension negatively affects administrative and clinical outcomes.

Poor communication was evident in several other cases discussed in Section 2:

- Ozark Air Lines Flight 650 accident, 1983 (i.e., neither the approach controller, nor the local controller advised OZ650 of snow removal operations);
- Avianca Flight 52 accident, 1990 (i.e., limited command of the English language; mismatch between FAA's and Boeing's meaning of the word "priority"; flight crew and the dispatcher did not communicate with each other

when they were clearly able to do so; failure to relay bad weather condition causing less than adequate airport acceptance rate);

- Überlingen mid-air collision, 2002 (i.e. Flight 611's unable to immediately inform controller about descent due to controller been dealing with Flight 2937);
- Pan Am Flight 845, 1971 (i.e., wrong information provided to flight crew);
- National Airlines Flight 193, 1978 (i.e., lack of crew communication resulted in false awareness of altitude and descent rate);
- United Airlines Flight 173, 1978 (i.e., failure of flight crewmembers to successfully communicate their concern to the captain);
- Independent Air Flight 1851, 1989 (i.e., bad communications techniques on the part of the co-pilot and controller, non-adherence to standard phraseology);
- USAir Flight 1493, 1991 (i.e., failure of the FAA Air Traffic Service to provide adequate policy direction and oversight to its air traffic control facility managers);
- Thai Airways International (i.e., misleading communications - due partly to language problems of the air traffic controller - ensued between air traffic control and the pilots);
- US Airways Flight 1016, 1994 (i.e., windshear warning not received due to different radio frequency);
- Vnukovo Airlines Flight 2801, 1996 (i.e., crew lacked sufficient English skills);
- United Express Flight 5925, 1996 (i.e., failure to effectively monitor both the common frequency and to scan for traffic);
- Avjet Aspen crash, 2001 (i.e., FAA unclear wording of communication regarding the nighttime restriction for the approach; FAA's failure to communicate this restriction to the Aspen's Airport tower);
- Crossair Flight 3597, 2001 (i.e., the hills the plane crashed into was not marked in the approach chart used);
- TAROM Flight 3107, 2007 (i.e., poor communication between ATC and airport maintenance workers;
- Medical Case: Joan Morris (i.e., laboratory calls the floor to send "Morrison" down, but the clerk hears "Morris");
- Medical Case: Willie King (i.e., clerk mistakenly entered into the computer system wrong leg for amputation);
- Medical Case: Wrong drug event (handwriting is difficult to read);
- Piper Alpha 1983 (i.e., poor work-permit system causing miscommunication of unfinished maintenance work);
- NASA Mars climate orbiter (i.e., wrong impulse produced by thruster firings provided; communications difficulties between the subsystem engineers);
- Tokyo Disneyland Space Mountain derailment (i.e., two different drawings existed within the company after the changes were made and the old drawing showing the 44.14 mm diameter was used to order the axles);

- LER #: 87-005-0 (i.e., poor communication between the maintenance crew and the control room concerning the evolution of the situation);
- LER #: 86-006-00, (i.e., procedural inadequacy - it did not provide a description of what constituted non-functional barrier);
- LER #: 89-019-00 (i.e., procedural inadequacy - design change not transferred into station procedures or operator training);
- LER #: 86-044-00 (i.e., Shift Supervisor was not kept adequately abreast of work in progress);
- LER #: 87-008-00 (i.e., failure to establish an adequate line of communication; procedure did not note that half or full scrams will result when leads are lifted; procedure did not provide the optimum method of jumping the relays);
- LER #: 95-027-00 (i.e., no formal two way communication was demonstrated)>

Collaboration

In a general sense, collaboration is an act or instance of working or acting together for a common purpose or benefit. In the domain specific world, collaboration can mean different things. For example, in the ecology domain, collaboration is the mutually beneficial interaction among organisms living in a limited area.

Here OI collaboration is defined as the relationship between two or more organizations to achieve a successful IOb transaction. It is a very important OI function simply because lack of collaboration among the individuals representing each organization (or, the TrAcs) can lead to IOb transaction failure. A lack of collaboration can be materialized in many ways, such as, when TrAcs do not abide by rules and regulations agreed upon, or when TrAcs adopt a disrespectful, hostile or unapproachable attitude towards interfacing TrAcs. A lot the accidents discussed in Section 2 shows that not abiding by rules, regulations and procedures played a role including:

- Continental Express Flight 2574 accident, 1991 (i.e., failure of maintenance/inspection personnel to adhere to maintenance and quality assurance procedures);
- Texas International Airlines Flight 655, 1973 (i.e., violation of Federal Aviation Regulation (FAR) rules);
- Pacific Southwest Airlines (PSA) 182, 1978 (i.e., failure of the PSA flight crew to follow proper ATC procedures);
- Independent Air Flight 1851, 1989 (i.e., non-observance by the crew of established operating procedures);
- USAir Flight 5050, 1989 (i.e., captain executed takeoff procedure not compliant to recommendations);
- Crossair Flight 3597, 2001 (i.e., pilot failure to perform correct navigation and landing procedures);
- TAROM Flight 3107, 2007 (i.e., maintenance worker's car was not signalized and had no beacons lit contrary to procedures);

- Airblue Flight 202, 2010 (i.e., captain ignored or did not properly respond to a multitude of Air Traffic Control directives);
- CANUSA (i.e., decision not to support the total system upon demand);
- LER #: 87-005-0 (i.e., failure of the maintenance personnel to follow procedure);
- LER #: 87-008-00 (i.e., failure of the maintenance personnel to follow procedure).

Two accidents shows that disrespectful, hostile or unapproachable attitude among interfacing TrAcs played a role in the accident:

- USAir Flight 5050, 1989 (i.e., failure of the captain to transfer control back to the first officer in a smooth and professional manner);
- Medical Case: Wrong drug event (i.e., doctor known for "difficult personality" prevents pharmacist to communicate further and ascertain the right medication);

The best way to prevent poor collaboration among TrAcs playing a role in OI failures is to improve it and maintain it. In order to do so a structured approach to seeking collaboration must be in place, which must clarify the collaborative efforts required, the implication of lack of collaboration and the criticality of collaboration to OI transaction success. To establish and maintain OI collaboration, one must identify and understand the elements that causes and/or contribute to its creation, perpetuation and dissolution. Therefore, a literature investigation was implemented to pursue these factors. The literature on the subject of collaboration provides several factors that can reduce or increase collaboration. The factors that are more relevant to OI are: History of Collaboration, TrAcs mutual respect, understanding, and trust; TrAc perception of self-interest; TrAcs ability to compromise; TrAcs Flexibility; development and adherence of TrAcs clear roles and responsibilities guidelines.

History of Collaboration

OI collaboration is largely influenced by a successful past experience of collaboration among TrAcs within each interfacing organization and whether they perceive one another as reliable. A history of collaboration means that the TrAcs have experience understanding the OI characteristics and the interdependencies of each TrAcs actions towards a successful IOb transaction. The works of Austin (2000), Bierly (1988), Campbell et al. (1999) and Davidson (1976) provide insights on how history of collaboration has a positive effect on level of collaboration.

TrAcs mutual respect, understanding, and trust

When TrAcs share respect and mutual trust, the collaborative effort flows smoothly and chances that IOb transaction is successful are higher. Mutual trust emerges when the TrAcs set aside the purpose of the collaboration and devote energy to learning about each other, where each organization present its intentions and agendas honestly and openly. Building strong relationships can take time and, therefore, organizations that allow sufficient time for trust and understanding to develop are more prominent to bring the collaborative endeavor to fruition. When time is not set aside to understand how language is used and how members perceive each other, conflicts may develop due to a lack of understanding about the other TrAcs. This was evidenced by the “*wrong drug*” event, where the pharmacist, unable to read the doctor’s handwriting, did not contact the doctor to make sure the right drug will be provided due to the doctor’s “*difficult personality*”.

The literature is swamped with work addressing the importance of mutual respect, understanding, and trust among the organizations for the success of collaboration including Abbott et al. (1995), Agranoff and Lindsey (1983), Auluck and Iles (1991), Austin (2000) and Bierly (1988). In the other hand, the Tenerife airport disaster shows evidence that this factor had a negative effect. According to Job (1995), the KLM’s flight engineers and the first officer apparently hesitated to challenge the captain further about their concern regarding the Pan Am not being clear of the runway. The official investigation suggested that this might have been because the captain was not only senior in rank, but also one of the most respected pilots working for the airline.

TrAc perception of self interest

Another element that influences collaboration is the organizations seeing the collaboration effort as in their self-interest. In other words, TrAcs believe that they will benefit from their involvement in the collaboration and that the advantages of membership will offset costs such as loss of autonomy and turf. Chances for success increases when it is clear what member organizations stand to gain from the collaboration, those expectations are built into the goals and remain visible throughout the life of the collaborative effort, incentives for individual organizations to get involved and stay involved are built into the collaborative effort, and those incentives are monitored to see if they continue to motivate members.

Lennett and Colten (1999), Lukas and Weiss (1995), McCann and Gray (1986), Means et al. (1991) and Pitt (1998) examined the positive influence on collaborative efforts emerged when organizations see the collaboration as in their self-interest.

This factor was evident in the CANUSA example. The fact that CANUSA OI relied on informal agreements and that no provisions were made for subsystems to link at interface points posed each participating organization at a decision making dilemma: reaching economic goals by being loyal to the total system so that operating efficiencies could be attained, or achieving service reliability to serve the participant's own customers.

TrAcs ability to compromise

When decisions regarding OI characteristics cannot possibly fit the preferences of every interfacing organization perfectly they must be able to compromise by giving their representatives some latitude in working out agreements (rigid rules and expectations can render collaboration unworkable). Examples of the importance of the ability to compromise on collaborative efforts can be found in Agranoff and Lindsey (1983), Block et al. (1999), Davidson (1976), Holman and Arcus (1987), and McCann and Gray (1986).

TrCA Flexibility

In order for organizations to collaborate successfully, they need to be flexible to adapt to transaction characteristics alteration (e.g., change in transaction vehicle, transaction rout, transaction timing and rate, etc.) as the need to change these characteristics arise. Communicating the need and expectation for flexibility is crucial at the outset of an OI collaborative effort. Block et al. (1999), Rist et al (1980), Rubin (1998), Trubowitz and Longo (1997) and Wiewel and Lieber (1998) elaborate on the positive effects of this factor on collaboration.

Development and adherence of TrAcs clear roles and responsibilities guidelines

When organizations collaborate with each other, they must clearly understand their roles, rights, and responsibilities, they understand how to carry out those responsibilities and the consequences that can unfold for not abiding by. In order to achieve these, the organizations need to discuss the roles, rights, and responsibilities of the partners, reach agreement on these, and clearly communicate them to all relevant parties. Any conflict resulting from the competition between demands placed on them as employees of the organization they represent and demands they face as members of a collaborative team must be identified and addressed. The studies of Harrison et al. (1990), Isles and Auluck (1990), Lennett and Colten (1999), Rogers et al (1996) and Unban and Bennett (1999) touch upon this topic.

Coordination

OI coordination is the process that governs the way each organization within the OI environment act to achieve the objectives of the OI. It is just intuitive that the activities inherent to an OI transaction must be coordinated, as coordination facilitates harmonious progress of IOb transactions.

When two or more organizations engage in an OI effort, each organization's coordination strategy can have significant impact on the achievement of the OI objectives. The interdependence of their activities that are relevant to OI objectives achievement must be well understood, and the level of this understanding plays a vital role in the success of the OI objectives. However, in most cases, organizations have their own coordination strategies that may or may not be the best to serve the purpose of the OI. These coordination strategies are a function of three organizational characteristics: organization design, organizational environment complexity and organizational culture, all of which can impact on the success or failure of IOb transactions.

Unfortunately, these organizational characteristics cannot be derived from the accidents discussed in Section 2. Therefore, the accidents cannot be used as supporting evidence that the organizational characteristics played a role in OI weaknesses and the accidents. Instead, the strategy is to explore theories on these organizational characteristics in search for arguments supporting the hypothesis that these characteristics can potentially play a role in OI failures, which are empirically tested in Section 4.

Organizational Design

Organizational design is the process by which managers select and manage aspects of organizational structure in order to control the activities necessary to achieve its goals. (Etzioni, 1964). It consists of activities such as task allocation, coordination and supervision, which can be designed in many different ways, depending on their objectives. The design of an organization will determine the modes in which it operates and performs, and allows the expressed allocation of responsibilities for different functions and processes to different entities within the organization. It affects organizational action in two big ways. First, it provides the foundation on which standard operating procedures and routines rest. Second, it determines which individuals get to participate in which decision-making processes, and thus to what extent their views shape the organization's actions. Organization design is a very complex subject and, due to the dynamic nature of the market, innovative ways to design organizations are proposed at fast pace, leading to a number of characteristics used to describe the organizational design.

In general, organizational design can be characterized by three dimensions: level of structural complexity, level of formalization (or level of bureaucracy) and level of decision making centralization **(**Burton and Obel, 2005), Fredrickson, 1986 and Robbins, 1990**)**.

<u>Level of structural complexity</u>

Level of structural complexity refers to the degree of spatial and geographical differentiation. Spatial differentiation refers to the number of departments within a hierarchical level, how these departments are structured, the number of people within each department and the level of skills and technology necessary to perform the functions in those departments. Geographical differentiation refers to the number of geographical areas that the organization is located. Each of these characteristics have inherent advantages and disadvantages.

Aiken et al. (1980) affirms that structural complexity can promote more ideas and new knowledge that can reduce costs and improve organizational performance in achieving its goals for several reasons. First, high levels of complexity indicate diverse bases of expertise, which may result in the identification of a wide range of problems (related to both costs and performance) and the availability of diverse kinds of information and perspectives about problem solving. Second, complexity also implies a diversity of interests that stimulate new proposals as the various occupational groups and departments strata seek to improve or protect their position in the firm. Third, structural complexity makes possible, and may often require, a formal or informal assignment of special responsibilities for proposing organizational changes to particular roles and subunits to improve performance improvement strategies or reduce costs.

There are many forms of organizational structure, two of which are very common: the functional and the divisional. A *functional structure* is a design that groups people into separate functions or departments because they share common skills or expertise or because they make use of the same resources. An organization groups tasks into functions to increase the effectiveness with which it achieves its goals (Duncan, 1979). As functions specialize, skills and abilities improve, and the core competences that give an organization a competitive advantage emerge. Different functions emerge as an organization responds to increasingly complex task requirements.

The problem facing the functional structure is how to keep control of increasingly complex activities as the organization grows. For example, as the organization produces more and more products, becomes geographically diverse, interfaces with more suppliers, etc. control problems impede ability to coordinate organizational activities (Williamson, 1977), including communication problems. As more organizational functions develop, each with its own hierarchy, they become increasingly distant from one another. They develop different subunit orientations that cause communication problems (Lawrence and Lorsch, 1967).

A divisional structure is meant to cope the control issues in the functional structure. If an organization limits itself to producing a small number of similar products, produces those products in one or a few locations and sells them to one major type of customer, managers will be able to solve most of the control problems associate with a functional structure.

This structure groups functions according to the specific demands of product, market and customers. The goal is to create smaller, more manageable subunits within an organization. The type of divisional structure depends on the specific control problems. If the control problem is due to the number and complexity of products, the organization divides its activities by product and uses a product structure (the same follows for market structure and customer structure). In this structure, there are corporate managers and divisional managers. Corporate managers are responsible for long-term planning for the corporation as a whole and for tailoring the mission of the divisions to suit the goals of the whole organization (e.g., by monitoring the performance of divisional managers).

Despite that the extra control provided by the corporate office encourages the stronger pursuit of internal organizational efficiency by divisional managers, this structure come with challenges as well. One challenge is coordination problems between divisions. In divisional structures measures of effectiveness are used to compare divisions' performance, so that corporate headquarters can allocate capital to the divisions on the basis of their performance. One problem with this approach is that divisions may begin to compete for resources, and rivalry between them may prevent them from cooperating. Such rivalry can lower organizational performance when a company's effectiveness depends on the divisions' sharing of knowledge and information to enhance the performance of all divisions.

The coordination problems, in effect, causes communication challenges, in particularly the distortion of information. The head of a division may deliberately disguise falling divisional performance to receive larger capital allocations. When a company has, say, 200 divisions, such deception can be hard to detect. In addition, it may take so long for headquarters to make decisions and transmit them to divisions that responses to competitors are too slow. Therefore, the more centralized an organization, the more of a problem communication will be.

<u>Level of formalization</u>

Level of formalization refers to the degree in which rules and procedures control the way the organization functions. Procedures include the best practices that decision makers learn from experience, reduce ambiguity, and allow employees to deal more effectively with contingencies in their jobs (Adler and Borys, 1996; Jansen et al., 2006). Rules providing specific behavioral directives for members to follow generate cost savings through the reduction of money wasted and time lost, but can equally encourage collaboration and cooperation between individuals (Cordón-Pozo et al., 2006).

The articulation of rules and regulations shapes the structure and content of interactions; these rules and regulations facilitate the circulation of the knowledge produced across different departments, nurturing them with new ideas and different viewpoints (Cohendet et al., 2004). Without a formalized structure, organizational members' attempt to improve performance may remain disorganized, infrequent, sporadic, or ineffective (Okhuysen and Eisenhardt, 2002). Thus, the content of rules may provide insights and cognitive material that firms can use to reduce costs (Reynaud, 2005).

The literature about total quality management (TQM) points out that the analysis and evaluation of all the activities developed within the firm may generate a series of formal documents that lead to improved quality and to the avoidance of deviations from the established standards. As Beckmann et al. (2007) and Meirovich et al. (2007) show, formalization correlates positively with the quality of the products or services that the firm offers, which is a way to reduce costs and to improve differentiation at the same time.

Despite written rules and standard operating procedures (SOPs) and unwritten values and norms being important forms of behavior control in organizations, they can lead employees to follow written and unwritten guidelines too rigidly instead of adapting them to the needs of a particular situation, which stifle innovation. Detailed rules specifying how decisions are to be made leave no room for creativity and imaginative responses to unusual circumstances. As a result, decision making becomes inflexible and organizational performance suffers.

Level of decision-making centralization

Level of decision making centralization refers to how the people that make part of the organization influence and participate in decision making. It reflects the level of authority each organizational member has in making decisions that affect organizational goals. Authority, for example, gives one person the power to hold other people accountable for their actions and the right to make decisions about the use of organizational resources. Hierarchy of authority is always present in every organization, and how much decision-making authority to delegate to each hierarchical level is an important design topic.

It is possible to design an organization in which managers at the top of the hierarchy have all power to make important decisions. Subordinates take orders from the top, are accountable for how well they obey those orders, and have no authority to initiate new actions or use resources for purposes that they believe are important. When the authority to make important decisions is retained by managers at the top of the hierarchy, authority is said to be highly centralized (Pugh et al, 1968). By contrast, when the authority to make important decisions about organizational resources and to initiate new projects is delegated to managers at all levels in the hierarchy, authority is highly decentralized.

Different levels of (de)centralization have advantages and disadvantages and finding a balance has been subject of investigation. Decision making decentralization fosters the incorporation of a greater number of individuals and organizational levels into the process of strategic reflection (Hall and Saias, 1980; Robbins, 1990). Thus, the more individuals become involved in the decision-making process, the more variety and more ideas will arise to improve differentiation strategies (Jansen et al., 2006). Participation in the decision-making process facilitates the understanding of decisions adopted and development.

Decision making centralization reduces the likelihood that organizational members seek innovative and new solutions (Damanpour, 1991). When managers allow individuals to act autonomously the organization can achieve better business opportunities in relation to new products or services (Nonaka, 1988, 1994). Decentralization allows for the interplay between a variety of perspectives and leads to a rich internal network of diverse knowledge resources to reduce costs or increase differentiation. Centralization may increase costs because of the existence of time-consuming formal communication channels (Sheremata, 2000) and also reduce creative solutions and hinder interdepartmental communication and frequent sharing of ideas (Souitaris, 2001). Decentralization facilitates spontaneity, experimentation, freedom of speech, and circulation of ideas.

Within the realm of level of structural complexity, level of formalization (or level of bureaucracy) and level of decision making centralization, two very popular organizational design characterizations are the ones proposed by Mintzberg (1979) and Burns and Stalker (1961). Mintzberg characterizes organizational design into five different typologies: simple, machine bureaucracy, professional bureaucracy, divisionalized form and adhocracy.

The simple design is the most basic structure. Power is centralized in top management, with few middle managers. Usually small companies use this form and control is exercised personally by managers who are able to know all their workers and talk to them directly on a daily basis. It is appropriate for entrepreneurial companies, companies with simple products and start-up companies.

The machine bureaucracy is highly efficient but not flexible, and there is high emphasis on standardization of production processes. Most employees perform highly specialized tasks that require few skills. The organization needs detailed planning and so requires administrative management. It is appropriate for organizations involved in mass production, or that produce simple products in stable environments (discussed in Section 3.4.2).

The professional bureaucracies relies on standardized skills, rather than standardized processes. Use of professionals permits organization to give its employees discretion in performing tasks for which they have been professionally trained. Have less hierarchy than machine bureaucracies although professionals are supported by more mechanistically (see mechanistic structure below) organized staff. It is best suited for companies operating in complex, stable environments.

In the divisionalized form, relatively autonomous divisions run their own businesses, each producing specialized products for particular markets. Divisions overseen by corporate staff who set divisional goals, control behavior by regulating resources, and monitor performance using standardized financial measures (e.g., sales target, rates of return, etc.). It is appropriate for complex and unstable environments where relatively autonomous divisions run their own businesses and executives and corporate staff manage through standardized financial and performance measures.

Adhocracies, is a design of interacting project teams whose task is to innovate solutions to constantly changing problems. It employs many experts who produce non-standardized products to their customers' specifications. Decision-making is highly decentralized and strategy emerges from actions taken throughout the company. It is best suited for organizations within turbulent environments requiring constant innovation and decentralized decision-making handled in interacting project teams.

Burns and Stalker (1961), synthetized Mintzberg's typologies into two types of designs: mechanistic and organic. Mechanistic designs are designed to induce people to behave in predictable, accountable ways. Decision making authority is centralized, subordinates are closely supervised, and information flows mainly in a vertical direction down a clearly defined hierarchy. In a Mechanistic design, the tasks associated with a role are also clearly defined. There is usually a one-to-one correspondence between a person and a task. Each person is specialized and knows exactly what he or she is responsible for, and behavior inappropriate to the role is discouraged or prohibited.

At the functional level, each function is separate, and communication and cooperation among functions are the responsibility of someone at the top of the hierarchy. Thus, in a Mechanistic design, the hierarchy is the principal integrating mechanism both within and between functions. Because tasks are organized to prevent miscommunication, the organization does not need to use complex integrating mechanisms. Tasks and roles are coordinated primarily through standardization and formal written rules and procedures specify role responsibilities. Standardization together with the hierarchy, are the main means of organizational control.

Given this emphasis on the vertical command structure, the organization is very status conscious and norms of protecting one's turf' are common. Promotion is normally slow, steady, and tied to performance, and each employee's progress in the organization can be charted for years to come. Because of its rigidity, a Mechanistic design is best suited to organizations that face stable environments.

Organic designs are at the opposite end of the organizational design spectrum from Mechanistic designs. Organic design promote flexibility, so people initiate change and can adapt quickly to changing conditions. Organic designs are decentralized so that decision-making authority is distributed throughout the hierarchy; people assume the authority to make decisions as organizational needs dictate. Roles are loosely defined and people continually develop new kinds of job skills to perform continually changing tasks. Employees from different functions work together to solve problems; they become involved in each other's activities. As a result, a high level of integration is needed so that employees can share information and overcome problems caused by differences in subunit orientation. The integration of functions is achieved by means of complex mechanisms like task forces and teams. Coordination is achieved through mutual adjustment as people and functions negotiate role definitions and responsibilities and informal rules and norms emerge from the ongoing interaction of organizational members.

Over time, in an Organic design, specific norms and values develop that emphasize personal competence, expertise, and the ability to act in innovative ways. Status is conferred by the ability to provide creative leadership, not by any formal position in the hierarchy.

Clearly, organic and Mechanistic designs have very different implications for the way people behave. Which one is better depends on the industry in question. Organic designs encourage the kinds of innovative behaviors: teamwork and self-management to improve quality, customer service, and reduce the time needed to get new products to market. However, an Organic design would not suit the defense industry because of the many authority and status problems that would arise in getting the army, air force, marines, and navy to cooperate. An Organic design would not suit the nuclear power generation industry because, if employees adopt a creative, novel response in an emergency situation, it might result in a catastrophe. An Organic design would probably not suit a restaurant because the one-to-one correspondence of person and role allows each restaurant employee to perform his or her role in the most effective manner. Conversely, a Mechanistic design would not fit a high-tech company like Apple or Microsoft where innovation is a function of the skills and abilities of teams of creative programmers working jointly on a project.

In an OI perspective, since in organic designs coordination is achieved through mutual adjustment among people as they negotiate responsibilities, rules and norms, this could potentially slow or event impair communication flow as disagreements may emerge among transaction actors, and, therefore, organic designs are more prone to contribute to OI failures.

Organizational Environment Complexity

Every organization is inserted within an external environment that are characterized by forces that could impact the performance of the organization. Therefore, IOb transactions among organizations could potentially be impacted by such external environmental forces. The external environmental forces can be subdivided by social, cultural, legal, political, economic, technology and physical forces and are defined as follows:

- Legal - defined by the constitutions, laws, and legal practices of nations in which an organization conducts its business. It involves such matters as corporate, antitrust (anti-monopoly), tax, and foreign investment law.
- Political - refers to the distribution and concentration of power and the nature of political systems (e.g. democratic vs. autocratic) in the areas of the world in which the organization operates.
- Economic - is comprised of labor and financial markets for goods and services. Fiscal policies, consumption pattern, patterns of capital investment, and the banking system all contribute to shaping the economic forces.

- Technology - provides knowledge and information in the form of scientific developments and applications that organizations can acquire and use to produce outputs (goods and services). Such knowledge takes the form of educated employees, equipment and software, and services provided by consultants and other professionals.
- Social - is associated with class structure, demographics, mobility patterns, lifestyles, social movements, and traditional social institutions including educational systems, religious practices, trades, and professions. In the United States and Western Europe, aging populations, increasing workforce diversity, and professionalization of many types of work, including management, are all examples of recent trends affecting organizations operating in those parts of the world.
- Cultural - revolves around issues such as history tradition, normative expectations for behavior, beliefs, and values. Examples of conditions in the cultural sector for Western organizations include emphasis on leadership, technical rationality, and material wealth, while cultural sector trends in these parts of the world show decreasing value for hierarchical authority and increasing value for ethical business practices, human rights, and protection of the physical environment.
- Physical - includes natural resources and the effects of nature. Some organizations have direct and immediate concerns with physical sector elements ranging from coal and oil reserves (e.g., firms operating in the oil industry), accessible harbors (e.g., firms in import/export trades or those operating shipping companies), viable transportation routes (e.g. trucking companies), and pollution levels (e.g. manufacturing concerns), to severe weather conditions (e.g.. firms in the air transportation, shipping, construction, and tourism industries).

These environmental forces may have strong influence on the organization's ability to serve the purpose of the OI objectives. There are two ways the environmental forces influence organizations: (1) the level of uncertainty about the environmental force and amount of information needed to understand the environmental forces to reduce this uncertainty and (2) the need of resources from the environmental forces (Harris, 2004). Environmental forces uncertainty pertains primarily to those forces that an organization deals with on a regular basis. Although environmental forces such as economic conditions, social trends or technological changes can create uncertainty, determining environmental uncertainty generally means focusing on how many environmental forces influence the organization (complexity) and how rapidly these environmental forces change (instability/dynamism) (Dess and Beard, 1984). Uncertainty means that organizations do not have sufficient information about environmental forces, and it is difficult for organization to predict external changes (Koberg, 1987).

Environmental complexity is a function of the number and interconnectedness of the environmental forces that an organization has to manage (Dooley, 2002). The greater the number and the differences between them, the more complex and uncertain is the environment and the more difficult to predict and control.

The instability dimension refers to whether the forces in the environment are dynamic. It is a function of how quickly characteristics of a particular environmental force change over time and thus increase the uncertainty the organization faces (Aldrich, 1979). An environment is stable if environmental forces affect the organization in a predictable way. It is unstable if an organization cannot predict the way in which environmental forces will change over time. If technology, for example, changes rapidly as it does in the computer industry, the environment is very dynamic. An organization in a dynamic, unstable environment will seek ways to make it more predictable to reduce the uncertainty it faces.

However, complexity and instability are only related to how organizations adapt to lack of information and uncertainty related to these environmental forces. The environment is the source of scarce and valued resources essential to an organization's survival. Environmental richness (i.e., the amount of resources available to support the organization's domain) is another factor that affect uncertainty. In rich environments, uncertainty is low because resources are plentiful and organizations need not to compete for them. Biotechnology companies in Boston, for example, have a large pool of high-quality scientists to choose from because of the presence of so many universities in the area (MIT, Harvard, Boston University, etc.). In poor environments, uncertainty is high because resources are scarce and organizations have to compete for them. The supply of high quality scientists in Alaska, for example, is limited, and meeting the demand for them is expensive.

Environments may be poor due to an organization being located in a poor country or poor region of a country or due to high level of competition over available resources (Aldrich, 1979). In poor environments, the greater the problems organizations face in managing resource transactions. Organizations have to battle to attract customers or to obtain the best inputs or the latest technology, which result in uncertainty.

Various theories on organization environment complexity were developed. The most popular include the transaction cost theory and the resource dependence theory. Transaction costs refers to the costs of negotiating, monitoring and governing transactions with people. Whenever people work together, there are costs associated with controlling their activities (Alchian and Demsetz, 1972). When organizations exchange resources or information, there are costs associated to it. Organizations interact with other organizations to get the resources they require, and they have to control those symbiotic and competitive interdependencies. According to resource dependence theory, organizations attempt to gain control of resources and minimize their dependence on other organizations.

According to transaction cost theory the goal is to minimize the costs associated with exchanging resources with the environment and the costs of managing exchanges inside the organization (Williamson, 1979). The money spent on activities related to negotiating or monitoring exchanges with other organizations, or with people inside the organization, is money not being used to create value. Organizations try to minimize transaction costs and bureaucratic costs because they siphon off productive capacity. Organizations try to find mechanisms that make inter-organizational transactions relatively more efficient. Health care provides a dramatic example of just how large transaction costs can be and why reducing them is so important. It is estimated that over 40% of the U.S. health-care budget is spent handling exchanges (such as bills and insurance claims) between doctors, hospitals, the government, insurance companies, and other parties. Any improvements that reduce transaction costs would result in a major saving of resources. The desire to reduce transaction costs was the impetus for the formation of health maintenance organizations (HMOs) and other networks of health-care providers. HMO providers agree to reduce their costs in return for a more certain flow of patients, among other things. This trade-off reduces the uncertainty they experience.

Inter-organizational transaction costs are caused by a combination of human and environmental factors (Williamson, 1977). The environment is embedded with uncertainty and complexity and people have limited ability to process information and to understand the environment (Simon, 1957). Due to this limited ability, the higher the level of uncertainty (either regarding changes in the environmental forces or regarding the impact changes in environmental forces would cause the organization), the greater the difficulty of managing transactions between organizations.

Most people and organizations behave honestly and reputably most of the time, but some always behave opportunistically-that is, they cheat or otherwise attempt to exploit other forces or stakeholders in the environment (Williamson, 1979). For example, an organization contracts for component parts of a particular quality. To reduce costs and save money, the supplier deliberately substitutes inferior materials but bills for the more expensive, higher quality parts. Individuals, too, act opportunistically: Managers pad their expense reports or exploit customers by manufacturing inferior products.

For example, when an organization is dependent on one supplier or on a small number of trading partners, the potential for opportunism is great. The organization has no choice but to transact business with the supplier, and the supplier, knowing this, might choose to supply inferior inputs to reduce costs and increase profit. When the prospect for opportunism is high because of the small number of suppliers to which an organization can go for resources, the organization has to expend resources to negotiate, monitor, and enforce agreements with its suppliers to protect itself.

Organizations base their choice of inter-organizational linkage mechanisms on the level of transaction costs involved in an exchange relationship. Transaction costs are low when organizations are exchanging nonspecific goods and services, uncertainty is low and there are many possible exchange partners. In these environmental conditions, it is easy for organizations to negotiate and monitor inter-organizational behavior. Thus, in a low-transaction-cost environment, organizations can use relatively informal linkage mechanisms, such as reputation and unwritten, word-of-mouth contracts.

Transaction costs increase when organizations begin to exchange more specific goods and services, uncertainty increases and few transaction partners are available. In this kind of environment, an organization will begin to feel it cannot afford to trust other organizations, and it will start to monitor and use more formal linkages, such as long-term contracts, to govern its exchanges. Contracts, however, cannot cover every situation that might arise. If something unexpected happens, the other party to the exchange has a perfect right to act in the way that most benefits itself, even though its actions are harmful to the other organization.

According to transaction cost theory, an organization should choose a more formal linkage mechanism to manage exchanges as transaction costs increase. The more formal the mechanism used, the more control organizations have over each other's behavior. Formal mechanisms include strategic alliances (joint ventures), merger, and takeover, all of which internalize the transaction and its cost. In a joint venture, two organizations establish a third organization to handle their joint transactions. Establishing a new entity that both organizations own equally reduces each organization's incentives to cheat the other and provides incentives for them to do things that will create value for them both. With mergers, the same arguments hold because one organization now owns the other.

From a transaction cost perspective, the movement from less formal to more formal linkage mechanisms occurs because of an organization's need to reduce the transaction costs of its exchanges with other organizations. Formal mechanisms minimize the transaction costs associated with reducing uncertainty, opportunism, and risk.

Despite formal linkage mechanisms are an efficient way to minimize the transaction costs of exchanges with the environment, organizations do not use these mechanisms all the time. Some organizations prefer using an informal linkage mechanism such as a contract instead of a joint venture or a merger. This is due to the fact that bringing the transactions inside the organization minimizes but does not eliminate the costs of managing transactions (Coase, 1937). Managers must still negotiate, monitor, and govern exchanges between people inside the organization (Jones, 1983).

Resource dependence theory states that an organization's structure and function is determined by its environments, where dependent relationships exist between organizations and other actors in their network environment (Pfeffer and Salancik, 1978). Understanding these power/dependence relationships is instrumental for creating strategic countervailing dependence to offset uncertainty and overbearing external influence. The theory argues that an analysis of the inter-organizational network can help an organization's managers understand the power/dependence relationships that exist between their organization and other network actors. Such knowledge allows managers to anticipate likely sources of influence from the environment and suggests ways in which the organization can offset some of this influence by creating countervailing dependence for others.

An organization's dependence on its environment is the result of its need for resources such as raw materials, labor, capital, equipment, knowledge, and outlets for its products and services-resources that are controlled by the environment. The environment derives power over the organization from this dependence, which it uses to make demands on the organization for such things as competitive prices, desirable products and services, and efficient organizational structures and processes.

According to Ulrich and Barney (1984), resource dependence means that organizations depend on the environment but strive to acquire control over resources to minimize their dependence. Organizations are vulnerable if vital resources are controlled by other organizations, so they try to be as independent as possible. Organizations do not want to become too vulnerable to other organizations because of negative effects on performance. The goal of the organization is to minimize its dependence on other organizations for the supply of resources in its environment and to find ways to influence them to secure the needed resources (Pfeffer and Salancik, 1978). Therefore, the dependence on resources forces the organizations to exert influence over other organizations so it can obtain resources and also respond to the needs and demands of the other organizations in its environment (Pfeffer, 1982). This influence exertion resulting from resource dependency along with uncertainty about environmental forces (and amount of information needed to understand the environmental forces to reduce this uncertainty) could lead to tensions among interfacing organizations, reduce trust, and increase chances of OI failures.

Organizational Culture

Organizational culture can be defined as the set of values, norms, guiding beliefs and understandings that is shared by members of an organization and taught to new members as the correct way to think, feel and behave (Duncan, 1989; Smircich, 1983; Brown and Starkey, 1994). It controls the members of the organization in terms of how they interact with each other, suppliers, customers and other people outside the organization. Culture is shaped by the people inside the organization, by the ethics of the organization, by the rights given to the employees and by the type of structure adopted. It influences how people respond to situations and how they interpret the environment the organization is inserted in.

Subcultures are also formed within an organization. According to Maanen and Barley (1984) a subculture is a subset of an organization's members that identifies itself as a distinct group within the organization based either on similarity or familiarity. Subcultures based on similarity arise from shared professional, gendered, racial, ethnic, occupational, regional, or national identities. Subcultures based on familiarity develop when employees interact frequently, as they often do when they share space and equipment such as particular areas within a factory or office building.

Siehl and Martin (1984) define subcultures by the ways in which they relate to each other. Because of the way power is distributed in most organizations, top management typically creates the dominant subculture, which many refer to as the corporate culture, even though it might be more accurate to call it the corporate subculture. The impact subcultures have on organizations depends upon the influence they exercise. Subcultures can undermine coordination and limit communication between parts of an organization when the subcultures are self-contained, making collaboration between them difficult or impossible and leading to unproductive conflict.

Chatman and Cha (2003) defined strong culture in terms of two variables: agreement about what is valued and the intensity with which values are held within a culture. Strong cultures are the product of high agreement combined with high intensity. Applying the concept to subcultures suggests that, when high intensity and agreement produce strong subcultures the strength of the subcultures undermines that of the overall organizational culture, leading to poor communication and lack of coordination.

According to Jones (2010) organizational culture develops from the interaction of four factors: the personal and professional characteristics of people within the organization, organizational ethics, the property rights that the organization gives to employees, and the structure of the organization. The interaction of these factors produces different cultures in different organizations and causes changes in culture over time.

The ultimate source of organizational culture is the people who make up the organization. According to Schneider (1987), different organizations develop distinctly different cultures because they attract, select, and retain people who have different values, personalities, and ethics. People may be attracted to an organization whose values match theirs; similarly, an organization selects people who share its values. Over time, people who do not fit in leave. The result is that people inside the organization become more and more similar, the values of the organization become more and more parochial, and the culture becomes more and more distinct from that of similar organizations.

According to Schein (1983), the founder of an organization has a substantial influence on the organization's initial culture because of his or her personal values and beliefs. Founders set the scene for the later development of a culture because they not only establish the new organization's values but hire its first members. Presumably, the people selected by the founder have values and interests similar to the founder's (George, 1990). Over time, members buy into the founder's vision and perpetuate the founder's values in the organization (Schein, 1992). An important implication of this "people make the place" view of organizational culture is that the culture of an organization can be strengthened and changed over time by the people who control and lead it.

Many cultural values derive from the personality and beliefs of the founder and the top-management team and are in a sense out of the control of the organization. These values are what they are because of who the founder and top managers are. For example, according to Jones (2010), Microsoft founder Bill Gates is a workaholic who often works 18 hours a day. His terminal values for Microsoft are excellence, innovation, and high quality, and the instrumental values he advocates are hard work, creativity, and high standards. Gates expects his employees to put in long workdays because he requires this level of commitment from himself, and he expects them to do everything they can to promote innovation and quality because this is what he does. Employees who do not buy into these values leave Microsoft, and those who remain are pressured by organizational norms to stay on the job after the normal workday is over and to go out of their way to help others and take on new tasks that will help the organization. Cultural values at Microsoft are out of the organization's control because they are based on who Gates is.

An organization can, however, consciously and purposefully develop some cultural values to control members' behavior. Ethical values fall in to this category. Organizational ethics are the moral values, beliefs, and rules that establish the appropriate way for organizational members to deal with one another and with the organization's stakeholders. In developing cultural values, top managers must constantly make choices about the right or appropriate thing to do. For example, organizations might wonder whether it should develop procedural guidelines for giving advance notice to employees and middle managers about impending layoffs or store closings. Traditionally, companies have been reluctant to do so because they fear employee hostility and apathy. In 2001, Ford and Firestone had to decide whether to recall Explorers because burst tires were causing many rollovers, resulting in serious harm or injury to passengers. Similarly, a company has to decide whether to allow its managers to pay bribes to government officials in foreign countries where such payoffs are an illegal yet accepted way of doing business. In such situations, managers deciding on a course of action have to balance the interests of the organization against the interests of other stakeholder groups (Goodin, 1975).

To make these decisions, managers rely on ethical instrumental values embodied in the organization's culture (Jones, 1991). Such values outline the right and wrong ways to behave in a situation in which an action may help one person or stakeholder group, but hurt another. Ethical values, and the rules and norms they embody, are an inseparable part of an organization's culture because they help shape the values that members use to manage situations and make decisions.

One important aspect in organizational culture is that different organizational structures give rise to different cultures. Structures should be designed in a certain way to create a certain kind of organizational culture. Mechanistic structures and organic structures, for example, give rise to totally different sets of cultural values. The values, rules, and norms in a mechanistic structure are different from those in an organic structure.

Mechanistic structures are tall, highly centralized, and standardized and organic structures are flat and decentralized and rely on mutual adjustment. In a tall, centralized organization, people have relatively little personal autonomy, and desirable behaviors include being cautious, obeying superior authority and respecting traditions. Thus mechanistic structure is likely to give rise to a culture in which predictability and stability are desired end states. In a flat, decentralized structure, people have more freedom to choose and control their own activities, and desirable behaviors include being creative or courageous and taking risks. Thus an organic structure is likely to give rise to a culture in which innovation and flexibility are desired end states.

An organization's structure can promote cultural values that foster integration and coordination. Out of stable task and role relationships, for example, emerge shared norms and rules that help reduce communications problems, prevent the distortion of information, and speed the flow of information. Moreover, norms, values, and a common organizational language can improve the performance of teams and task forces. It is relatively easy for different functions to share information and trust one another when they share similar cultural values. One reason why product development time is short and the organization is flexible in product team structures and matrix structures is that the reliance on face-to-face contact between functional specialists in teams forces those teams quickly to develop shared values and common responses to problems.

Whether a company is centralized or decentralized also leads to the development of different kinds of cultural values. In some organizations, it is important that employees do not make decisions on their own and their actions be open to the scrutiny of superiors. In such cases, centralization can be used to create cultural values that reinforce obedience and accountability. For example, in nuclear power plants, values that promote stability, predictability, and obedience to superior authority are deliberately fostered to prevent disasters (Perrow, 1984). Through norms and rules, employees are taught the importance of behaving consistently and honestly, and they learn that sharing information with supervisors, especially information about mistakes or errors, is the only acceptable form of behavior (Mintzberg, 1979). Conversely, by decentralizing authority, an organization can establish values that encourage and reward creativity or innovation.

Hofstede's (2001) approach to organizational culture is derivative of the idea that organizations are subcultures of larger cultural systems. In the late 1970s Hofstede studied the influence of national cultures on IBM. At the time of the study IBM operated in seventy countries, the forty largest of which Hofstede used for his study. IBM's annual employee surveys conducted from 1967 through 1973 provided Hofstede with his data. Using IBM data, Hofstede constructed measures of work-related values that he then compared across countries. Further analysis revealed some dimensions of national cultural difference operating within IBM's organizational culture, which may influence the occurrence of OI failures: power distance, uncertainty avoidance and individualism vs. collectivism.

Power distance refers to the extent to which the members of a culture are willing to accept an unequal distribution of power, wealth, and prestige. Hofstede's data showed that low power distance characterized countries like Denmark where inequalities of status are difficult to accept. For instance the Danish Jante Law proclaims that no individual should have more than, or stand out in any noticeable way from other Danes. When Danes try to put themselves forward as more prestigious or powerful than others they are quickly reminded that they are no better than anyone else.

Organizations from high power distance cultures, such as Brazil, Singapore, and the Arabic countries, rely heavily on hierarchy. Their unequal distributions of authority are accompanied by a lack of upward mobility. When organizations from higher power distance cultures attempt to impose their authority structures on subsidiaries from lower power distance cultures like Denmark, difficulties generally follow. Similarly Danish managers face problems when they try to use egalitarian leadership practices to control international subsidiaries in countries noted for high power distance. Such cultural mismatches, according to Hofstede, result from different cultural norms and expectations.

In high power distance cultures subordinates expect to be told what to do; subordinates have little to no participation in decision-making activities. In low power distance cultures, hierarchy is considered an inequality of roles created for convenience rather than reflecting essential differences between people, thus subordinates in low power distance cultures expect to be consulted by their superiors (i.e., subordinates participate in decision-making process). Unfortunately, decision makers, in many instances, to not have a full understanding of the problems the organization faces. Subordinates often have deep insight on the organization's state of affairs and consulting with them can increase superior's knowledge base and drive better decisions. Therefore, high or low power distance culture affects communication and coordination effectiveness, which can potentially influence in the occurrence of OI failures.

Uncertainty avoidance can be defined as the degree to which members of a culture avoid taking risks. Hofstede argued that different societies have different levels of tolerance for uncertainty and that these differences show up in a variety of ways. In low uncertainty avoidance cultures, for example, people are more accepting of innovative ideas, differences of opinion, and eccentric or deviant behavior, whereas in cultures with high uncertainty avoidance these things are resisted or even legislated against. Rules, regulations, and control are more acceptable in high than in low uncertainty avoidance cultures and Hofstede claimed that organizations in these cultures have more formalization and standardization, whereas organizations in cultures with low uncertainty avoidance dislike rules and resist formalization and standardization.

Lack of rules, formalization and standardization is a potential culprit of OI failures, as reliable OIs transactions require adequate Transaction planning quality/TrPlQ in terms of, for example, what the objectives of the IOb transaction are, what the roles and responsibilities of the TrAc are, what the IOb transaction characteristics that must be monitored are, etc., all of which should be formalized and standardized. Therefore, whether or not an organization is characterized by uncertainty avoidance culture may have an influence in the occurrence of OI failures.

Individualism versus collectivism involves the degree to which individuals in a culture are expected to act independently of others in their society. In highly individualistic cultures, individual rights are paramount. You will find evidence of individualism versus collectivism in the ways in which people live together (e.g., alone, in shifting partnerships, tribes, or nuclear families) and in their religious beliefs (e.g., whether or not an individual can have a personal relationship with the supernatural).

Hofstede pointed out that in cultures such as the United States individualism is seen as a source of wellbeing, whereas in Chinese or Mexican cultures it is seen as undesirable and alienating. This orientation toward individualism or collectivism has implications for the sorts of relationships preferred within different cultures. Relationships between members of individualistic cultures are loose and individuals are expected to take care of themselves. By contrast in collectivist cultures, cohesive groups (e.g., extended families) give individuals their sense of identity and belonging, demanding considerable loyalty in return.

Individualism versus collectivism helps to explain why those from collectivist cultures find the highly adverse reactions among many US citizens to calls for universal health insurance so unfathomable. On the other hand, the progress made toward providing more social services may indicate a shift in the US toward a more collectivist culture. Related to this distinction, Hofstede claimed that, in individualistic culture like the US, tasks take precedence over relationships, whereas relationships prevail over tasks in organizations from collectivist cultures, like those of Asia.

Since people within collective cultures foster the creation of cohesive groups and loyalty, people within an organization characterized by a collectivist culture may be more prone to develop better intra and inter-organizational collaboration compared to people within organizations characterized by an individualistic culture. Therefore, whether or not an organization is characterized by individualist or collectivist culture may have an influence in the occurrence of OI failures.

The importance of Hofstede's research is not only that it identified specific, measurable, national cultural differences but also that it revealed organizational culture to be a mechanism through which societal cultures influence organizations. This work is extended here to explore the potential influence that organizational culture (as defined by his characterization) exert in the occurrence of OI failures as it will be discussed in the next Section.

OI Failure Modes and Potential Causes/Influencing Factors

The previous Section elaborated on OI characteristics and the three functions necessary for a successful transaction. These are necessary elements to describe how OI transactions among organizations can fail and the potential causes/influencing factors for such failures.

As mentioned previously, OI transactions involve the transfer of IObs from the IOb Origin (IOb-Or) to the IOb Destination (IOb-Dt). The IOb is transferred by a transaction vehicle, at a determined transaction rate and along a transaction route until its destination. The IOb has properties that must be maintained during the transfer until achieving its destination.

Transaction actors (Tr-Ac) within the interfacing organizations are responsible for adequate transaction planning quality (Tr-PlQ), through the selection of adequate transaction rate and timing (Tr-R&T), selection and operation of adequate transaction vehicle and transaction routes. Transaction actors (Tr-Ac) are also responsible for adequate transaction surveillance and control process (Tr-S&C) to assure the transaction is developing as planned and to deal with foreseen and unforeseen Transaction characteristics alteration (Tr-CA).

In order to achieve these, the transaction actors (Tr-Ac) must exercise efficient coordination of all these activities through exercising effective communication (e.g., who knows whom; who knows what; who has what resource; who does what; who works where; what informs what; what knowledge is needed to use what resource; what is needed to do a given task; what knowledge is where; what resources can be substituted for which; what resources are needed to do a given task; what resources are where; what tasks are done where; which task must be done before which; which organization works with witch, etc.) and maintaining a collaborative environment.

Along the lines of the description above, examples of IOb transaction failure modes are:

1. Transaction involves less than adequate IOb (IObF1): Examples include wrong information transferred between parties engaged in communication, wrong merchandise purchased online received from the mail, wrong medicine or wrong medicine dose delivered to a patient (e.g., wrong drug event and wrong dose cases 1 and 2 discussed in Section 2.1), wrong part delivered on a car manufacturing facility, wrong maintenance procedure is performed on a power plant, etc.
2. IOb is delivered at wrong destination (IObF2): Examples include one's mail being delivered at someone's else address, a patient transported to the wrong hospital section (e.g., wrong patient case discussed in Section 2.1), one's luggage delivered at the wrong airport, a firefighter truck arriving at the wrong location, a medical procedure is performed on the wrong patient;
3. IOb is delivered at less than adequate rate/timing (IObF3): examples include airport reduced airplane landing rate, water/energy supply outage (e.g., the CANUSA outage and the continuous gas supply to Piper Alpha platform feeding the fire, which should have been stopped), merchandise arrived at later date than expected, critical information (i.e., needed to prevent undesirable consequences) received too late (i.e., when undesirable consequences already materialized), etc.
4. IOb is delivered with less than adequate properties (IObF4): tangible and intangible IObs have distinguished properties desired at the origin. Passengers desire to arrive at their destinations unharmed by the transaction process (e.g., the Tenerife disaster), food must be in edible conditions, information must be up to date, purchased merchandise must be received undamaged, petroleum must be received at processing facility at desired pressure and sand loading levels, etc.
5. IOb is not delivered at all (IObF5): this refers to cases where no efforts are made to transfer the IOb, which do not leave its origin (i.e., IOb Origin/IObOr).

Also along the lines of the description above, examples of IOb transaction failure potential causes/influencing factors are:

- Ineffective coordination:
    - Less than adequate organizational design
    - High organizational external environmental complexity
    - Less than adequate organizational culture
    - Inadequate Transaction rate and timing (Tr-R&T)
    - Inadequate Transaction vehicle quality (Tr-VhQ)
    - Inadequate Number and/or quality of transaction routes(Tr-NQRt)
    - Inadequate Transaction characteristics alteration (Tr-CA)
    - Inadequate Transaction planning quality (Tr-PlQ)

    - Inadequate Transaction surveillance and control process (Tr-S&C)
- Inefficient communication
- Poor collaboration among Transaction Actors (Tr-Ac)

Conclusion

This Section provided the building blocks for understanding OI transactions through a characterization of OI elements and essential functions necessary for OI transaction success. These building blocks were then used to propose OI transaction failure modes and potential causes/contributing factors. These are necessary elements to build a causal model describing the causal relationships OI failures and their potential causes/contributing factors. This causal model is proposed in the next Section.

However, most of the potential causes/ contributing factors proposed can be traced back to the incidents and accidents discussed in Section 2, which were discussed within Sections 3.1, 3.2 and 3.3. These are supporting evidence of potential causal relationship between, for example, ineffective communication and OI failure. There is no evidence in favor of causal relationships between OI failures and the causes/contributing factors related to organizational design and organizational external environmental complexity. This drawback will be addressed also in the next Section where an empirical study was conducted to explore the dependencies OI failures and the potential causes/contributing factors. The results of this empirical study will determine the structure of the causal model proposed.

Chapter 4: OI Failure Causal Model and Empirical Research

This Section aims to propose a limited scope OI reliability estimation model taking into account some of the OI characteristics and influencing factors. It is limited scope, for simplicity purposes, as it accounts for only one IOb – information/knowledge. The objective of the OI reliability model is to serve as a tool to predict the likelihood of critical information/knowledge transaction failures (e.g. critical information/knowledge is sent to the wrong receiver, critical information/knowledge is sent at the wrong time, wrong critical information/knowledge is sent, critical information/knowledge does not reach the receiver, critical information/knowledge reaches the wrong receiver, critical information/knowledge does not reach the receiver at the right time and critical information/knowledge is dismissed by receiver) using OI influencing factors as predictors.

The likelihood of the occurrence of critical information/knowledge transaction failures (referred to IKTrF) will be estimated by evaluating the states of the following potential influencing factors: organizational design, organization's environmental complexity, organizational culture, transaction rate and timing (TrR&T), transaction vehicle quality (TrVhQ), transaction planning quality (TrPlQ), transaction surveillance and control process (TrS&C), transaction characteristics alteration (TrCA) and level of collaboration.

A very popular and powerful likelihood evaluation model is the Bayesian Belief Network (BBN). BBN's are probabilistic graphical models that represent a set of random variables and their conditional dependencies. Here, a BBN model is applied to represent the probabilistic relationships between IKTrF and the influencing factors.

Formally, a BBN is a graph like that of Figure 3. Each node represents a random variable, or uncertain quantity, which can have various possible states. The arrows signify the existence of influences between variables, and the strengths of these influences are quantified by conditional probabilities. The structure of a BBN can be determined by assigning a node to each variable and connecting with arrows all other variables assumed to influence it. The strengths of these influences are then quantified by assigning to each node a conditional probability table, which represents judgmental estimates of the conditional probabilities of a node given any value combination of the nodes linked to it.

In Figure 3, for example, the nodes representing TrR&T and TrS&C influence the IKTrF node. Therefore, IKTrF is called child node and TrR&T and TrS&C are called parents of IKTrF. The strengths of these influences are set by assigning to the IKTrF node a conditional probability table that represents estimates of the conditional probabilities of the IKTrF likelihood given any value combination of the states of TrR&T and TrS&C. Assuming that 1) TrR&T can have two possible states, say, "*routinely*" (meaning, the critical information/knowledge is transmitted routinely), and "*under special circumstances*" (or "*USC*" for brevity), 2) TrS&C can have two possible states, say, "*mechanisms to assure the transaction is successful are in place*" (or "*in* *place"* for brevity) and "*mechanisms to assure the transaction is successful are NOT in place*" (or "*NOT in place"* for brevity), and 3) IKTrF node can have two possible states, say, "*likely*" and "*not likely*", then the conditional probability table for the IKTrF node is shown in Table 1.

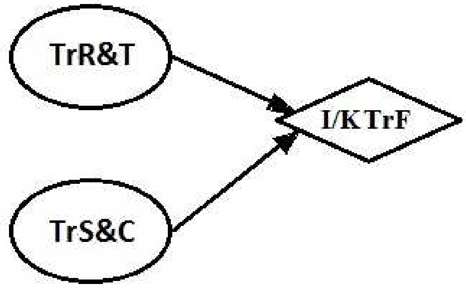

FIGURE 3 - SIMPLE BBN EXAMPLE

TABLE 1 - CONDITIONAL PROBABILITY TABLE FOR IKTRF NODE

	TrR&T: routinely		TrR&T: USC	
	TrS&C: in place	TrS&C: NOT in place	TrS&C: in place	TrS&C: NOT in place
IKTrF : likely	P(IKTrF : likely | TrR&T: routinely, TrS&C: in place)	P(IKTrF : likely | TrR&T: routinely, TrS&C: NOT in place)	P(IKTrF : likely | TrR&T: USC, TrS&C: in place)	P(IKTrF : likely | TrR&T: USC, TrS&C: NOT in place)
IKTrF : unlikely	P(IKTrF : unlikely | TrR&T: routinely, TrS&C: in place)	P(IKTrF : unlikely | TrR&T: routinely, TrS&C: NOT in place)	P(IKTrF : unlikely | TrR&T: USC, TrS&C: in place)	P(IKTrF : unlikely | TrR&T: USC, TrS&C: NOT in place)

The values that compound the conditional probability table can be gathered in an elicitation process (e.g., Ayyub, 2001) with experts in the areas organizational design, reliability engineering, probabilistic risk assessment, and human factors. These values can then be used in Eqs. (1) and (2) to estimate if IKTrF is likely or not likely.

Equation 1: P(IKTrF: likely) = P(TrR&T: routinely)*P(TrS&C: in place)*P(IKTrF: likely | TrR&T: routinely, TrS&C: in place) + P(TrR&T: routinely)*P(TrS&C: NOT in place)*P(IKTrF: likely | TrR&T: routinely, TrS&C: NOT in place) + P(TrR&T: USC)*P(TrS&C: in place)*P(IKTrF: likely | TrR&T: USC, TrS&C: in place) + P(TrR&T: USC)*P(TrS&C: NOT in place)*P(IKTrF: likely | TrR&T: USC, TrS&C: NOT in place).

Equation 2: P(IKTrF: unlikely) = P(TrR&T: routinely)*P(TrS&C: in place)*P(IKTrF: unlikely | TrR&T: routinely, TrS&C: in place) + P(TrR&T: routinely)*P(TrS&C: NOT in place)*P(IKTrF: unlikely | TrR&T: routinely, TrS&C: NOT in place) + P(TrR&T: USC)*P(TrS&C: in place)*P(IKTrF: unlikely | TrR&T: USC, TrS&C: in place) + P(TrR&T: USC)*P(TrS&C: NOT in place)*P(IKTrF: unlikely | TrR&T: USC, TrS&C: NOT in place).

In the BBN framework, each node acts whenever a certain condition develops among its neighbors. When changes occur in a given node state, the impact of these changes is viewed as a perturbation that propagates through the network via a message passing between adjacent nodes. The laws of Bayesian theory govern this message-passing mechanism.

This means that the links in the network are the instruments that direct and propel the flow of data through the process of updating node states probabilities. When changes occur in the state probabilities of parent nodes, the node representing this parameter acts against its child nodes updating their states probabilities. This updating process develops throughout the network from parent to child, until reaching the level of IKTrF. Therefore, the nodes positioned in the lowest level of the BBN (those representing OI failure influencing factors) are the network's central supervisors that activate the updating procedure. Putting it differently, as new evidence about OI failure influencing factors become available the lower level nodes capture the evidence and propagate it to the network's higher level nodes, updating the of the likelihood IKTrF.

One important step to build the proposed IKTrF BBN model is to determine which influencing factors influence IKTrF. This was achieved by designing and carrying out an empirical research aiming to collect empirical insights on dependencies between IKTrF and their potential influencing factors. The steps adopted to develop this empirical research were (each of which are elaborated further in the following paragraphs):

1. Develop a survey questionnaire to collect empirical evidence on relationships between critical information transaction success likelihood and the OI failure influencing factors;
2. Collect questionnaire responses from professionals from different hierarchical levels and different industries;
3. Use the data collected to perform chi-square test of dependency to determine if there are significant relationships between transaction success likelihood and the selected potential characteristics. The test was done through the following steps:
    a. Develop the null hypotheses: assume that there is no dependency between each individual selected potential OI influencing factors and OI failure (e.g., organizational design - Organic/ Mechanistic - and OI failures are independent). A total of 33 null (H0) hypotheses were tested to determine dependency between the 33 potential OI influencing factors and OI failure.
    b. Select a significance level to compare the chi-square statistics with (if the chi-square statistic calculated is less than the significance level selected, then the hull hypothesis is rejected);
    c. Use the questionnaire responses to build contingency tables to compare the observed frequencies of each of the individual selected potential characteristics with OI failure likelihood. For example, Figure 4 below shows a generic contingency table that displays the frequencies of responses received that have: mechanistic organization design and OI failure likely to occur; organic organization design and OI failure likely to occur; mechanistic organization design and OI failure unlikely to occur; and organic organization design and OI failure unlikely to occur. A total of 33 contingency tables were built.

d. From the values in each table calculate the total number of answers that have OI failure selected as likely (i.e., the value W in Figure 4) and unlikely (i.e., the value Z in Figure 4)
e. From the values in each table, calculate the total number of answers for each individual selected potential characteristics. In Figure 4, for example, the value X is the total number of answers with a mechanistic organizational design and the value Y is the total number of answers with an organic organizational design;
f. From the values in each table calculate the percentage of answers that have OI failure selected as likely (i.e., the value K in Figure 4) and unlikely (i.e., the value U in Figure 4)
g. Use the values calculated in the contingency table of observed frequencies to build a table of expected values comparing the expected frequencies of each of the individual selected potential characteristics with OI failure likelihood. Figure 4 for example, shows the expected frequencies of mechanistic organization design and OI failure likely to occur; organic organization design and OI failure likely to occur; mechanistic organization design and OI failure unlikely to occur; and organic organization design and OI failure unlikely to occur;
h. Use the values in both observed and expected value tables to calculate the chi-square statistics by using the formula $\chi^2=\sum(\text{Observed}-\text{Expected})^2/\text{Expected}$.
i. Compare the chi-square statistics calculated with the significance level selected to determine if each individual selected potential characteristic and OI failure is dependent (i.e., there is significant relationship).

4. Build the BBN causal model with the OI failure influencing factors that have significant relationships with transaction success likelihood.

	Observed			
	Mechanistic	**Organic**	**Tot**	**%**
OI Failure Unlikely	a	b	**Z=a+b**	**U = Z/N**
OI Failure Likely	c	d	**W=c+d**	**K = W/N**
Total	**X=a+c**	**Y=b+d**	**N=a+b+c+d**	

	Expected	
	Mechanis	**Organic**
OI Failure Unlikely	X*U	Y*U
OI Failure Likely	X*K	Y*K

FIGURE 4 - CHI-SQUARE CONTINGENCY TABLES (OBSERVED AND EXPECTED)

The tool adopted to collect empirical evidence was a survey questionnaire. The questionnaire includes background information on what OIs are, why it is important to study them and the objectives of the survey. The questionnaire inquires participants to consider any organization the participant worked in the past in order to answer the questions (the questionnaire can be seen in the Appendix). The first part of the questionnaire inquires participants to answer questions related to:

1. The organization's design: whether the organizational is better characterized by an organic design or mechanistic design.
2. The organization's environmental complexity:
    a. Whether unknown/unforeseen environmental forces are likely to impact the organization;
    b. The level of uncertainty the organization has regarding changes in the environmental forces (i.e., legal, political, economic, social, cultural, physical and technology);
    c. The level of uncertainty the organization has regarding the impact changes in environmental forces could cause to the organization; and
    d. The level of dependency the organization has on the environmental forces.
3. The organization's culture:
    a. Whether the organization is better characterized by low or high power distance culture;
    b. Whether the organization is better characterized by an uncertainty avoidance or engagement culture;
    c. Whether the organization is better characterized by an individualistic or collectivist culture;

In the second part of the questionnaire the participant is instructed to think about a piece of information/knowledge that 1) the participant believes to be critical to the his/her organization, and 2) that another organization prepares and transmits this critical piece of information/knowledge to the participant's organization. The participant is then inquired about the following OI characteristics:

1. Transaction rate and timing/TrR&T: how often this critical piece of information/knowledge is transferred from the other organization to the participant's organization (routinely or under especial circumstances);
2. Transaction vehicle quality/TrVhQ: what media is used for the transfer (i.e., verbal or written);
3. Transaction planning quality/TrPlQ:
    a. Whether there are guides/procedures on how the information/knowledge should be prepared (e.g., document templates, verbal protocol); and
    b. Whether there are guides/procedures on how the information/knowledge should be transmitted (e.g., phone call, e-mail);
4. Transaction surveillance and control process/TrS&C: whether there are mechanisms to assure the transaction is successful or not;
5. Transaction characteristics alteration/TrCA: whether the characteristics of the transaction is dynamic or static (e.g., whether the sender and/or receiver change over time, whether the content of the information change over time, whether the media used for transfer change over time, etc.)

6. Collaboration level between the organizations: whether there is good or poor collaboration between the two organizations in question;

Finally, the questionnaire inquires the participant to evaluate the likelihood (i.e., likely or not likely) of critical knowledge/information transaction failure (e.g., critical information/knowledge is sent to the wrong receiver, critical information/knowledge is sent at the wrong time, wrong critical information/knowledge is sent, critical information/knowledge does not reach the receiver, critical information/knowledge reaches the wrong receiver, critical information/knowledge does not reach the receiver at the right time and critical information/knowledge is dismissed by receiver). A total of 207 questionnaire answers were obtained by contacting professionals in different industries to participate either by e-mail or phone call solicitation. Out of the 207 responses obtained, a total of:

- 29 answers come from professional from the Basic Materials industry
- 30 answers come from professional from the Conglomerates industry
- 5 answers come from professional from the Consumer Goods industry
- 3 answers come from professional from the Financial industry
- 17 answers come from professional from the Healthcare industry
- 19 answers come from professional from the Industrial Goods industry
- 50 answers come from professional from the Services industry
- 32 answers come from professional from the Technology industry
- 22 answers come from professional from the Utilities industry

The answers were used to perform a Chi-Square test of dependency with alpha value arbitrarily chosen at 0.0001 for conservatism. The null hypotheses tested were "*there is no dependency between IKTrF and its hypothesized influencing factors*". A total of 33 null (H0) hypotheses were tested:

1. Organizational design (Organic/ Mechanistic) and OI failures are independent
2. Likelihood that unknown/unforeseen forces can impact the organization and OI failures are independent
3. Level of uncertainty regarding changes in LEGAL forces and IKTrF are independent
4. Level of uncertainty regarding changes in POLITICAL forces and IKTrF are independent
5. Level of uncertainty regarding changes in ECONOMIC forces and IKTrF are independent
6. Level of uncertainty regarding changes in SOCIAL forces and IKTrF are independent
7. Level of uncertainty regarding changes in CULTURAL forces and IKTrF are independent
8. Level of uncertainty regarding changes in PHYSICAL forces and IKTrF are independent
9. Level of uncertainty regarding changes in TECHNOLOGY forces and IKTrF are independent

10. Level of uncertainty regarding the impact of changes in LEGAL forces and IKTrF are independent
11. Level of uncertainty regarding the impact of changes in POLITICAL forces and IKTrF are independent
12. Level of uncertainty regarding the impact of changes in ECONOMIC forces and IKTrF are independent
13. Level of uncertainty regarding the impact of changes in SOCIAL forces and IKTrF are independent
14. Level of uncertainty regarding the impact of changes in CULTURAL forces and IKTrF are independent
15. Level of uncertainty regarding the impact of changes in PHYSICAL forces and IKTrF are independent
16. Level of uncertainty regarding the impact of changes in TECHNOLOGY forces and IKTrF are independent
17. Level of resource necessity from LEGAL forces and IKTrF are independent
18. Level of resource necessity from POLITICAL forces and IKTrF are independent
19. Level of resource necessity from ECONOMIC forces and IKTrF are independent
20. Level of resource necessity from SOCIAL forces and IKTrF are independent
21. Level of resource necessity from CULTURAL forces and IKTrF are independent
22. Level of resource necessity from PHYSICAL forces and IKTrF are independent
23. Level of resource necessity from TECHNOLOGY forces and IKTrF are independent
24. Low or high power distance culture and IKTrF are independent
25. Uncertainty avoidance or engagement culture and IKTrF are independent
26. Collectivism or individualism culture and IKTrF are independent
27. Transaction rate and timing/TrR&T and IKTrF are independent
28. Transaction vehicle quality/TrVhQ and IKTrF are independent
29. Transaction planning quality/TrPlQ (guides/procedures on how the information/knowledge should be prepared) and IKTrF are independent
30. Transaction planning quality/TrPlQ (guides/procedures on how the information/knowledge should be transmitted) and IKTrF are independent
31. Transaction surveillance and control process/TrS&C and IKTrF are independent
32. Transaction characteristics alteration/TrCA and IKTrF are independent
33. Collaboration level between the organizations and IKTrF are independent

Table 2 below shows the null hypotheses that were rejected along with their respective p-values. Using the results from Table 2 above, the IKTrF BBN model can be derived and is shown in Figure 5 below. The states of the parent nodes in Figure 5 are as follows:

- Collaboration level between the organizations: Good collaboration, Poor collaboration;
- Transaction planning quality/TrPlQ (guides/procedures on how the information/knowledge should be transmitted): Available, Not available;
- Uncertainty culture: Uncertainty avoidance, Uncertainty engagement;
- Level of uncertainty regarding changes in SOCIAL forces: High uncertainty, Low uncertainty;
- Level of uncertainty regarding the impact of changes in CULTURAL force: High uncertainty, Low uncertainty
- Level of dependency on CULTURAL forces: High dependency, Low dependency;
- Level of dependency on ECONOMIC forces: High dependency, Low dependency;
- Transaction surveillance and control process/TrS&C): Available, Not available;
- Transaction characteristics alteration/TrCA: Static, Dynamic;
- Transaction rate and timing/TrR&T: Routine, Under special circumstances;

TABLE 2 - LIST OF REJECTED NULL HYPOTHESES

Null Hypothesis (H0)	p-value
Collaboration level between the organizations and IKTrF are independent	7.12E-17
Transaction planning quality/TrPlQ (guides/procedures on how the information/knowledge should be transmitted) and IKTrF are independent	8.27E-12
Uncertainty avoidance or engagement culture and IKTrF are independent	6.30E-10
Level of uncertainty regarding changes in SOCIAL forces and IKTrF are independent	2.72E-09
Level of uncertainty regarding the impact of changes in CULTURAL forces and IKTrF are independent	1.13E-08
Level of resource necessity from CULTURAL forces and IKTrF are independent	1.75E-08
Level of resource necessity from ECONOMIC forces and IKTrF are independent	1.96E-08
Transaction surveillance and control process/TrS&C and IKTrF are independent	3.42E-07
Transaction characteristics alteration/TrCA and IKTrF are independent	4.67E-07
Transaction rate and timing/TrR&T and IKTrF are independent	6.91E-07

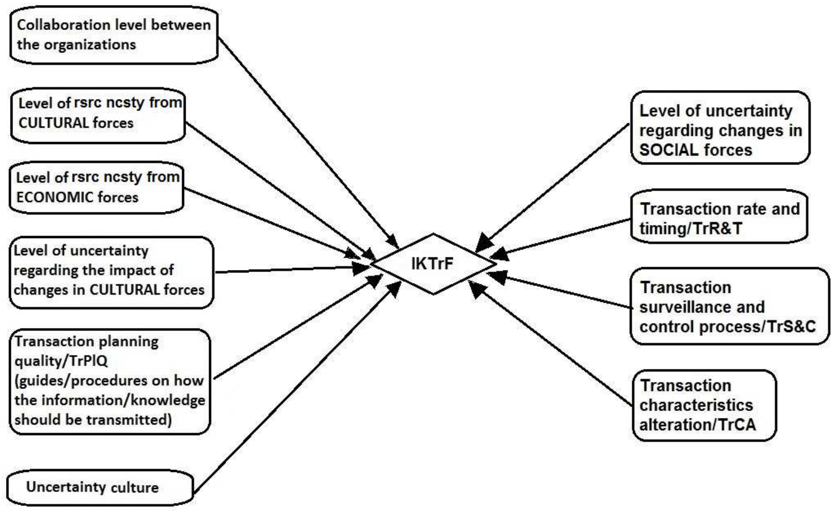

FIGURE 5 - IKTRF BBN MODEL

According to the results, the influence that is exerted from dependency on cultural and economic forces cannot be deemed as being independent from IKTrF. Similarly, the limited ability to process information and to understand the uncertainties regarding the impact of changes in cultural and social forces cannot be deemed as being independent from IKTrF.

As stated in Section 3.4.3, lack of rules, formalization and standardization, which are characteristics of an "*uncertainty engagement culture*", can have strong influence in OI failures, which is confirmed by the results.

The results also show that some of the OI characteristics tested cannot be considered independent from IKTrF. It is instinctive that the existence of 1) guides/procedures on how critical information/knowledge should be transmitted and 2) mechanisms that assure the critical knowledge/information is transferred successfully can influence the chances that IKTrF will not occur. Also, when critical knowledge/information is transferred routinely, the transaction actors/TrAc involved benefit from increasing their learning process inherent to the recurring transaction activities, which contributes to decreased IKTrF. In the other hand, when the characteristics of critical information/knowledge transaction (e.g., the content of the information, the media used for transfer) change over time, potential novel contingencies inherent to these new characteristics may emerge contributing to IKTrF.

"*Collaboration level between the organizations*" in particular was found to be the strongest IKTrF influencing factors with the lowest p-value, which is consistent with the work of Leischnig et all (2014). They developed and empirically tested a research framework that incorporates key factors of Inter-organizational Technology Transfer (ITT) success. According to them, ITT is an important means of acquiring technological knowledge from external partners and involves the movement of know-how, technological knowledge, or technology from one organization to another. ITT consists primarily of one-way transactions, from a technology source (technology transferor) to a technology recipient (technology transferee).

Their work test the influence that four key parameters may potentially have on ITT success, including what they defined as "*alliance transformation***"**. Alliance transformation refers to the flexibility of transfer partners (same concept as Transaction actors/TrAc) to adapt the transfer process in reacting to changed conditions, which is to "*Transaction characteristics alteration (TrCA) Flexibility*", one of the OI collaboration influencing factors discussed Section 3.3.

While the IKTrF BBN model proposed can be used for quantitative assessment, and aims to provide a systematic and structured approach to measure the likelihood of critical information/knowledge transfer failure, the building blocks of the OI characterization can also be used to enrich qualitative reliability assessment tools such as Failure Modes and Effects Analysis (FMEA). This is the subject of the next Section.

Chapter 5: Organizational Interfaces Failure Modes and Effect Analysis (OI-FMEA)

As OI transactions involves the process of transferring interface objects (IObs) from one location to another, the OI-FMEA proposed here is a structured analytical tool to identify and evaluate the potential failures of the IOb transaction process. Following the lines of the previous Section, this work will concentrate on critical knowledge/information as the IOb. Transfer of critical knowledge/information from one actor to another can have serious undesirable impacts if not conducted successfully (e.g., wrong/outdated information transferred, information misunderstood, information ignored, etc.).

In general, Failure Mode Effects Analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a process (e.g., manufacturing, assembly), or a product or service; studying the consequences, or effects, of those failures; and eliminating or reducing failures, starting with the highest-priority ones. The OI-FMEA proposed here is a typical "*process FMEA*" that involves the process of transferring critical information from one entity to another and, therefore, involves failures in the information transfer process, the consequences or effects inherent to these failures and eliminating or reducing the likelihood of these failures.

The first step to perform an OI-FMEA is to determine the critical information/knowledge OIs inherent to a process. These must be characterized by the source of the critical knowledge/information, the recipient(s) of the information and a description of the critical knowledge/information. Once all the critical information/knowledge OIs inherent to a process are defined the following step is, for each one, to evaluate the failure modes inherent to the critical information/knowledge transfer process, which include:

- Critical information/knowledge is sent to the wrong recipient(s)
- Critical information/knowledge is sent at the wrong time
- Wrong critical information/knowledge is sent
- Critical information/knowledge does not reach the recipient(s)
- Critical information/knowledge reaches the wrong recipient(s)
- Critical information/knowledge does not reach the receiver at the right time
- Critical information/knowledge is dismissed by recipient(s)

The following step is to determine, for each failure mode, the potential causes or contributing factors, which include:

- Inadequate transaction rate and timing/Tr-R&T
- Inadequate transaction vehicle quality/Tr-VhQ
- Inadequate number and/or quality of transaction routes/Tr-NQRt
- Inadequate transaction planning quality/Tr-PlQ (poor coordination among Transaction Actors/Tr-Ac)
- Inadequate transaction surveillance and control process/Tr-S&C
- Highly dynamic transaction characteristics alteration/Tr-CA
- Poor collaboration among Transaction Actors/Tr-Ac

Next, for each failure mode, the consequences intrinsic to each one of them, which depends on the particular process under evaluation. The last step is to determine, for each failure mode, mitigation measures to prevent the failure from happening, which also which depends on the particular process under evaluation. A few examples are:

- assigning a designated person to assure the interface is effective on a round the clock basis;
- clearly defining roles and responsibilities regarding communications;
- assuring formal records and documents regarding OIs are passed on to management for their review;
- implementing systems/strategies that establish the importance or criticality of communications in the field;
- establishing and maintaining communication protocols between key operating positions;
- identifying and eliminating potential language barriers that might impede effective communications;
- identifying persons that can intervene in difficult communications;
- establishing systems to communicate the status of equipment between maintenance and operations (e.g., "permit to work" system);
- establishing systems for procurement of emergency supplies, parts and chemicals during odd hours;
- establishing systems to ensure timely and accurate communications between complimentary positions at shift change;
- establishing systems to counteract or revoke standing orders and instructions made necessary by changing conditions;
- establishing systems to communicate emergency instructions to all personnel including contractors and subcontractors;
- establishing systems that allows workers to challenge instructions that may be unclear or inappropriate.

A literature research was conducted in search for process FMEAs applications that accounted for failure in transmission of critical information among interfacing parties. A few process FMEA applications within the health care industry were found to account for failure in the transfer of critical information, including the works of Su et al (2012), Nguyen et al. (2013), Rodriguez-Gonzalez et al. (2015) and Abrahamsen et al (2016). This does not come as a surprise as it is in line with the discussion in Section 2.2 that indicates communication failure is a leading cause of medical errors.

Su et al. (2012) used a process FMEA to improve the blood transfusion process in a particular university-affiliated hospital. They have identified through the FMEA exercise that a potential threat during the blood ordering phase were miscommunications due to unclear phone conversation regarding the required blood. In order to reduce transcription errors and mistakes caused by miscommunication on the telephone, they proposed the improvement action by establishing an online blood product ordering system.

Nguyen et al. (2013) and Rodriguez-Gonzalez et al. (2015) exercise process FMEA to improve the safety in the medication administration process. They identify several critical information related causes of misadministration of medication including: lack of communication between the doctor and nurse, drug dose not available, discrepancies in information on patient records as a whole and drug administration sheet contents, discrepancies in information on work tools that have or have not been approved by the hospital, etc.

Abrahamsen et al (2016) present an FMEA helicopter emergency medical service (HEMS) that accounts for critical communication interfaces within the several organizations involved including air traffic control, ambulances on scene, emergency medical communication center and prehospital units. They indicate that communication and decision-making in HEMS often rely on sparse, inadequate or ambiguous information and uncertain data and, therefore, these must be understood and analyzed in HEMS process FMEA.

Outside the health care industry realm only the work of Chao and Ishii (2007) was found to account for critical information transfer in process FMEAs. They present an application of FMEA on design processes, which decomposes the design process into six potential problem areas, including communication. They propose design error classification system categories, in which mistransfer or misinterpretation of information is a potential threat.

Nonetheless, as elaborated in Sections 2 and 3, critical information transfer errors that contribute to undesirable events spread through other industries and complex social technical systems. The critical information OI-FMEA method proposed is meant to be simple, but very powerful if applied in a thorough manner. The next section presents a case study on the application of the critical information OI-FMEA in the oil and gas industry. The case study involves loss of positioning events in mobile offshore drilling units and discusses the seriousness of these events, the reasons why these events happen, the current reliability assessment practices in the industry and its weaknesses, and the results of the application of the critical information OI-FMEA proposed.

Case study: Mobile Offshore Drilling Unit (MODU) Loss of Position (LOP) OI FMEA

Problem Statement

Over the past several decades, the expansion of offshore exploration, development and production into deeper water has transformed an industry once characterized by relatively simple, domestic shallow water fixed platforms and small logistical vessels into an industry with complex, international floating vessels supplied and serviced by other large, international multipurpose vessels. This has given rise to the use of Dynamic Positioning (DP) as a practical means for keeping these vessels within precise geographic limits. Failure of a DP system on a vessel conducting critical operations such as oil exploration and production could have severe consequences including loss of life, pollution, and property damage. This is particularly true for

Mobile Offshore Drilling Units (MODUs), where a loss of position (LOP, discussed in the following Section) could result in a subsea spill and potentially catastrophic environmental consequences. There have been several DP related incidents in the Gulf of Mexico involving both DP system equipment failures and human error on MODUs. Because of the consequences associated with a deepwater subsea spill, the US Coast Guard believes DP incidents on MODUs engaged in drilling represent an immediate concern (USCG, 2012).

When Petrobras (the Brazilian state owned oil company) started using DP-operated vessels, the state-of-the-art technology had been developed for shallow water operations and was not necessarily appropriate to be used in deeper water. Before 1992, operations such as drilling, production, testing and well intervention have been done by vessels using mooring systems. In deeper water, however, purely DP-operated vessels have been proven to be the best alternative to that existing technology (Costa & Machado, 2006).

The International Marine Contractors Association (IMCA) collects DP records of station keeping incidents and reports their findings through its annual Dynamic Positioning Station Keeping Incidents reports (e.g., IMCA, 2002). The reports includes an evaluation of all the recorded incidents in the particular year with respect to root causes, geographical location (e.g., Golf of Mexico, Brazil, North Sea, etc.), type of DP vessel activity involved (e.g., drilling, pipe/cable lay, etc.), etc.

Similar to IMCA, looking for opportunities to improve the oil wells drilling work quality, Petrobras has developed a DP Incidents Database t called BDIP (or DP Incidents Database - acronym in Portuguese) (Costa & Machado, 2006). By gathering available information related to the incidents, Petrobras is able to analyze potential failure modes on which their associated causes are identified, considered and addressed. BDIP contains information gathered since 1984 when the first DP-operated vessel started working for Petrobras.

The station keeping incidents from IMCA and Petrobras will be presented on Section 5.1.3. The next Section provides a brief description of Dynamic Positioning (DP) systems to appreciate its complexity and better understand the information on Section 5.1.3.

Dynamic Positioning (DP) Systems

A typical DP system structure is shown in Figure 6. The figure is greatly simplified to fit the detail level of this dissertation. The red lines of indicate signals between equipment, while the blue lines indicate transfer of power. The red lines have arrows pointing in both directions to indicate two-way communication. Power always have a single direction indicated and therefore has one-way arrows.

As the Figure shows, a typical DP system structure contains: power generation subsystem (generators and Uninterrupted power supply (UPS)), power distribution subsystem (switchboards, bus bars, power management system and wiring/cables), propulsion subsystem (thrusters), position references subsystem (Differential Global Navigation Satellite System (DGNSS), Differential Global Positioning System (DGPS), laser radar, hydro acoustic position reference systems (HPR), Artemis and taut wire), sensors (gyrocompass, draught sensors and wind sensors), and DP control subsystem (DP hardware and DP software. These systems are briefly examined next.

Generators and their distribution systems are, as a minimum, to have the capacity to supply sufficient power to the thrusters to maintain vessel's position within the specified operating area in addition to supplying industrial activities and essential ship service loads. When power is shared, power supply to industrial activities and essential ship service loads is not to affect DP operations (ABS, 2013).

The generators are to supply the propulsion units with the necessary power to uphold the position in a DP operation. The power is delegated through the switchboard and controlled by the power management system. Typically a ship has several main generators working in parallel to avoid full loss of power in the event of a single generator failure. In addition emergency generator(s) should be on stand-by.

UPS subsystem has to be provided for the DP control system and its reference and sensor system. The UPS' are delegated power from the switchboards. Each UPS is to be capable of supplying power for a minimum of 30 minutes after failure of the main power supply.

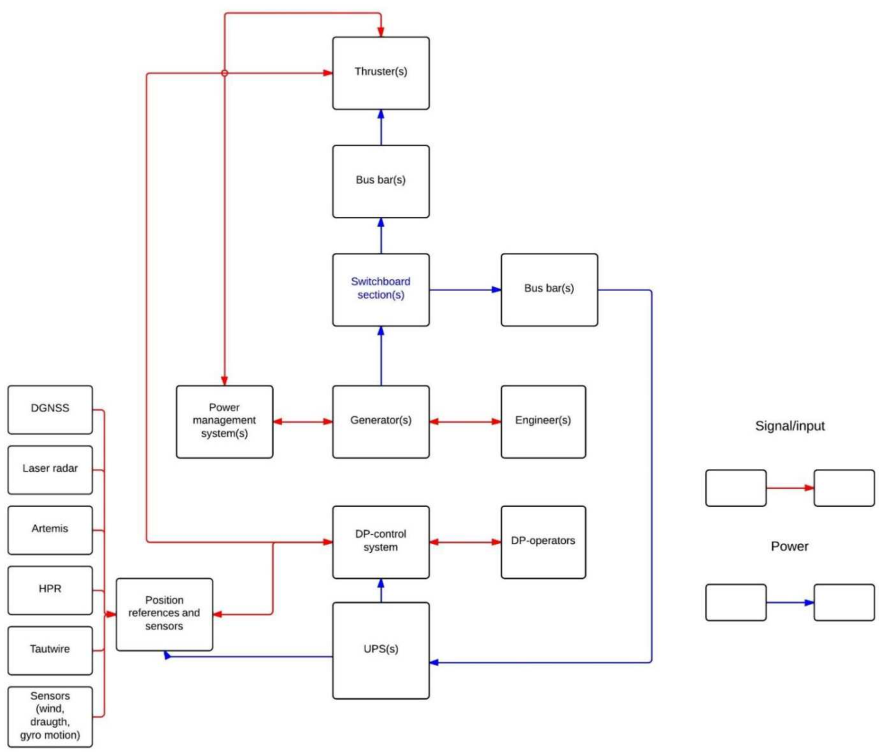

FIGURE 6 - DP SYSTEM STRUCTURE

Power distribution subsystem distributes the power generated in a controlled and consistent manner to the correct consumers at all time. The switchboards divides the power supply from the generators to the references and propulsion units, (the consumers). An emergency switchboard should exist in the event of a failure. The switchboard is to be arranged for manual and automatic control. The switchboard is usually divided in at least two separate parts to provide redundancy, but may be run as one system during operation. Even then they should be connected only through bus-tie breakers (bus bars) to separate automatically upon failures. The separation is to avoid common cause failures which could be transferred across systems, including overloading and short-circuits

The bus bars are electrical conductors that may carry power at a specific voltage. The bus bars connects different circuits together in the system, and are designed to break the connections in case of, for example, a voltage drop.

The power management system is actually a part of the DP control system but could also be looked at as part of the power distribution system, due to its important task of delegating power between consumption units.

When operating in DP mode, the DP control system continuously monitors the generator power and power to thrusters. If any of the generators reach a level that is defined as too close to the maximum load, typically 90%, the power management system (PMS) will reduce thrust to reduce the risk of overloading the generator(s), which could result in a blackout. The power management system will reduce thrust and hold the thrust as close to limit as possible but never exceed it. When a new generator has been connected, the thrust will be restored to the desired level.

Wiring/cables is a loosely defined equipment group created due to the immense diversity of electrical delegators in a DP system. In general static equipment that serves to distribute power are included in this equipment group, such as wires and cables that in the event of a failure may create short circuits in the power system.

Beside the shaft propeller, thrusters are the main propulsion units utilized by DP vessels. The motors of the shaft propellers may be directly connected to the shaft which give a simple and robust propulsion suitable for "simple" operations like transit. However for more complex maneuvering, thrusters are commonly used for their increased flexibility.

The propulsion system is critical for the overall performance of the vessel, including the vessel's station keeping ability. Electric propulsion is the preferred solution for many DP vessels (Hackman, Ådnanes, & Sørensen, 1997).

Thrusters are the main power consumers in a DP system. Their job is to provide the necessary thrust which enables the DP system to maintain the desired position in a dynamic environment. There exists several types of thrusters, commonly divided into Tunnel thrusters, Azimuth thrusters and Azipods. Tunnel thrusters produce thrust in a fixed direction, while the Azimuth thrusters are rotatable and may produce thrust in any direction, as well as a certain degree of negative thrust to avoid continuous rotation in a DP operation. Finally the Azipods besides being freely rotational like the Azimuth thrusters, have the propeller mounted directly on the motor shaft, the removal of the gear gives the Azipods a higher transmission efficiency than the Azimuth thrusters, at the cost of the flexibility a gear provides (Hackman, Ådnanes, & Sørensen, 1997).

The position reference system provides the DP control system and the operator with continuous feedback on the vessel position, either by satellites or as relative to nearby objects. A modern DP vessel has several position references active at the same time, depending on the type of operation. The resulting "weighted" position is based on the accuracy reported positions by all the position reference systems enabled in the DP system. The position reference with the least deviation is given the highest weighting. The purpose of combining several position references, is to give the vessel the most precise and reliable position possible. Some of the most common positioning references are:

- DGNSS and DGPS are relative position signals based on satellite input, and is perhaps the most common position reference system.
- The laser radar system, commonly referred to as "Fanbeam", as this model is much used, is a positioning system that is used to measure distance and angle by reflecting pulsed laser light. The system measures the vessel position based on relative distances to reflective targets, for example placed at an offshore installation.
- HPRs are commonly used in several kind of DP operations. Three primary types of HPR exists: Ultrashort baseline, short baseline and long baseline. No further study into these systems differences is practical for the detail level of this dissertation. The HPR system determines the bearing from a transceiver at the vessel to underwater beacons. Acoustic pollution (underwater noise) may be an issue for this system (Vickery, 1998).
- Artemis is a radio system used to measure the position of the vessel. The system operates using a microwave frequency to measure the position and bearing of the vessel relative to a fixed station. The station could for example be installed on an offshore installation
- The taut wire is a position reference that utilizes a tensioned wire vertically to the seabed, or horizontally to a fixed object, to measure a vessel's position
- Sensors feed the DP control system with additional information besides the position of the vessel, necessary to calculate the necessary thrust to uphold the desired position. Some very common sensors used in DP vessels are:
- Gyrocompass is a nonmagnetic compass which bases the geographical direction on the rotation of the earth and is therefore unaffected by the normal deviations of a regular compass. The gyrocompass will therefore always point true north.
- Draught sensors measure the vessel's draught continuously. Draught sensors are placed at the hull of the vessel, usually at least at bow and stern.
- Wind sensors measure the speed and direction of the wind, and will be especially exposed for environmental forces.

The DP control system is the set of computers that combines automatic computation with instructions from operators, enabled through its interfaces. The DP control system allows simple inputs from the operator such as a wanted position. The wanted position is combined with the information provided from the position reference system and sensors. The combined input is continuously evaluated by various software to determine the correct amount, and direction, of thrust power. A simple presentation of the system is shown in Figure 7. The number of equipment presented in Figure 7, is merely an illustration to indicate redundancy. The actual number of diesel generators (DG), and thrusters (Thr) varies from each vessel.

The DP hardware represents the physical interface that enables operator commands to the computers, such as monitors, keyboards and joysticks. DP software represents software that continuously calculates how the vessel reacts upon the external forces. The calculated "vessel model" is a hydrodynamic description, as a result of inputs, and also includes vessel characteristics as mass and drag. The wind, current and thruster forces, as well as the current position speed and heading goes into the vessel model" (Holvik, 1998). The outputs from the mathematical calculations are thruster commands based upon estimates of the vessel's heading, position and speed estimates, which then again produces new estimates and inputs. The "loop" of information makes the computer able to continuously monitor and adjust the thrusters, to achieve the wanted position given by the controller (Holvik, 1998).

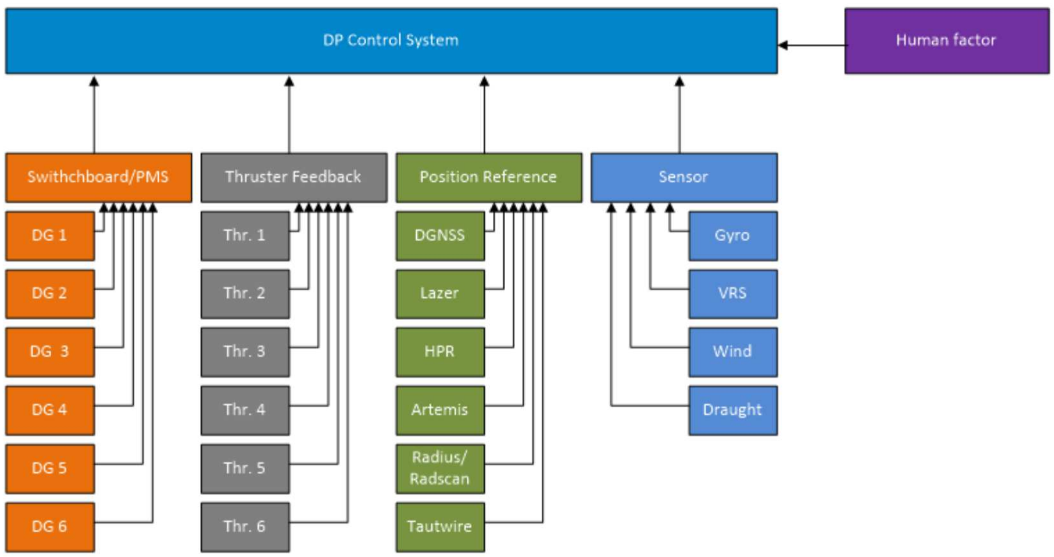

FIGURE 7 - DP CONTROL SYSTEM

Given the complexity of DP systems, there are several ways in which it can fail and cause the vessel to move away from its desired geographical location. This situation is commonly referred to Loss of Position (LOP). The following Section discusses LOP on Mobile Offshore Drilling Units (MODUs), its potential causes and contributing factors.

MODU LOP causes and contributing factors

Mobile Offshore Drilling Units (MODU) are offshore vessels that use the DP technology while performing drilling activities in geographical regions were mooring is deemed unfeasible (i.e., very deep waters), unsafe or uneconomical. Figure 8 below shows a sketch of a MODU performing drilling activities using DP technology. In normal operations the MODU should be positioned within a green zone inside the yellow limit. When the vessel loses the capability to maintain position by means of thruster force, she may have an excursion beyond the yellow or even the red limit. This LOP condition is denoted drive-off or drift-off event.

A drive off is a powered move away from the desired vessel position. A drive off may occur at full power. The drive-off may occur due to false position information or wrong position inputs from the operator. A drift-off is a loss of power that causes the vessel to move off location in the direction of the prevailing environment. The distance that the vessel travels before the drift-off is stopped depends on the forces the vessel is subjected to, and how quickly the situation leading to the drift-off is resolved. There are three situations that may lead to a drift-off: total power blackout, partial power blackout resulting in insufficient thrust, or incorrect thrust commands (Shi, Phillips, & Martinez, 2005).

If the vessel passes the yellow limit (either due to drive-off or drift-off), the drilling operation must be stopped and the driller starts to prepare for disconnection (i.e., disconnect the riser from the wellhead, see Figure). If the vessel passes the red limit, emergency disconnection must be initiated in order to disconnect the riser from the wellhead and shut in the well using the Blow Out Preventer (BOP, a mechanical device that works as a shut-off valve for the wellhead). Failure of disconnection may result in damage of riser, wellhead or BOP. This could cause significant financial losses and vessel downtime, and, in worst case, could escalate into a subsea blowout (i.e., given that the drilling activity already reached the reservoir).

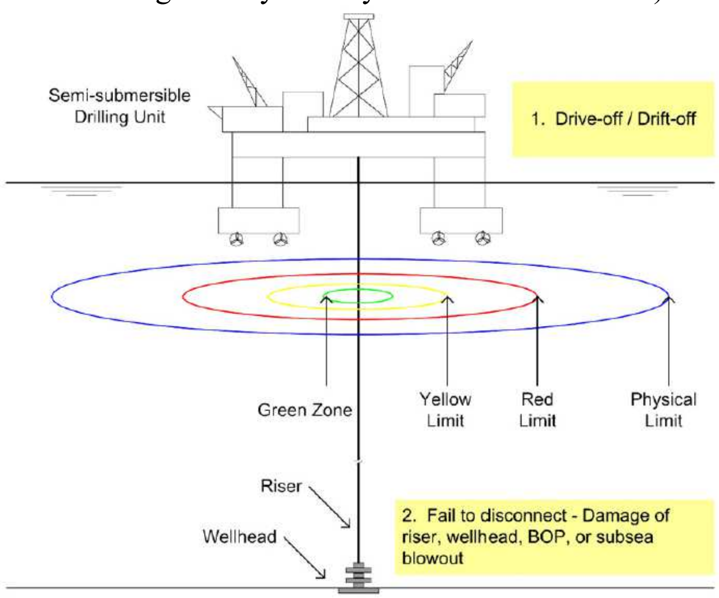

FIGURE 8 - LOP DEPICTION

According to Chen et al (2008) there are three sequential events that are critical to the safety of DP drilling operation: loss of position, critical loss of position and loss of well integrity. A loss of position occurs when the MODU loses the capability to maintain position by means of thruster force, and consequently has a position excursion beyond the yellow limit. If the excursion is not stopped and the vessel continues to have an uncontrolled movement beyond the red limit, a critical loss of position situation occurs. If the MODU moves away from the red zone and the riser angle increases, usually between 8° and 10°, the angle cannot increase any further due to physical constraints. This angle determines an offset at the surface which is called the physical limit, or the point at which physical damage to equipment may incur if disconnection is not successful. The emergency disconnection will fail if it cannot be completed before the vessel passes the physical limit. Given an unsuccessful disconnection, some part of the BOP/riser configuration will bend and/or break. The worst case scenario is that the BOP is toppled and the wellhead is sheared off. This scenario, as well as the riser breakage combined with the BOP's blind shear ram not closed, could lead to an ''open-hole'' situation in the well, or loss of well integrity, which could escalate into a hydrocarbon release.

Preventing or mitigating each of the sequential events given they occur is a mix of organizational, technical and human factors challenge. One loss of position scenario that is critical for DP drilling operations is a drive-off due to erroneous position data from two differential global positioning systems (DGPSs). This event is initiated when the DGPSs generate erroneous position data simultaneously or almost simultaneously. The erroneous data is sent to the DP software which uses it for (wrong) positioning calculations, and a drive-off is initiated causing the MODU to drive to a wrong target position.

At the time the drive-off is initiated, action needs to be performed to prevent the vessel from reaching a position where integrity is compromised and the DP operator is the only element that is able to carry out actions to arrest the vessel movement, once a drive-off has occurred.

DP MODUs can be designed with a large propulsion capacity, which implies it could have high acceleration and high speed given a worst case drive-off, and could move beyond the yellow or red limit in a very short time. The incident experiences and simulation results from vessel owners (Chen, 2008) both indicate less than 1 min for a vessel movement of 25m in a worst case drive-off scenario. Hence, in order to arrest the movement of the vessel before it passes the yellow/red limit, the DP operator has to initiate recovery actions very shortly after drive-off initiation. The likely allowable time for actions in order to successfully arrest vessel movement is within 1 min. Results from an earlier study of DP operator reaction in a similar context (Chen and Moan, 2004) indicate that this is probably too short time for a successful intervention.

In order to arrest the vessel, the DP operator needs to detect that a drive-off scenario initiated, then observe information sources (e.g., in the DP control panel) to diagnose the problem, to formulate recovery action and then execute the action. In real life, there are factors that influence the recovery actions executed not to be successful, forcing the DP operator to go through another one or more processes of observation, failure diagnosis, task formulation and execution for alternative recovery tasks. If eventually, the DP operator believes that the vessel movement is out of control, and the MODU is passing the red limit, he or she will then activate the Emergency Quick Disconnection (EQD).

LOP causes and contributing factors are vastly reported in the literature. According to Petrobras' BDIP the first period between 1984 and 1992, despite working with few rigs, was characterized for a great number of DP incidents mainly due to poor operational procedures and contingency plans, unfamiliarity of Petrobras Engineers with DP vessels' details, poor communication among departments and lack of specific procedures (Costa and Machado, 2006). In line with Petrobras information, Fuhrmann (2012) indicates that the majority of DP operational personnel have been trained to know what to do, how to do it, and when to do it. However, many do not know why certain actions are performed or what the potential consequences of those actions may be. Furthermore, the nature of the policies, procedures, and requirements enacted by many operators, charterers, and regulatory authorities increases potential risk by placing DP operational personnel into unfavorable and altogether avoidable situations. This is because much of the DP industry presumes that existing DP training and certification regimes provide adequately trained and competent Dynamic Positioning Operators (DPOs). Existing training and certification is targeted primarily at developing DP operating skills. It is not designed to teach DPOs how to handle the types of failure modes, fault conditions, and field situations that typically cause DP incidents, nor does Nautical Institute certification provide knowledge of the trainee's aptitude for these skills. Currently, training to handle the failure modes and fault conditions that typically cause DP incidents is accumulated by experience only. As a result, when emergencies arise, many operating personnel are caught by surprise and do not know how to react.

"*Human error*" is a common category used to describe causes of LOP. Thorogood and Bardwell (1998) state that, historically, operator error has been the largest single contributor to position loss. Their statement is supported by Figure 9 and Figure 10 below. Figure 9 shows Human Error as the top root cause of Petrobras LOP incidents collected from 1992 to 2005. Figure 10 shows "Operator Error" as the top 3 causes of LOP incidents reported by IMCA in 2005 (IMCA, 2007). In fact, human error is an issue of increasing concern in the offshore domain. According to Miller and Howard (1999), the concern with human errors in the offshore domain is not limited to the U.S alone, with both the UK's Health & Safety Executive (HSE) and the Norwegian Petroleum Directorate (NPD) placing considerable attention on the prevention of human errors in their sectors of the North Sea oil fields.

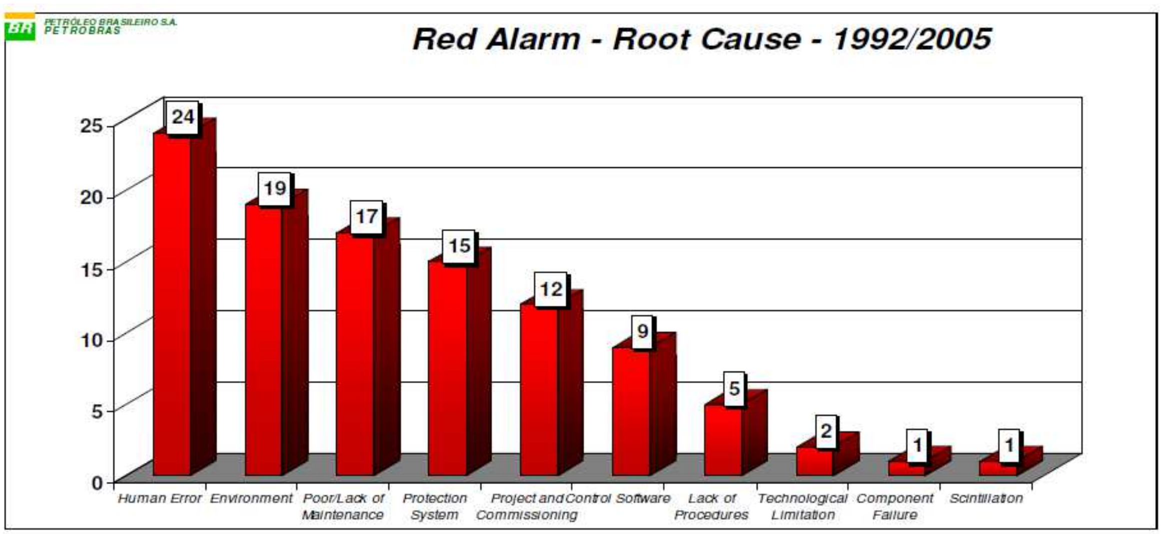

FIGURE 9 - ROOT CAUSES OF LOP

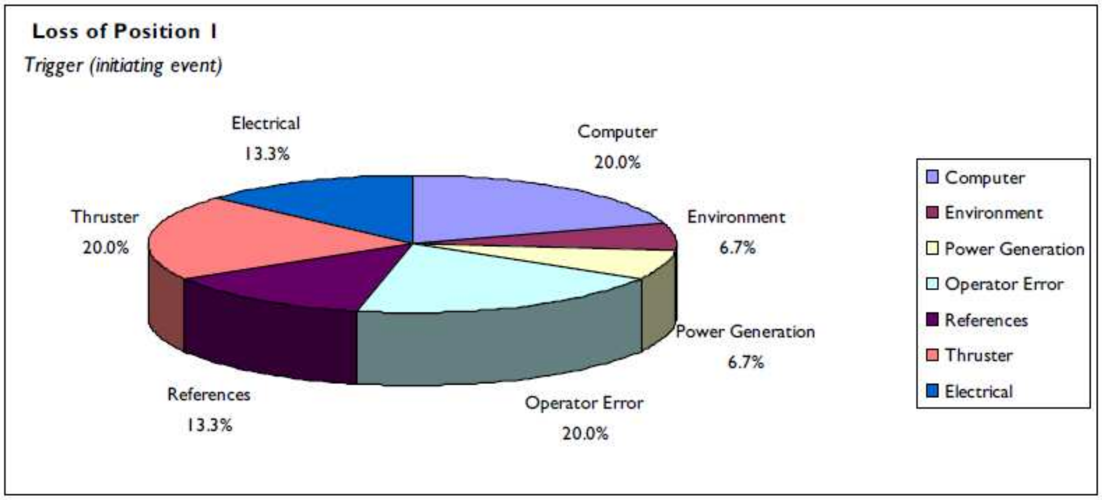

FIGURE 10 - LOP INFLUENCING FACTORS

One topic of interest raised by Miller and Howard (1999) is the quality of human interactions (or interfaces) in offshore activities. As they describe, individuals who work in the marine industry seldom work in a vacuum, even on a vessel or platform with minimum sized crews. They give and take directions from others, both on a peer basis as well as on a supervisor/employee basis. The maritime industry has functioned on a well-defined caste system, where the master is the ultimate authority on a ship controlling a one-way, top down, chain-of-command. As a consequence of this organizational design the maritime world is replete with accidents in which a subordinate crew member detected or suspected that an error had been made by a higher authority but did not believe that he/she had the authority, right, or duty to speak up.

As a reaction to this organizational design weakness, organizations of all sorts, including those in the maritime industry, are converting to more team oriented organizations. Spurred by the airline industry's innovative training efforts in what has come to be called "crew resource management", the maritime industry has now launched its own version of this team building training with the intent to get all who serve on an offshore facility to feel free to give and take input from the others regardless of rank or function to achieve maximum personal and structure safety.

According to Olson (2001), proper communication will always be essential to conducting successful DP operations. Most observed voice communication problems fall into three categories: (1) Not enough; (2) Too much; and (3) Miscommunication of critical data. A common example of not enough information is when DP control does not keep the main operating station informed as to the possibility of system problems or worsening environmental conditions, until the situation becomes critical. Too much information often causes a voice communication overload. Confusion results from the main point being lost, resulting in the need of additional information for clarification, or an improper reaction.

Fuhrmann (2012) describes an incident in which less than adequate communication led to a LOP situation. The incident occurred in late 2011 when a DP vessel experienced the loss of a generator and switchboard. The vessel was maintaining position using the remaining thrusters as the environment was well within the vessel's position keeping capability. After the standby generator came on line and restored power, the DPO was able to restore all thrusters with the exception of a single thruster. Failing to execute a routine step necessary to restore the thruster, the DPO instead took full manual control of the vessel's propulsion, which resulted in a loss of position. The charterer, in cooperation with the vessel operator, conducted a full investigation and DP Operator competency assessment, viewing the incident as a relatively straightforward example of poor organizational interfaces.

Engine Room standard operating procedures in effect in that particular vessel called for the engineering staff to alternate generators regularly in an effort to maintain even running hours between engines. As this procedure was assumed to be general knowledge, the engineers neglected to call and notify the bridge (i.e., the vessel's main control room). In this instance, a healthy generator was taken offline and the oncoming generator experienced a serious fault that resulted in the loss of power. Widely accepted recommended practice (namely, the International Marine Contractors Association (IMCA) and Marine Technology Society (MTS)) specifies that no maintenance be conducted on items of DP critical equipment during DP operations. Further, any imminent or potential change in operating status of DP critical equipment should be communicated to all concerned parties.

The vessel's Master was unable to intervene in the situation. From the time the first phone call was made to the Captain's cabin to the time the Master physically arrived on the Bridge several minutes had passed. It was not until a runner was sent that the Master was made aware of the situation, well after events had run their course. The phone system had been reported as being unreliable for some time prior to the incident and this status reported to company management but no significant corrective action had been taken.

Examples like this are very common in the marine industry. The following bullets are transcripts of reported communication failures:

1. *DP crew to deck crew…"lower the taut wire"…(the vessel has two taut wires)….the wrong one is lowered* (Olson, 2001).
2. *DP to Engine room……"shut down thruster T-2" (failed thruster)…..Engine room shuts down thruster T-1 causing loss of heading and position control….(no repeat for verification)* (Olson, 2001).
3. *A DP operator called a member of the deck crew and asked him to go and lift the port transponder up because it appeared to be giving problems. He deselected the transponder and selected his closed circuit TV on the port transponder winch position. Nothing appeared - but then suddenly the DP control system chased the starboard transponder because the wrong transponder had been lifted in error. On this occasion, there was no confirmation with the DP operator before the lifting was commenced* (Phillips, 1998).
4. *During this incident the wind had been steadily increasing and there were communications problems between Master, OOW (Officer of the Watch) and DPO (Dynamic Positioning Operator). This was added to by lack of specific*

operational procedures and by unwritten common practice. DPO informed Master that thunderstorm is approaching vessel. Master instructs DPO & OOW to move vessel from location in due time before the storm's arrival. DPO advised OOW to move from location in DP but advice not followed by OOW (IMCA, 2009).

5. *A situation occurred causing all generators & thrusters to go offline. The power room engineer left an unqualified person in charge of power management system, who did not communicate with DP personnel, causing the vessel to drift until Red alert and the necessity for emergency disconnect* (IMCA, 2010).
6. *… However, due to miscommunication, power was shut off to the fire and gas system whilst the UPS power was off. This caused the thrusters to shut down. The vessel ended up riding on one anchor 147 meters from starting position* (IMCA, 2012).
7. *In many of these incidents communications, or rather the absence of effective communications can be seen as a factor. Examples of this are the incident where, when re-plumbing a taut wire a broadcast on an open channel was misinterpreted, or the re-siting of a GPS without communicating with all those parties who may be affected by such an action* (IMCA 2008)

In order to reduce LOP incidents, DP Failure Modes and Effect Analysis (DP FMEAs) are developed to determine the safety, reliability and redundancy of onboard systems for DP positioning and DP related marine systems. Unfortunately, as it will be discussed in the next Section, current DP FMEAs formats do not address OI weknesses, including the effective communication of critical information during MODU drilling activities.

Current DP FMEA Practices

The literature offers several work related to the importance of DP FMEA/FMECA in assuring safe DP operations (e.g., Hansen, 2011; MTS, 2012; Phillips, 2011; Tobin and Cornes, 1998; Shaughnessy and Armagost, 1999; Cornes and Stockton, 1998). The Marine Technology Society (2012), for example, states that DP vessel's DP FMEA is the most important technical document in the list of required documents, and that key DP personnel, including the vessel Master, DPOs, Engineers and Electricians should have a detailed knowledge of the DP FMEA and should use the information provided to be fully informed about the capabilities and limitations of the vessel's DP system. The DP FMEA is generally the only document on board a ship that provides a general overview of the critical installed equipment and their interaction.

The first DP FMEAs began to appear in the late 1980's although it was not until the 1990's that industry requirements began to make them mandatory. Despite the mandatory requirement for a DP FMEA by the year 2000, LOP events continued to occur. The industry responded by increasing the specified redundancy requirements and creating new standards and guidelines. Yet single failures continue to cause vessels to lose position with consequent damage to life, property and environment (Hodge and Kerr, 2012).

Hodge and Kerr (2012) lists several weaknesses in current DP FMEA practices including: "*FMEAs mainly address technical failures. The human operator and the shore management are excluded from the definition of the DP system*". IMCA's Guidance on Failure Modes & Effects Analyses (IMCA, 2002) for example makes no mention on the importance of addressing human factors issues such as communication weaknesses.

Communication weaknesses in particular are of crucial importance in DP operations and not addressed in DP FMEAs. The literature contains work stressing the importance of effective communication during DP operations including the MTS' DP Operation Guidance (MTS, 2012) and the American Bureau of Shipping's Guide for Dynamic Positioning Systems (ABS, 2012). MTS' DP Operation Guidance. The MTS' DP Operation Guidance includes the following recommendations regarding communications:

- Operational specific visual and voice communications should ensure that the pertinent information flows between the key operating points as well as to and from assets and/ or other vessels that might be affected by the operation being carried out.
- These operating points may be onboard the vessel as well as on other facilities involved with the activity. Communication protocols are to be set up to provide pertinent information regarding intent, current status of planned as well as unexpected events during the execution of the activity.
- Continuity of communications during foreseeable emergency situations should be taken into account.
- Communications should be taken into account when detailing the roles and responsibilities of key personnel during the planning stages for the intended task, ensuring that a common working language and terminology is used at all times.

The American Bureau of Shipping's Guide for Dynamic Positioning Systems (2012) includes the following recommendations regarding communications:

- A means of voice communication between the main DP control station, and the thruster room(s) is to be tested and confirmed to be functioning satisfactorily.
- A means of voice communication between the main DP control station, the engine control position and any operational control centers associated with DP is to be tested and confirmed to be functioning satisfactorily.

A total of 20 DP FMEAs developed by consultancy companies that provide FMEA expertise services were acquired from a DP consultant. A review of these FMEAs was done and no evidence that communications weaknesses are addressed was found. Some of the DP FMEAs reviewed are listed below with a brief statement of their scope.

<u>Noble Denton Consultants Ltd. Hyundai Heavy Industries (HHI) New Build Drill Ship H2148 Preliminary DP Failure Modes and Effects Analysis. Report No: A5810-D/NDC/B/KS/JD/CB. Aberdeen UK, October 2008.</u>

"*The purpose of the FMEA is to identify any single point failure on the equipment and vessel systems which provide functions critical to vessel's station keeping. The FMEA will consider the failure of mechanical, electrical, and control system hardware*".

Daewoo Shipbuilding and Marine Engineering Co Ltd. DP Class 2 drillship Discoverer Clear Leader, Failure Modes and Effects Analysis of the DP system, Report number: WS 5502680700 A6445, Rev 0. May 2009.

"*Objective of FMEA is to identify any single failures of the DP system of the drillship Discoverer Clear Leader that may lead to a significant loss of position by 'drift off' or 'drive off'*".

Global Maritime, Marine Offshore and Engineering Consultants. FMEA of Atwood Condor Semi-Submersible Drilling Unit. Report number GM 45446-0311-471017 December 2011

"*The objective of this Failure Modes and Effects Analysis (FMEA) was to:*

- *identify any failures that would lead to a loss of station keeping by drift off, drive off, unexpected loss of heading or large excursion;*
- *Identify and provide recommendations to eliminate or mitigate the effects of all single point failures and common mode failures in the vessel's DP equipment which, if any occur, would cause total or partial loss of position keeping capability;*"

Offshore Commissioning Solutions. TRANSOCEAN – "Discoverer 534" Preliminary Failure Mode Effect Analysis; DP & Propulsion Systems. Report number: OCS- 2004 – 040 - 1035, July 2004.

"*The objective of the Failure Mode Effects Analysis (FMEA) is to identify any failures that may lead to a loss of position, loss of power generation, or a loss of main propulsion. Any of these failures may result in an incident*."

Det Norske Veritas (DNV) and Daewoo Shipbuilding & Marine Engineering Group Co. Ltd. DYNPOS-AUTRO FMEA for H3614 Drillship Vessel – FMEA REPORT. Report No. FWBPL356PGUS111208-1 April 2012

"*The objective of this FMEA is to address the class requirement, where the essential task is to identify the "maximum single failure" of active components and substantiate that this failure will not result in essential loss of the vessels ability to maintain position. Consequently the analysis is not considering the variety of internal failures in equipment that is safely backed up by the redundancy of the system. By "active components", coolers, filters, motorized valves and service tanks are also included*."

One aspect common to all the DP FMEAs reviewed is that none of them addressed the potential risks imposed by poor communication interfaces among operators in the vessels under investigation. The importance of addressing interactions among operators in MODUs in particular is discussed in Bakken and Olsen (2001) and King and Robinson (1997). In reality, there are several crucial interfaces in a MODU during drilling activities while on DP position keeping. The next Section presents the application of the OI-FMEA methodology discussed in the beginning of this Section in order to improve current DP FMEAs practices by taking into consideration critical OI interfaces within a MODU performing drilling activities while on DP position keeping.

DP OI-FMEA application

The objective of the DP OI-FMEA application was to revisit an existing DP FMEA by a DP expert armed with the OI-FMEA principles in order to determine if the knowledge gained by the OI-FMEA principles would promote unearthing critical scenarios overlooked by the DP FMEA being revisited by the DP expert.

The DP OI-FMEA process consists of three steps:

1. Enlightening the DP expert on the OI subject;
2. Exercise the OI knowledge by listing critical communication information (CCI) among key personnel in a MODU; and
3. Revisiting an existing DP FMEA armed with the simplified DP OI FMEA;

The DP expert in question has over 35 years of experience in DP systems and is a well-known DP consultant in the industry (credentials can be found at http://www.dpconsultant.com/). The first step involved edifying the DP expert on the OI subject. A lengthy discussion was held with the DP expert that went over the detrimental impacts that poor OI could potentially have in complex socio technical systems (including historical perspective on OI influence on disasters, OI characterization and OI failures potential contributing factors) and the OI-FMEA proposed.

Next, DP expert was asked to exercise the knowledge gained and build a list addressing critical communication information (CCI) among key personnel in a MODU containing the source and the recipient of the critical information, what actions are expected by the recipient once the information is received and the consequences if these actions are not carried out (e.g., due to receiver's misunderstanding, disregarding the information, or not receiving the information at all). In order to build this list, it is necessary initially to identify key personnel in the MODU, which are:

- The Master Mariner: highest rank in the MODU and is responsible for the overall management of the MODU;
- DPO (senior, junior, trainee, etc.): in charge of control with Dynamic Positioning System. Again, the purpose of the DP system is to automatically maintain a vessel's position and heading by using its own propellers and thrusters
- Chief Engineer: responsible for overseeing the entire MODU's engineering department on the vessel and responsible for the operation availability of all MODU's engineering equipment;
- Engine Control Room watchkeepers: responsible for the engine control room equipment's integrity and operational availability;
- Electronic and instrumentation maintenance staff: responsible for all the electronic and instrumentation equipment maintenance;
- Electrician: responsible for the electrical system's integrity and operational availability;
- Drilling staff: the staff responsible for drilling activities (e.g., drillers, tool pushers, drilling superintendent, drill floor crew).

The DP expert developed a list of CCI among these key personnel, which are presented in Table 3. The DP expert then, equipped with the CCI table, revisited an existing MODU DP FMEA that was developed in 2004 by a consultancy group in the industry for a specific MODU belonging to a drilling company, which, for confidentiality, are not disclosed in this work.

The DP expert reviewed the FMEA with consideration of the MODU's Critical Communications Interfaces (CCI). Specifically, the DP expert assessed what would change in the evaluation of effect and criticality of failures if the CCIs were included in analysis. The DP expert's first observation was an acknowledgement that the FMEA in question only considers the power plant and not the industrial mission. The only FMEA requirement from the International Maritime Organization (IMO) is the power plant, so that is all that drilling rig FMEAs consider. FMEAs performed in other industries focus on the industrial mission. The DP expert's assessment of the effect of CCI on failures assumed the failure to be avoided is "*interruption of the industrial mission*", not just the power plant, which is one of many subsystems in a rig.

The DP expert detected two communications issues. Historically, the single largest cause of an interruption to operations is lack of, or incorrect, human response to trigger events (usually equipment issues). In a high percentage of DP Incidents, the required human response is mobilizing other human resources, perhaps to remove a faulty generator or start a spare unit. In these cases, CCI can make the difference between interruption of the industrial mission and temporarily increased risk. The FMEA didn't consider the value of communications between key personnel as a means to mitigate or prevent DP Events as it focused on how equipment could fail, and ignored the fact that communications can prevent a trigger progressing to an incident.

TABLE 3 - CCI AMONG KEY DP MODU PERSONNEL

Sender => Receiver	Critical Information (CI)	What receiver must do after receiving CI	Consequences if CI is misunderstood, not received, received too late or ignored by receiver
Drilling staff => DPO	Problems noted during change in heading (e.g., slip ring not rotating, hoses getting tight, etc.).	Stop changing heading until corrected.	Injury to personnel, or damage to equipment from rig motion (people may lose balance or equipment may swing and hit people /get damaged). Possibility to damage service loops and reduce ability to control BOP and mud flows to BOP. Significant loss of revenue while repairs are completed.
Chief Engineer => Master Mariner	There is a major problem with the power plant that isn't covered by the Well Specific Operating Guidelines (WSOG).[1]	Master to review risk and decide on action.	Possible LOP if Master Mariner doesn't understand the technical details of the situation.
Chief Engineer => DPO	Additional generators were activated (e.g., squall coming).	DPO can enable more thrusters, change heading, whatever required more power	LOP possible if DPO fails to recognize additional power is available to prepare for coming squall.
Chief Engineer => DPO	Finished helping with ballasting rig.	Restore ballast control to DPO.	May impact drilling operations when DPO finds out ballast panel doesn't work from bridge (no impact on DP).
Chief Engineer => DPO	Thrusters are restarted and available after tripping.	Put the thruster back in DP mode.	Possibility LOP due to insufficient thrust.
Chief Engineer => DPO	Critical equipment taken out of service for repair or maintenance.	DPO to adjust operating procedures as needed.	DPO might not realize reduced capability while equipment is being serviced and potential for LOP.
DPO => Senior DPO	Problem setting up position reference sensors, (GNSS/Acoustic/Inertial etc.)	Senior DPO to help find out why setup cannot proceed.	Possible initiation of LOP and interruption of operations if task is done incorrectly or unable to complete task.
DPO => Senior DPO	Problems turning thrusters on/off.	Senior DPO to help find out why thruster start/stop cannot proceed.	Possible initiation of LOP and interruption of operations if task is done incorrectly or unable to complete task.
DPO => Senior DPO	Unsure how to change heading or other DP parameters.	Senior DPO to train / demonstrate process or if critical, do the job him/herself.	Possible initiation of LOP and interruption of operations if task is done incorrectly or unable to complete task.

TABLE 3 – CCI AMONG KEY DP MODU PERSONNEL (CONTINUED)

Sender => Receiver	Critical Information (CI)	What receiver must do after receiving CI	Consequences if CI is misunderstood, not received, received too late or ignored by receiver
DPO => Senior DPO	Unable to start, stop, connect, disconnect generators, switchboards, pumps, etc.	Senior DPO to train / demonstrate process or if critical, do the job him/herself.	Possible initiation of LOP and interruption of operations if task is done incorrectly or unable to complete task.
Master Mariner => Drilling staff	Entering Advisory Status[2] due to some concern not part of the WSOG.	Evaluate situation and, depending on risk assessment, either cease drilling operations or continue with mitigations in place (if applicable).	Possibility that driller will continue or commence operations that are higher risk than the accepted risk for the situation. Could result in equipment damage.
Master Mariner => Drilling staff	Exiting Advisory Status.	Resume normal operations.	Loss of productivity and revenue if operations are not resumed.
Master Mariner => Drilling staff	LOP Yellow/Red alert not part of the WSOG.	Prepare to disconnect as per procedure.	Failure to disconnect could damage rig equipment or well head. Potential significant revenue loss, and environmental hydrocarbon discharge if LOP continues to Point of Disconnect and driller hasn't completed emergency disconnect.
Master Mariner => Chief Engineer	It's OK to work on critical DP Equipment.	Equipment is taken out of service via permit to work policy and serviced.	Possible increase of risk or interruption to operations.
Master Mariner => Chief Engineer	Critical DP Equipment out of service temporarily is required to be operational ASAP.	Equipment returned to operating status ASAP.	Possible interruption of operations or LOP.
Master Mariner => Chief Engineer	Challenging weather approaching. Postpone taking equipment out of service and make sure everything is in good running condition.	Prepare for weather by postponing maintenance on thrusters or generators Start additional generators.	Potential LOP.
Master Mariner => DPO	Standing instructions for the day, operational plan.	Perform tasks as indicated by the list, inform Master Mariner of any problems, or if further information is required.	Possible increase of risk or interruption to operations if not done correctly.

Table 3 – CCI among key DP MODU personnel (Continued)

Sender => Receiver	Critical Information (CI)	What receiver must do after receiving CI	Consequences if CI is misunderstood, not received, received too late or ignored by receiver
Master Mariner => DPO	Cargo to be loaded on or off the rig.	Inform Master Mariner of any problems, or if further information is required.	Possible increase of risk or interruption to operations if not done correctly.
Master Mariner => DPO	Challenging weather approaching.	Prepare for weather by postponing maintenance on thrusters or generators, start additional generators.	May result in LOP if DPO doesn't prepare for weather, particularly if thrusters under service are not made available.
Master Mariner => DPO	Request change of heading for operational purposes	Change heading.	Possible initiation of LOP and interruption of operations if task is done incorrectly.
Master Mariner => DPO	Request change of position for operational reasons.	Change position.	Possible to damage BOP and cause extensive downtime if not performed correctly.
DPO => Electronic and instrumentation maintenance staff	Request Help with technical problem with DP system sensor or malfunction of DP software.	Check out equipment and advise DPO of method to repair, perhaps create Permit To Work if repairs are required to avoid affecting other operations.	Possible increased time to correct problem if problem not understood, increasing length of time at risk; Possible making worse by turning off or disconnecting a working redundant unit by accident (potential LOP if no sensors left working); Possible to affect other equipment by tripping a breaker and reduce DP system redundancy.
DPO => Drilling staff	Change in operational configuration and splitting main power bus or joining bus sections.	Follow procedure for splitting or joining bus sections.	Potential for blackout, LOP and equipment damage.
DPO => Drilling staff	Oil sheen spotted.	Follow procedure for oil sheen.	Potential for increased oil discharge and larger fine if source of oil is well related and procedure would have stopped the discharge.
DPO => Drilling staff	Change in heading.	Monitor equipment for hazardous situation, in which case inform DPO to stop change in heading.	Injury to personnel, or damage to equipment from rig motion (people may lose balance or equipment may swing and hit people /get damaged). Possibility to damage critical equipment and loss of revenue while repairs are completed.

Table 3 – CCI among key DP MODU personnel (Continued)

Sender => Receiver	Critical Information (CI)	What receiver must do after receiving CI	Consequences if CI is misunderstood, not received, received too late or ignored by receiver
Senior DPO => DPO	Ballasting instructions.	Perform task as instructed, inform senior DPO of progress, any problems, or if further information is required to perform the task correctly.	Possible stability or structural issues or interruption to operations if not done correctly.
Senior DPO => DPO	Set up position reference sensors, (GNSS, Acoustic, Inertial etc.)	Perform task as instructed, inform senior DPO of progress, any problems, or if further information is required to perform the task correctly.	Possible stability or structural issues or interruption to operations if not done correctly.
Senior DPO => DPO	Turn thrusters on/off.	Perform task as instructed, inform senior DPO of progress, any problems, or if further information is required to perform the task correctly.	Possible stability or structural issues or interruption to operations if not done correctly.
Senior DPO => DPO	Change heading or other DP parameters.	Perform task as instructed, inform senior DPO of progress, any problems, or if further information is required to perform the task correctly.	Possible stability or structural issues or interruption to operations if not done correctly.
Senior DPO => DPO	Start, stop, connect, disconnect generators, switchboards, pumps, etc.	Perform task as instructed, inform senior DPO of progress, any problems, or if further information is required to perform the task correctly.	Possible stability or structural issues or interruption to operations if not done correctly.
Chief Engineer => Drilling staff	Work on critical drilling equipment is complete.	Put equipment back in service and continue drilling activities.	Delay of drilling operations and loss of revenue due to unproductive time.
Drilling staff => Chief Engineer	It is ok to work on critical drilling equipment needing urgent servicing.	Critical drilling equipment is taken out of service via permit to work policy and serviced.	Critical drilling equipment not serviced. Potential for damaging equipment.
Engine Control Room watchkeepers => Chief Engineer	Critical DP-related equipment in engine control room service is finished.	Test equipment and notify DP personnel the equipment is ready to be back in service.	Extended reduced DP capability and potential LOP event.

Table 3 – CCI among key DP MODU personnel (Continued)

Sender => Receiver	Critical Information (CI)	What receiver must do after receiving CI	Consequences if CI is misunderstood, not received, received too late or ignored by receiver
Engine Control Room watchkeepers => Chief Engineer	Critical DP-related equipment (monitored in engine control room) stopped working.	Follow procedure to restart critical DP-related equipment.	Extended reduced DP capability and potential LOP event.
Electrician => Chief Engineer	Critical DP-related electrical equipment service is finished.	Test equipment and notify DP personnel the equipment is ready to be back in service.	Extended reduced DP capability and potential for LOP event.
Electronic and instrumentation maintenance staff => DPO	Technical problem with critical DP Sensor fixed.	DPO to test critical DP sensor and put back in service or inform Electronic and instrumentation maintenance staff that it needs more work.	Possible degraded DP performance or LOP if nonfunctional critical DP sensor is put back in working order.

[1]*Well Specific Operating Guidelines*: document used to define actions to be taken by a DPO in the event of certain changes to the DP unit's station-keeping capability. Also serves as a DP emergency response primer and ready-reckoning checklist for DP operators and facilitates collaboration and understanding between all parties

[2]*Advisory Status*: condition which applies to all operations or situations where the vessel has no immediate risk of LOP, but something has occurred that requires a reevaluation of the risk. Any advisory status should immediately start the risk assessment process. The vessel cannot remain in any advisory status without the DPO taking action. After a comprehensive risk assessment, operations may continue with mitigating measures in place where the advisory status may be decreased to GREEN. The outcome of the risk assessment process, however, could also mean increasing to YELLOW preparing to cease operations.

Humans are not part of the automation system, but humans can fill gaps in the automation system. Any operating rig will have some subsystems that are very reliable, and others that aren't. Since the control room or rooms are manned 24 hours a day, over time humans will adjust to more closely monitor subsystems they have trouble with, and be much faster to call in help if something looks unreliable.

One example of the use of CCI ignored by the FMEA is related to the cooling water system. One failure the FMEA considered is loss of cooling water supply to critical equipment such as main engines. It mentions that the automation system would start a backup cooling water pump and considered the effects if no backup pumps were available or if the backup failed to start.

Cooling water is one of the most critical and understood and closely watched systems on the rig. The lowest level Engine Control Room staff understand what pumps do and how to start a backup pump manually. Most engine control room has the cooling water pumps on display constantly, and the watchkeeper checks pressure and flow for changes, not waiting for an alarm. In a real failure situation, if the backup pump failed to start within seconds, the engine room watchkeeper would immediately do the following:

1. If engine room watchkeeper knows a motor-man or oiler is working in the pump room area, the engine room watchkeeper will send motor-man or oiler to start a backup pump. The motor-man or oiler will know what pump is the backup because these systems are so important that every day when they come on duty one of the first items mentioned will be "*which pump is in service and which is standby*". This is also posted on the white board in the control room.
2. Inform anyone else present with watchkeeper in the control room, and either send them to start the pump or have them watch the board while engine room watchkeeper runs down to make sure it's started.
3. Call the Maintenance Supervisor and let him know. The Maintenance Supervisor would immediately call the rig electrician or someone else to go check on the pump.

Cooling water is so critical that nobody settles for the standard automation system oversight. CCI is used to enhance and expand the level of oversight and control and shorten the response time to problems. If the FMEA considered CCI, the conclusion would be that the greatest risk is if the rig changes countries and has all new maintenance personnel. It is not unusual with rigs relocating to India, Brazil, Africa, or the USA that cooling water issues are more frequent and severe until the crew perfects their CCI.

Another example of the use of CCI ignored by the FMEA is related to the thruster drives. Thruster drives are critical on this particular rig because it has very limited redundancy (only three thrusters at each end of the ship). From an FMEA point of view, a thruster is either working or failed. When it fails, there is no consideration of how long it takes to repair. On an operating drilling rig, the maintenance team knows insufficient thrusters is a liability. The maintenance team will visit each thruster drive regularly (as often as once an hour on some rigs) and check much more than is monitored by the automation system. Small issues like increasing water temperature, or external issues like leaking pipes overhead or bilges (i.e., the area on the outer surface of a ship's hull where the bottom curves to meet the vertical sides) suddenly having water in them which previously were dry, will be noticed, reported to the supervisor, and corrected before the equipment is affected. It is not unusual for electricians to shut down a drive to repair a small water leak inside a power stage, before any leakage is noticed by the protection circuits.

This applies to CCI at several levels. The electrician will notify the Engine Control Room Watchkeeper of the situation, potential harm, consequences, and time to repair. The Watchkeeper would then communicate external constraints (e.g., the need to shut down another thruster tonight, the possibility to delay shutting down by a day) to the maintenance supervisor to assure he/she understands the risk and solutions. The Maintenance Supervisor would then communicate with the Offshore Installation Manager (i.e., the overall person responsible for the rig and its personnel, equivalent to the Captain position on board a ship) and DP Operator to understand and evaluate the risks and effects on drilling and station keeping.

The FMEA makes no mention on how critical the timing of the transmission of these critical information are and the consequences to operations. Without exercising CCI practices, eventually the small connector will leak, the coolant will flood the power devices, which could eventually explode and the thruster is lost for six hours while repairs are made. The actual repair might be the same with or without exercising CCI, but the timing of the repair will be vastly different.

<u>Conclusion</u>

The critical information OI-FMEA proposed here intends to raise awareness of the potential threats that the failure to transfer critical information inherent to a process from one entity to another can pose to the process. Evidence was found indicating that critical information transfer failure is accounted for in process FMEAs in the health care industry and product design but not in process FMEAs application in other complex socio technical systems.

The proposed critical information OI-FMEA was exercised in the deep water oil and gas well drilling industry, which common FMEA practices embrace critical hardware systems failures only and exclude the critical nature of effective critical communication interfaces (CCI) among individuals within a DP MODU (for example, during the event of critical hardware systems failure). This was evidenced by exercising the OI-FMEA proposed by a DP expert through revisiting an existing DP FMEA, which assisted the DP expert to uncover a potential serious risk not accounted in the existing FMEA.

During a communication subsequent to this exercise, the DP expert revealed that the application of the OI-FMEA concepts proposed in this work is now current practice in his FMEA consultancies. In this communication, he mentioned an FMEA he managed on a rig in Spain, which for key failure events he questioned the crew how they would interface to cope with the problem. For many of these challenges, the crew responded, to his surprise: "*we never look at that or talk about it, if it failed we'd have to read the book to know what to do*". For these circumstances, the criticality was increased as the crew was not likely to respond quickly to the particular failure in question.

Chapter 6: Limitations and future research

This work targets a complex topic and, therefore, the approach to address it has limitations. The empirical study in particular deviates from traditionally accepted norms of survey development (i.e., use of previously validated surveys or adapted previously validated surveys as opposed to the use of new content), analysis (e.g., summated or surrogate factors based on multiple question surveys as opposed to single question analysis), and validation (e.g., factor analysis or similar statistical tool as opposed to chi-square test of independence), which is due to its broad scope (i.e., several factors explored in the study) as follows.

The survey involved analyzing the transfer of critical information/knowledge from one organization to another, with the objective of exploring characteristics that can impact the transaction success likelihood. Traditionally accepted norms of survey development calls for theoretical integration into survey question content. This was achieved by insights gained from historical evidence on OI failures and from theories on organizational behavior were the main drivers to select potential characteristics that can impact transaction success likelihood and, therefore, to formulate the questionnaire questions. A total of 32 potential characteristics were selected.

Traditionally accepted norms of survey development also calls for the use of previously validated surveys or adapted previously validated survey questions. A literature research was carried out in search of survey studies related to information/knowledge transfer (or management) and how these are impacted by characteristics similar or identical to the ones being explored in this study. The works of Liao et al (2011), Leischnig et al (2013) and Willem and Buelens (2009) have similar objectives and influenced the development of questions related to a few of the characteristics explored in this work.

Liao et al (2011) study builds and empirically tests an integrated model to investigate the relationship among organizational environmental uncertainty, knowledge management capability, and organizational structure. Some of their survey questions influenced the development of the questions related to organizational environmental uncertainty, power distance culture and uncertainty avoidance or embracement culture.

Leischnig et al (2013) elaborate on interorganizational technology transfer (ITT) by developing and empirically testing a research framework that incorporates key factors of technology transfer success to address how the interaction quality influence technology transfer success and which configurations of organizational and interactional factors contribute to technology transfer success. Some of their survey questions influenced the development of the question related to interorganizational collaboration level (or, as they call, interorganizational interaction quality).

Willem and Buelens (2009) studied how classic organizational structure dimensions should be altered to be more adapted to organizational knowledge sharing. They looked at the dimensions: coordination, centralization, formalization, and specialization, in their relationship to the concept of knowledge sharing. One of their empirical study questions influenced the development of the question related to transaction vehicle quality.

As 32 characteristics were selected for the questionnaire, a strong aspect that influenced the format and size was the time taken to complete it, as it has a strong impact on the number of respondents. Simplicity was necessary to attract a larger number of participants and, therefore, a binary answer format was chosen instead of multi-category scales (e.g., Likert scale). According to Dolnicar et al (2011) a number of good reasons exist for selectively substituting multi-category scales with alternative answer formats. Negative effects on data quality are known to occur when surveys are too long. When questionnaires become very time-consuming and tedious, respondents may not answer properly at later stages of the questionnaire or may stop completing the questionnaire half way through, at the expense of both data quality and field work efforts (for a comprehensive list of negative effects see Vriens et al., 2001).

Also, people are increasingly reluctant to volunteer their time to participate in survey research. A decrease in response rates has been noted by numerous authors (e.g., Hardie and Kosomitis, 2005; Bednell and Shaw, 2003). Hardie and Kosomitis investigated the main reasons for respondents to refuse participation in survey research. The length of the interview emerged as the second most important consideration, with short questionnaires increasing participation likelihood. Only the survey topic was considered more influential. Furthermore, questionnaire length is also crucial in attracting respondents with lower probabilities of participating (e.g., those who hold high hierarchical positions within organization). Among those who refuses to participate, the first reason given was that they were too busy; the second reason was that the survey was too long. Hardie and Kosomitis conclude that measures need to be taken to stop the trend of decreasing response rates, which supports the need for simpler, faster and less burdensome questioning procedures.

Determining whether a binary scale is better than a Likert scale is open to debate. A comparison of a binary and a Likert-scale version of a standardized health survey for example, led to the conclusion that replacing the original multi-category answer options with binary options did not decrease validity or the component structure of the test instrument (Grassi et al., 2007), but significantly reduced the time required to complete the questions, thus making it more suitable for administration in the clinical setting.

One disadvantage of binary scales is that since some people are more “Yes” or more “No” than others, having response options that include more variety will capture more of the real variance in participant responses. To put that into an example, if one is asked if he/she agrees with the statement: “I have high self-esteem.” A yes/no two-item response won’t capture all the true variance in people’s responses that might be otherwise captured by six items ranging from strongly disagree to strongly agree.

In the other hand, Likert scales, in addition to the fact that it takes longer for the respondent to select an answer, may also be subject to distortion due to, for example, the respondent avoiding using extreme response categories (central tendency bias), especially out of a desire to avoid being perceived as having extremist views (an instance of social desirability bias).

Many other limitations are shared by either binary or Likert scales including:

- Respondents agreeing with statements as presented (acquiescence bias), with this effect especially strong among persons subjected to a culture of institutionalization that encourages and incentivizes eagerness to please;
- Possibility of respondents not interpreting the questions and answers in similar ways;
- Respondents may not be fully aware of their reasons for any given answer because of lack of memory on the subject, or even boredom;
- Respondents providing answers that they believe will be evaluated as indicating strength or lack of weakness/dysfunction ("faking good");
- Respondents providing answers that they believe will be evaluated as indicating weakness or presence of impairment/pathology ("faking bad");
- Respondents disagreeing with sentences as presented out of a defensive desire to avoid making erroneous statements and/or to avoid negative consequences that respondents may fear will result from their answers being used against them, especially if misinterpreted and/or taken out of context;
- Respondents trying to portray themselves or their organization in a light that they believe the examiner or society to consider more favorable than their true beliefs (social desirability bias, the intersubjective version of objective "faking good");
- Respondents trying to portray themselves or their organization in a light that they believe the examiner or society to consider less favorable / more unfavorable than their true beliefs (norm defiance, the intersubjective version of objective "faking bad").

Another limitation is the use of questionnaire responses in a chi-square test of independency. The chi square test shows that there is a relationship between the two variables (i.e., OI failure likelihood and the characteristics analyzed) but the test itself says nothing concerning the nature of the relationship, other than that the relationship exists. With the chi square test for independence, there is no one directional test. In other words, the test tells the presence or absence of an association between the two variables but does not measure the strength of association.

As there are a 32 independent variables to be tested and that the objective is to develop a first order causal model of OI failures, the chi square test for independence was regarded as a first test to be conducted. As nothing is known about the relationship between OI failure likelihood and the characteristics analyzed, the chi square test for independence was conducted to see whether there is any relationship or not. Given that some of the characteristics tested as having no relationship with OI failures based on the chi square test, then other tests may not demonstrate any relationships either. Future research is needed to rectify this.

Given that some of the characteristics tested as having relationship with OI failures based on the chi square test, then further investigation of the nature of the relationship is called for. A limitation in this research is that future research may then spend some time closely examining the pattern of differences between observed and expected cases. These may allow the determining the nature of the relationships that exist between the variables. On this basis, other statistical test, such as the test for difference of means or proportions may be conducted.

Supplementary research could apply techniques like Exploratory Factor Analysis (EFA) to determine the underlying structure (latent factors) for the survey. This process allows a large number of survey questions to be grouped into factors based on their correlations and then input to multivariate analyses as summated or surrogate factors. These could be applied to the characteristics related to the characteristics related to organizational environment complexity. The questionnaire has:

1. 7 questions related to level of uncertainty the organization has about changes in the legal, political, economic, social, cultural physical and technology forces;
2. 7 questions related to level of uncertainty the organization has about the impacts that changes in the legal, political, economic, social, cultural physical and technology forces would cause to the organization; and
3. 7 questions related to level of dependency the organization has on resources from the legal, political, economic, social, cultural physical and technology forces.

Thus, instead of inputting 32 independent variables from a 32 question survey into multivariate analyses, a smaller set (grouped by statistical similarity) can be used. One could assume the 7 variables in each one of the items above, related to the different forces are correlated and can be condensed to 1. After performing EFA, statistical assumptions (normality, heteroscadasticy, linearity, multicollinearity) should be checked and transformations performed if necessary. Future research could be done for testing reliability and validity. Factor analysis or similar statistical tool (principal components or structural equation modeling) could be applied for verifying the latent factors and factor loadings for each question in the survey.

Chapter 7: OI causal model applications on Probabilistic Risk Assessment

An important contribution of the OI failure causal model is its applicability in Probabilistic Risk Analysis (PRA) models to study the impact of OI on systems risk. PRA is a systematic and comprehensive methodology to evaluate risks associated with complex systems. Risk in a PRA is defined as a feasible detrimental outcome of an activity or action. In a PRA, risk is characterized by two quantities:

- the magnitude (severity) of the possible adverse consequence(s), and
- the likelihood (probability) of occurrence of each consequence.

Consequences are expressed numerically (e.g., the number of people potentially hurt or killed) and their likelihoods of occurrence are expressed as probabilities or frequencies (i.e., the number of occurrences or the probability of occurrence per unit time). The total risk is the expected loss or the sum of the products of the consequences multiplied by their probabilities.

PRA usually answers three basic questions:

1. What can go wrong with the studied technological entity (or process), or what are the initiators or initiating events (undesirable starting events) that lead to adverse consequence(s)?
2. What and how severe are the potential detriments, or the adverse consequences that the technological entity (or process) may be eventually subjected to as a result of the occurrence of the initiator?
3. How likely to occur are these undesirable consequences, or what are their probabilities or frequencies?

Two important activities for developing PRAs are Event Tree Analysis (ETA) and Fault Tree Analysis (FTA). ETA is an analysis technique for identifying and evaluating the sequence of events in a potential accident scenario following the occurrence of an initiating event (items 1 and 2 above). ETA utilizes a visual logic tree structure known as an event tree (ET). The objective of ETA is to determine whether the initiating event will develop into a serious mishap or if the event is sufficiently controlled by the safety systems and procedures implemented in the system design. An ETA can result in many different possible outcomes from a single initiating event, and it provides the capability to obtain a probability for each outcome.

ETs is a graphical model of an accident scenario that yields multiple outcomes and outcome probabilities. An accident scenario is a series of events that ultimately result in an accident. The sequence of events begins with an initiating event (IE) and is (usually) followed by one or more pivotal events (PE) that lead to the undesired end state. An IE is a failure or an event that initiates the start of an accident (undesirable event) sequence, which may result in a mishap, depending upon successful operation of countermeasure methods designed into the system (or process). PEs are intermediary events between the IE and the final end states (ES). These are the failure/success events of the design established to prevent the initiating event from resulting in an undesirable ES.

In order to analyze and estimate the likelihood of IE and PE in the ET, a FTA is usually used. FTA is a deductive failure analysis method that models the pathways within a system that can lead to failures or undesired results. It is a top-down method which starts at a single point (i.e., top event) and then branches out downwards to display different states (i.e., basic events) of the system using logic symbols. In especial cases, the likelihood estimation of basic events in the Fault Tree needs further consideration by the application of other techniques like BBNs (refer to Section 4). Figure 11 below portrays a generic hybrid PRA model that combines the use of ET, FTs and BBN.

The following Sections elaborate on how the proposed OI failure causal model can be used in PRA models. Section 7.1 presents a detailed PRA model for the Oil and Gas industry by a particular examining risk scenario in a Loss of Position event (LOP) and how OI failures can contribute to these scenarios. Section 7.2 presents a simple PRA model for the health care by assessing undesirable events in a leg amputation procedure and how OI failures can contribute to these events. Section 7.3 presents a simple PRA model for product design focusing on the detrimental effects of less than adequate OIs in product design.

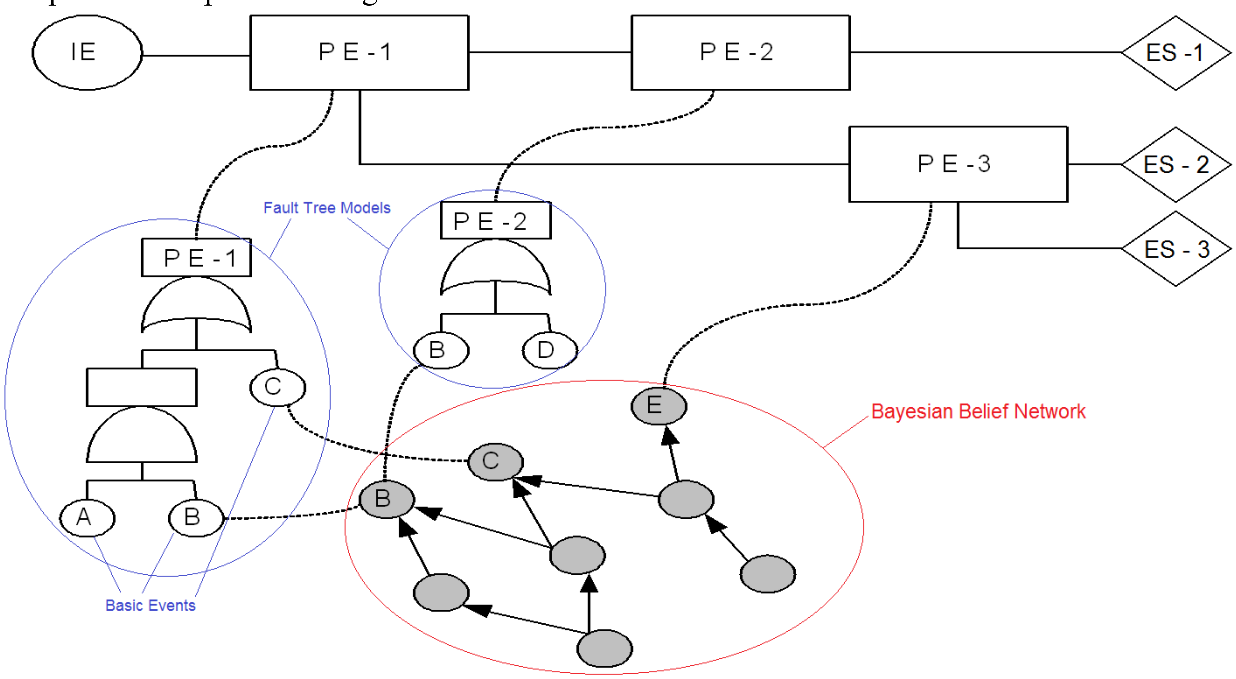

FIGURE 11 - GENERIC PRA MODEL

Loss of Position PRA

According to Section 5.1, a drive off is a powered move away from the desired vessel position. If the vessel passes the yellow limit (see Figure 8), the drilling operation must be stopped and the driller must prepare for disconnection (i.e., disconnect the riser from the wellhead). If the excursion is not stopped and the vessel continues to have an uncontrolled movement beyond the red limit, a critical loss of position situation occurs. If the MODU moves away from the red zone and the riser angle increases, the angle cannot increase any further due to physical constraints, at which point physical damage to equipment may incur if disconnection is not successful. The emergency disconnection will fail if it cannot be completed before the vessel passes the physical limit. Given an unsuccessful disconnection, some part of the BOP/riser configuration will bend and/or break. This scenario, as well as the riser breakage combined with the BOP's blind shear ram not closed, could lead to an ''open-hole'' situation in the well, or loss of well integrity, which could escalate into a hydrocarbon release.

One loss of position scenario that is critical for DP drilling operations is a drive-off. Figure 12 shows a PRA model for drive-off. According to the ET in the model:

- Once the drive-off initiated, the first line of defense is to stop the vessel before physical integrity of the system (e.g., riser, and LMRP) is compromised. If the vessel is arrested successfully, then there is no undesirable outcome;
- If the vessel movement is not arrested on time, then emergency quick disconnect (EQD) system must be activated and effectively disconnect the riser from the BOP. Failure to disconnect could potentially lead to loss of revenue (i.e., loss of production and damage to BOP/wellhead) and potential release of hydrocarbons to the environment;
- Given successful disconnection, the BOP must effectively shut the well. If the BOP shuts the well successfully the only undesirable outcome is loss of revenue (i.e., loss of production). Otherwise, if the BOP fails to shut the well, in addition to loss of revenue due to loss of production and damage to BOP/wellhead, there is a potential for release of hydrocarbons to the environment;

According to the PRA model (drive-off FT), a drive-off event is initiated when the Dynamic General Positioning System (DGPS) generates erroneous position data and this erroneous DGPS position data is used by the DP software. The Dynamic General Positioning System (DGPS) can generate erroneous position data due to either one of these conditions:

1. Dependence between DGPSs: this occurs when differential links are inter-connected to all DGPS units and hence one erroneous differential link could affect several DGPSs and lead to erroneous position data from all affected DGPSs; OR
2. Less than adequate DGPS antennae location: the locations of antennae have paramount importance to the quality of GPS and differential link signals. If the antennae locations are not optimal, multi-path, masking or interference problems may occur, and these may bring errors into GPS or differential link signals. These erroneous signals are fed into the DGPS unit, and may lead to erroneous position data as the consequence.; OR

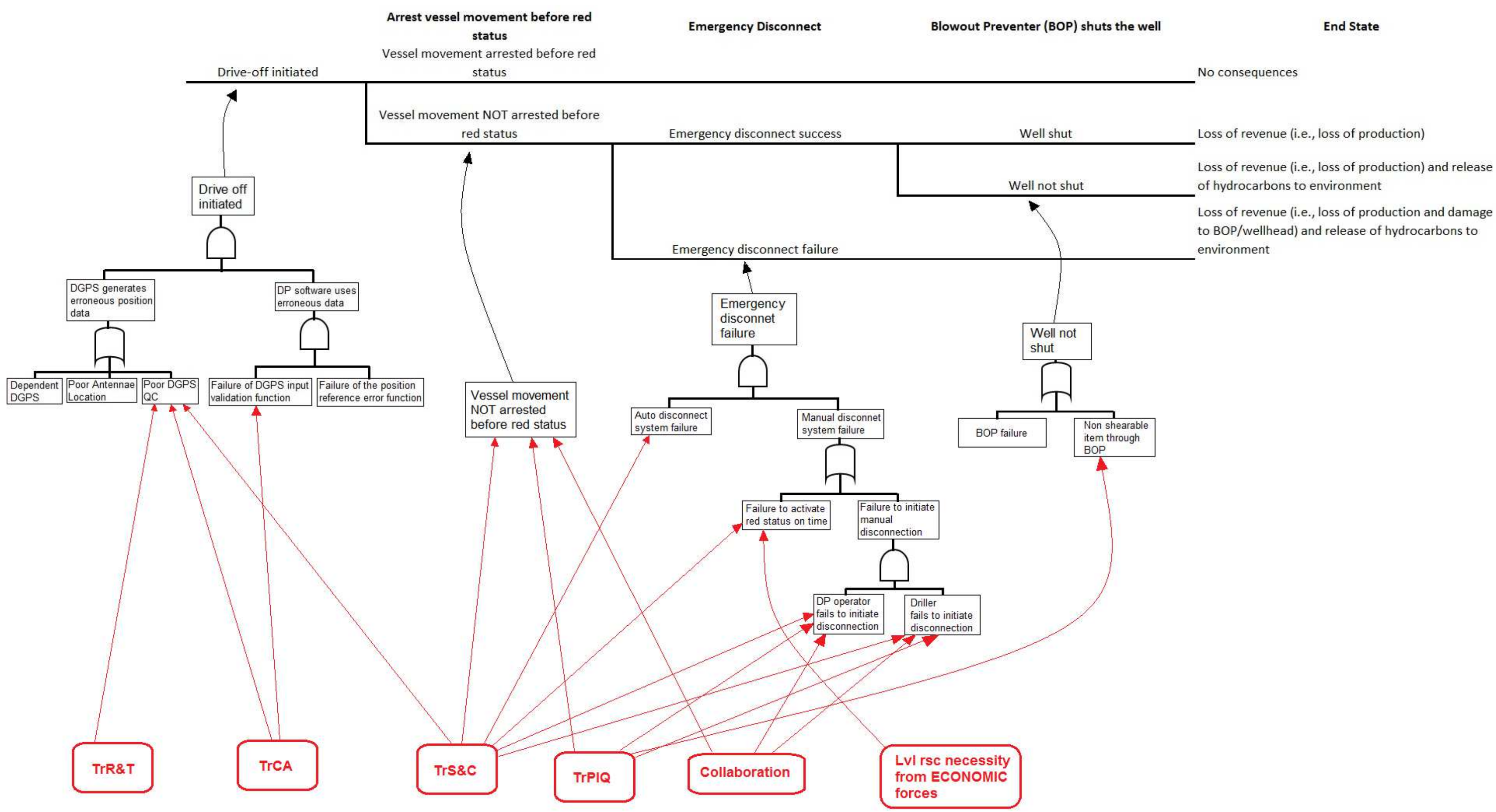

FIGURE 12 - LOP PRA MODEL

3. Poor DGPS quality control (QC): the DGPS QC function is built into the internal DGPS integrity software. It contains signal input validation parameters to verify whether the external conditions are valid for proper functioning of GPS and differential link. It also contains the quality indicators for both GPS satellite data and for position data produced by DGPS. If one or several QC parameters are out of limits, the DGPS system may stop delivering position data to DP software. In the meantime, DGPS QC function may provide text, warnings or alarms to alert the DP operator. Poor DGPS quality control function can be influenced by three OI failure influencing factors:
    a. Transaction characteristics alteration/TrCA: the DGPS QC parameters, together with many other functional parameters, may not be tuned by DP operators during operational shift change (i.e., change of DP operators), causing errors in the software setup;
    b. Transaction surveillance and control process/TrS&C: lack of management measures to maintain correct DGPS configuration in DP operations (e.g., who should be responsible for maintaining and updating DGPS configuration not determined; lack of definition of what the optimum configurations for various operational conditions are; lack of definition of when DGPS software configuration should be set up and be checked - on-arrival at field, daily operation, after maintenance and upgrade, and other possible operational situations. etc.);
    c. Transaction rate and timing/TrR&T: less than adequate frequency in which the DGPS software setup configuration is checked;

According to the drive-off FT model, erroneous DGPS position data can be used by the DP software due to:

1. Failure of the DGPS input validation function: this function checks if DGPS position data are produced in a valid condition. The rationale is that if the valid condition (e.g. minimum number of satellites) is not maintained, the DGPS data should be treated cautiously or even be excluded from further use in the DP software. Failure of the DGPS input validation function can potentially be influenced by one OI failure influencing factor:
    a. Transaction characteristics alteration/TrCA: the configurations of DGPS QC function are field-specific, and should be set up and maintained when arriving at a new field. Upon arriving at a new field, failure to configure the DGPS QC function could cause the DP software to apply erroneous DGPS position data;
2. Failure of the position reference error function: if DGPS inputs pass the validation check in DP software, the next step is to check whether all valid position reference inputs are correct. The DGPS inputs could be valid, but nevertheless erroneous. There are a number of position reference error tests being performed in the DP software, and the principles and algorithms for these tests may vary among different DP software.

At the time of DP software starts to use erroneous DGPS position data for positioning, drive-off is initiated and the vessel starts to move away from its desired location. The DP operator is the only individual able to carry out actions to arrest the vessel movement, once a drive-off has initiated. The ability of the DP operator to arrest the vessel successfully depends heavily on good quality operational procedures and training. These two aspects reflect a few important OI failure influencing factors:

1. Transaction planning quality/TrPlQ: poor quality DP operational manuals due to
    a. lack of procedures or guidance targeted on DP operator's action to detect deviations in the system (i.e., when and where to check what during DP watch);
    b. not being specific and detailed enough with respect to what the DP operator should do given the drive-off scenario (e.g., task allocations among DP operators, engine control room operator and driller under emergencies not addressed or clearly stated in the procedures).
2. Transaction surveillance and control process/TrS&C: lack of or poor mechanisms to monitor and measure DP operator's competence can heavily increase the risk that DP operator won't be able to arrest the vessel. This includes:
    a. lack of or poor training program for DP operators that combines theoretical and simulator training courses, targeting on the operator's knowledge of DP system and all related equipment, and the ability to perform recovery actions under various emergency situations. Even if there is such a training program, the training program should also address the refresh training at suitable frequency and the competence assessment after the training.
    b. poor DP simulator training exercises not developed based on real and/or assumed worst case DP incidents (given that such incidents on DP MODUs in real life are scarce).
    c. DP operators not going regularly through simulator exercises to improve their skills and experience and lack of competence assessment based on the operator's performance in the simulator.
3. Collaboration level within the MODU: given a drive-off scenario, the existence of good quality operational procedures and staff training can potentially be hindered by deficient collaboration among DP operators, engine control room operator and/or driller. All these parties must be in synchrony during a drive-off situation for effective problem diagnosing, decision making and action execution. Less than adequate collaboration can be detrimental to cognitive function and delay or prevent arresting the vessel before emergency disconnect is needed.

If the DP operator fails to arrest the vessel, and the vessel starts crossing the red limit, emergency disconnection must be activated in order to disconnect the riser from the BOP. The emergency disconnection sequence will typically involve an operation of 15–20 (or more) functions, and include the following major steps: cut pipe inside the BOP by the casing shear ram, retract the LMRP connectors from the BOP, and lift-off of the LMRP from the BOP. The well will be shut in by closing the blind shear ram either during or after the emergency disconnection sequence.

One critical aspect of the EQD is the time in which it is initiated. This is because even a technically sound EQD system may still fail to achieve emergency disconnection if it is activated too late. As shown in the PRA model, failure of EQD can happen if both the automatic and the manual methods fail. The automatic method means that the EQD sequence is activated by the DP control system when the vessel's position in the DP software crosses the pre-defined red limit. There are drive-off instances in which the estimated position in the DP software is erroneously kept within the red limit area while the vessel is being driven away beyond the red limit. Under such circumstance, the auto EQD will not function. One OI failure influencing factor plays an important role:

1. Transaction surveillance and control process/TrS&C: lack of or poor mechanisms to monitor and measure DP operator's competence in terms of having sufficient knowledge and experience with respect to the scenarios that the auto EQD will not function and how to deal with such scenario (e.g., lack of or poor simulator training in order to be able to recognize those scenarios, and react promptly).

The manual method (manual EQD) means that the EQD sequence is activated manually. According to the FT model, the manual method will fail if either the DP operator fails to activate the "*red status*" early enough (i.e., so that the entire EQD sequence could be completed before the vessel passes the physical limit) or the EQD is not manually initiated by either the driller or DP operator.

It is very important that the DP operator is able to initiate the red status immediately when it is clear that the vessel will cross the red limit, and the movement is not controllable. However, the scenarios that may involve the red status are generally rare events, and the DP operator may not have much experience with dealing with such situations. Hence, there are potentials that the DP operator may wait too long and activate the red status too late. Two OI failure influencing factors play important role in this situation:

1. Transaction surveillance and control process/TrS&C: lack of or poor mechanisms to monitor and measure DP operator's competence to evaluate the situation and initiate the red status in time when needed (i.e., handling of critical loss of position scenarios which involve the red status poorly/not implemented in the simulator training and re-training activities);
2. Level of resource necessity from economic forces: the DP operator does not feel supported (instead he/she feels blamed) by the operational management for the decision to activate the red status. Existence of economic pressures involved in disconnection can lead the DP operator not initiate the red status on time or at all. The general view of the DP industry is that the average cost of a single disconnection incident is around $2–$3 million (Chen et al. 2008).

Upon the red status activation, if it is the DP operator to initiate the EQD, he or she will then immediately press the EQD buttons from the bridge. However, in most cases it is the driller that pushes the EQD buttons after receiving the red status.

However, manually activating EQD is not a frequent operation, and this operation may require collaboration between DP operator and driller in a very stressful condition. Incidents and experiences from DP drilling operations have shown that the driller may not always react promptly after the DP operator initiates the red status (Chen et al. 2008). Three OI failure influencing factor play important role in this situation:

1. Transaction planning quality/TrPlQ: poor/lack of guidance/procedures indicating who (i.e., DP operator or driller) is responsible for activating the EQD given a critical loss of position and under what circumstances (i.e., in some cases it is safer for the DP operator to initiate EQD from the bridge);
2. Transaction surveillance and control process/TrS&C: lack of or poor mechanisms to monitor and measure DP operator's and driller's competence in working as a team during manual EQD situations. Poor or lack of drills implemented onboard to train manual activation of EQD (e.g. not repeated with sufficient frequency).
3. Collaboration level between DP operator and driller: lack of or poor initiative of operational management onboard the vessel to create a collaborative environment between DP operator and driller, so that they understand each other's work and are willing to collaborate under critical red status situations.

After the EQD has been completed, i.e. riser/LMRP is disconnected and any remaining part of cut pipe has been removed, shutting the well will take place. The blind shear ram will be closed via the automatic BOP control, and this will provide a complete well seal. According to the FT model the well will not be shut either due to BOP failure or presence of non-shearable item (i.e., too hard for the BOP shear rams to cut and seal the well effectively) through the BOP. One OI failure influencing factor play important role in dealing with non-shearable along the BOP:

1. Transaction planning quality/TrPlQ: poor/lack of guidance/procedures to train DP operator and driller to deal with non-shearable items in BOP. Given non-shearable items through BOP, special operational precautions are needed for both DP operator and driller to ensure higher alert and adequate communication between the two. In particular, the DP operator should be aware of the critical on-going operations. If any loss of position is suspected, the driller should be informed as early as possible, and this could provide the driller more time to prepare for disconnection.

Leg amputation PRA

Consider the leg amputation medical example presented in Section 2. The BBN model presented in Figure 5 could be applied to study the impact of OIs on risks related to the leg amputation process. If one divides the leg amputation process into:

1. filling out the patient form,
2. entering the data in the patient form into hospital computer system,
3. copy of patient form from the hospital computer system is delivered at the operation room

then, a simple event tree can be built to study the impact of OI risks during these steps (Figure 13). The evet tree depicts potential OI related failures that could happen during the steps followed by the hospital staff (i.e., steps 1 through 3 described above) that could have severe impact on the amputation procedure success likelihood: filling out Patient Admission Form (PAF) with the wrong leg to be amputated, entering PAF data into hospital computer system (HCS) with the wrong leg to be amputated, and delivering a copy of PAF from the HCS with the wrong leg to be amputated to the operation room (OR).

According to the leg amputation event tree in Figure 13:

1. If the correct leg to be amputated is entered in the PAF, there is also a chance that the wrong leg to be amputated will be entered in the HCS (i.e., the second step);
2. Alternatively, if the wrong leg to be amputated is entered in the PAF, there is also a chance that the error is caught by personnel and the correct leg is entered in the HCS;
3. If the correct leg to be amputated is entered in the HCS (i.e., either in the first or the second step), then a copy of PAF from the HCS with the correct leg to be amputated is delivered at the operation room (OR);
4. If the wrong leg to be amputated is entered in the HCS, then a copy of PAF from the HCS with the wrong leg to be amputated is delivered at the operation room (OR). This is, then, the last chance to catch the mistake. In other words, if the OR staff fails to recognize that there is a mistake in the printed copy of the PAF, then the wrong leg will be amputated.

The OI causal model proposed in this research can be used to determine how the different influencing factors in the model (e.g., collaboration level, uncertainty avoidance or embracing culture, transaction surveillance and control process, etc.) impact OI failures along the amputation procedure depicted in the event tree (i.e., fill out PAF, enter PAF data in to HCS, deliver copy of PAF from HCS to the OR). In other words, the BBN model can be used to estimate the likelihood of each event depicted in the event tree model. As shown in the PRA model for leg amputation:

1. The likelihood of the "PAF filled out with wrong leg" event can be influence by:
    a. Poor collaboration level between the patient and hospital staff during the process of filling up the PAF: potential lack of mutual respect between them could cause the patient not to speak clearly the correct leg to be amputated and/or the hospital staff not to ascertain that he/she obtained the correct surgery site;
    b. Poor TrPlQ: lack of or poor standardized procedure on how the information should be collected from the patient (e.g., communication protocols, exercising closed loop communication - i.e., asking the patient to go over the PAF to concur all the information is accurate, etc.);
2. The likelihood of the "Wrong leg information entered in HCS" event can be estimated by:

   a. Poor TrPlQ: lack of or poor standardized procedure on how the information should be entered in the HCS, lack of training by the hospital staff on how to use the HCS, inadequate HCS (due to, for example, not having an alert system to warn hospital staff entering the data about potential consequences of entering the wrong leg and double check correctness of data);
   b. Poor TrS&C: poor training and certification on how to use the HCS;
3. The likelihood of the "Error NOT caught - Wrong leg information entered in HCS" event can be estimated by:
   a. Poor collaboration level between hospital staff during the process of entering PAF data into HCS: potential lack of mutual respect between them could cause the hospital staff that enters the PAF data into the HCS not to double check with his/her counterpart (i.e., the staff that filled the PAF) that he/she understand the handwriting and is confident that the data is correct;
   b. Poor TrPlQ: lack of or poor standardized procedure on how the PAF information transfer should be done between hospital staff (i.e., personnel that fills out the PAF and personnel that enters PAF data into HCS);
4. The likelihood of the " Wrong leg information delivered - Error NOT caught at OR" event can be estimated by:
   a. Poor TrR&T: less than adequate number of amputation procedures per day scheduled to be performed by the surgeon could cause the surgeon to skip ascertaining with patient and/or OR staff the correct leg to be amputated reported in the PAF;
   b. Poor TrS&C: "sign your sight" (discussed in Section 2.2) practice is not implemented or standard operation procedure in the hospital;

Product design PRA

According to Chao and Ishii (2007), design errors usually occur in certain portions of the design task. In any task, the design team involved must perform an analysis of the situation to determine what must be done. Design tasks require knowledge by the design team to perform the task. The design team must communicate the requirements to begin the task, and the completed work once they execute the task. However, at all times, the design team and information are subject to change from other areas in the organizations, as well as noises or uncertainties.

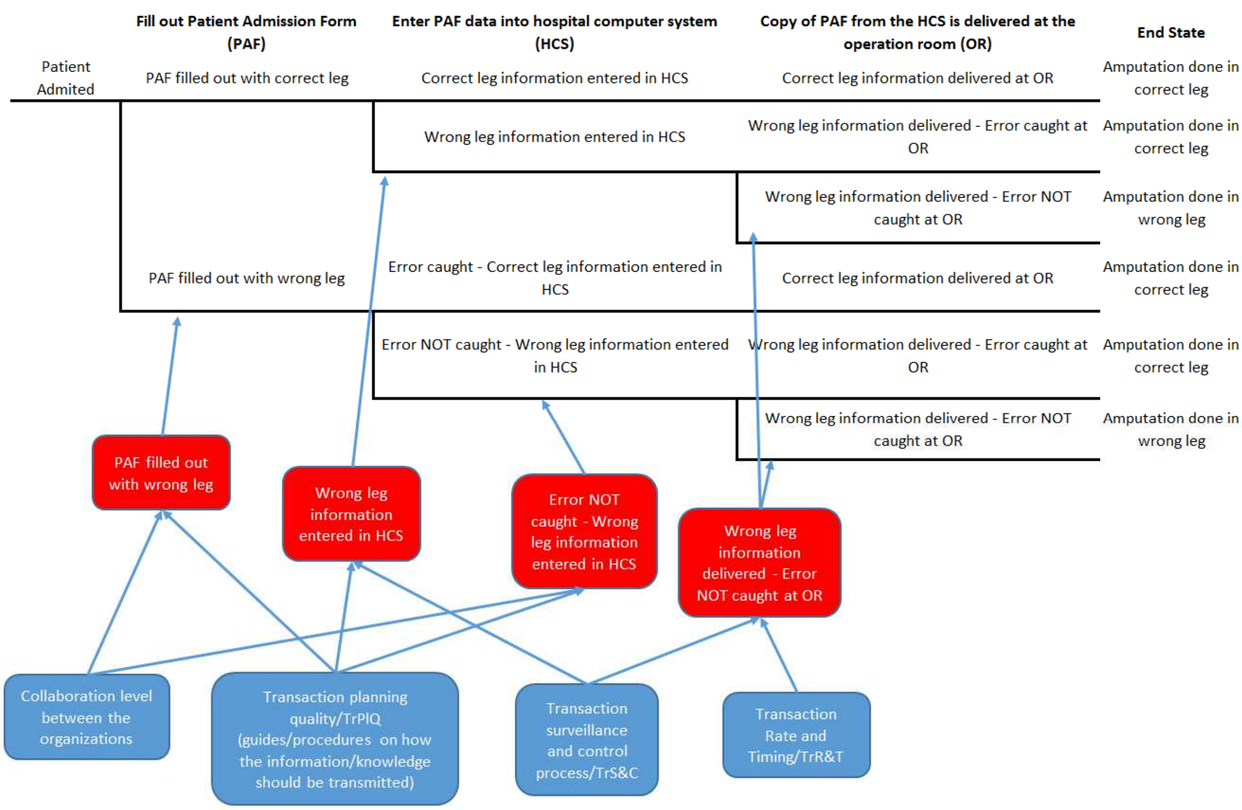

FIGURE 13 - SIMPLIFIED OI PRA MODEL FOR LEG AMPUTATION

Many assume design errors occur primarily in new projects, where the designers have not gained the knowledge, experience, or familiarity to anticipate or understand what may go wrong. However, design errors occur for products of all maturity levels, ranging from standard and familiar designs, to newer versions of existing designs, to new designs using innovative ideas. Using outdated information, for example, can result in knowledge errors. Some of these design errors can be rooted on poor OI due to, for example, the design team not gathering the necessary knowledge, poor communication among the design team members and wrong execution of design tasks.

Often, failures are a result of not fully or properly appreciating the situation; the designers failed to predict or under predicted the extent to which external inputs would affect the system. There are also often errors in the analysis of the internal system; the designers did not understand the behavior of the subcomponents or the interactions between different parts on a system level.

Communication errors involve for example incomplete delivery or communicating the wrong information either to the agents at the start of the task or by the agents at the end. Communication errors can also include ignored warnings or an incomplete context. Factors that influence these instances include how the information flow among team members between design tasks, whether there are mechanisms to verify the delivery and/or receipt of the information, how the information is interpreted, whether there is collaboration among the team members.

Task execution errors include those where all the information and instructions received and used were accurate and appropriate, yet, the design team did not execute the task properly or comprehensively. Often, they are simple human mistakes as, sometimes, people do not finish a task; other times, they complete it incorrectly, which reflects poor task coordination. Similarly to the previous case, a simple event tree can be built to study the impact of OI risks during these design steps (Figure 144). According to the event tree:

1. If the design team does not gain the necessary knowledge, then the design team could potentially be prepared with incomplete comprehension of what needs to be achieved (e.g., product requirements) and poor product design could ensue;
2. If the design team does gain the necessary knowledge but does not communicate knowledge effectively, then design team members could potentially gain less than adequate notion of design critical data, which could result in poor product design;
3. If the design team does gain the necessary knowledge, does communicate knowledge effectively, but does not execute tasks correctly (e.g., wrong order), then the final product design could potentially deviate from its requirements.

The OI causal model can be used to analyze the level of impact that OI influencing factors can have along the product design process depicted in the event tree (i.e., gain necessary knowledge, communicate knowledge and execute tasks). In other words, the BBN model can be used to estimate the likelihood of each event depicted in the event tree model. As shown in the PRA model for product design:

1. The likelihood that the "Design team does not gain the necessary knowledge" can be estimated by:
    a. Transaction surveillance and control process/TrS&C: a lack of an adequate systems engineering function can contribute to the lack of understanding on the part of design team of essential design characteristics and potential design challenges.
    b. Transaction characteristics alteration/TrCA: if the design process is characterized by a continuous stream of product requirements changes this could cause design team's misunderstanding of what requirements are in effect and which knowledge must be gained to reflect those new requirements.
2. The likelihood that the "Design team does not communicate knowledge effectively" can be estimated by:
    a. Collaboration level between the organizations: a potential lack of history of collaboration among participating organizations in the design project could cause these organizations ot operate in "isolation" and avoid establishing adequate avenues of communication;

b. Transaction rate and timing/TrR&T: a high rate at which critical design information must be transferred among team members could potentially overburden design team members and lead to missing the transfer of important design data;
c. Transaction planning quality/TrPlQ (guides/procedures on how information/knowledge should be transmitted): lack of governance on how information should be transmitted could lead to critical design knowledge received at less than adequate timing (e.g., the NASA Mars Climate Orbiter case -Section 2.5.1- when conflicts in the thrust data were uncovered, the team relied on e-mail to solve problems, instead of formal problem resolution processes such as the Incident, Surprise, Anomaly (ISA) reporting procedure);

3. The likelihood that the "Design team does not execute tasks correctly" can be estimated by:
   a. Transaction surveillance and control process/TrS&C: lack of mechanisms to control how design team members are applying the design knowledge gained along the design life cycle could lead to not detecting and acting upon cases in which design team members did not accomplish a task completely, out of order or incorrectly;
   b. Uncertainty culture: if the organizations participating in the design task are characterized by an uncertainty embracing culture, where design team members prefer to operate without being restricted by policies on how tasks should be executes, this could contribute to poor task execution coordination;

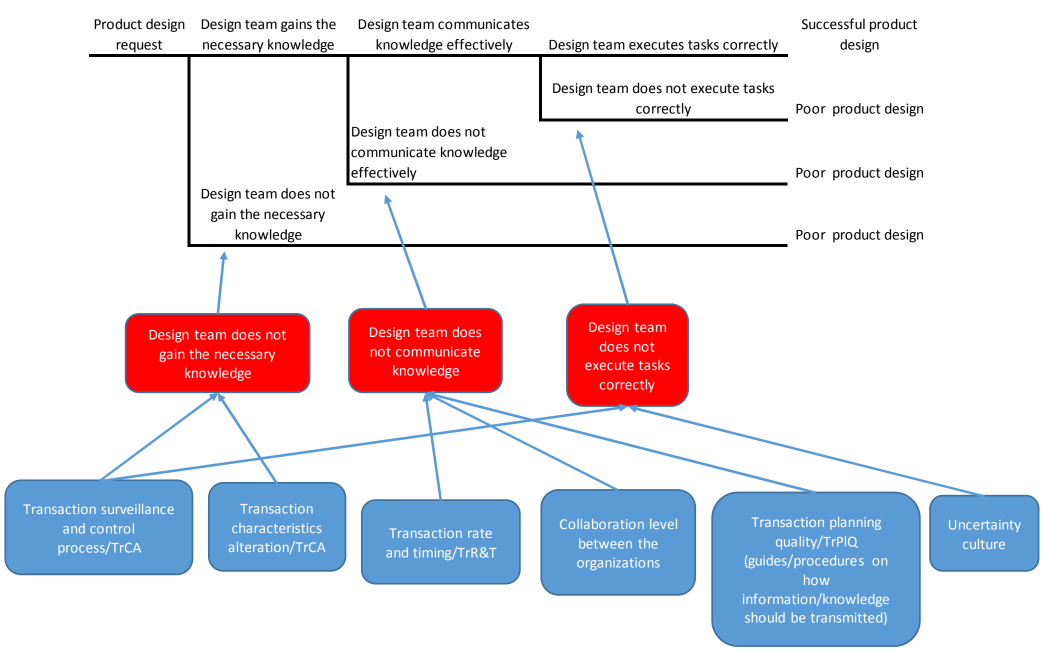

FIGURE 14 - SIMPLIFIED OI PRA MODEL FOR PRODUCT DESIGN

Chapter 8: Discussion and Conclusions

This work touches upon the topic of OI reliability, which is often ignored or overlooked in complex sociotechnical systems operations risk assessment. The objectives of this work were elaborate on the topic of the threats that poor OIs pose to social technical systems, which aimed at concentrating in the following questions:

1. Are OIs important contributors to risks?
2. What are the ways and means of OI failures?
3. Can a simple causal model of OI failures be developed?
4. Can improvements in the current practices of reliability discipline be made to incorporate the effects of OI failures in systems failure?

The analysis of the incidents and accidents in Section 2 revealed the importance of understanding the impact that less than adequate OIs among interfacing organization can have in influencing their occurrence. In fact, ignoring the value of assessing OI reliability aspects within inter-organizational operations in complex socio-technical systems is a recipe for more accidents and disasters similar to the ones presented. Indeed, disasters and incidents comparable to the ones displayed in Section 2 stroke history again.

As a reaction to the Northeastern USA Blackout in 1965, a non-governmental entity called the North American Electric Reliability Corporation (NERC) was created in 1968 with the sole mission of ensuring that the bulk electric system in North America is reliable, adequate and secure. NERC attempts to enable the reliable operation of the interconnected bulk electric system by facilitating information exchange and coordination among reliability service organizations (i.e., by improving the OIs among companies participating in power pooling).

Unfortunately, NERC has operated as a voluntary organization, relying on reciprocity, peer pressure and the mutual self-interest of all those involved to ensure compliance with reliability requirements, which reflects that the poor collaboration challenges among participating companies were not resolved. This culminated in the August 2003 USA-Canada power system outage that affected an area with an estimated population of 50 million people. The investigation on the blackout (DOE, 2004) reveals several causes for the outage including poor communication among key Transaction actors (TrAc), poor quality of transaction routes (TrNQRt) and poor Transaction surveillance and control process (TrS&C).

In the oil and gas industry, several other disasters followed the one of Piper Alpha, which can all be rooted in poor OIs due to widespread corporate culture of risk-taking (or *uncertainty engagement* culture as defined here). According to the Deepwater Horizon Study Group (2011), the Petrobras P36 production platform sinking offshore Brazil in 2005, the Texas City refinery disaster also in 2005, the blowout of the Montara well offshore Australia in the Timor Sea in 2009 and the Deep Water Horizon disaster in 2010 followed roadmaps to disaster that are very similar to each other including: not following required or accepted operations guidelines, multiple operations conducted at critical times with unanticipated interactions, inadequate communications between members of the operations groups, etc.

In order to prevent these types of disasters from happening, it is crucial to understand the ways and means of OI failures. In Section 3, a list of OI characteristics and three major OI functions were proposed to be used as the building blocks of OI reliability analysis. These building blocks were used further to propose an initial causal model of OI failures using a BBN approach. In order to support the causal relationships displayed in the BBD model an empirical study was conducted to explore the dependency between information/knowledge transfer failure (i.e., IKTrF) and different influencing factors (which derived from the OI characteristics).The IKTrF BBN model presented in Section 4 aims at setting forth a foundation for future work to be developed, including for example:

- expanding the BBN model proposed with potential consequences for IKTrF, exploring the impact that the influencing factors discussed may have on different types of IKTrF failure modes;
- exploring other influencing factors that were not included in the empirical study including Transaction rate and timing (TrR&T) and the factors that influence levels of collaboration (e.g., History of Collaboration; TrAcs mutual respect, understanding, and trust; TrAc perception of self-interest; TrAcs ability to compromise);
- developing OI reliability models for other types of IObs (i.e, electric energy, petroleum, etc.); etc.

The OI characterization and OI failures influencing factors were also used to propose an OI-FMEA intended at analyzing the risks related to failures in critical information/knowledge transactions. This OI-FMEA aims improving current practices of the reliability discipline by incorporating the effects of OI failures in systems failure. The OI-FMEA has a limited scope as it targets the consequences of failures in critical information/knowledge transfer among interfacing parties. Applying the concepts developed in this research to exercise the OI-FMEA for other IOb is subject of future work.

Unfortunately there are many criticisms of FMEA, usually regarding its implementation and utility, including its time requirements, the failure to identify key errors, the fact it is performed too late in the design process, and that the terms are poorly defined or inconsistent. In fact, OI-FMEA's in particular could potentially become vast depending on the complexity of the socio technical system being analyzed and the depth of the analysis.

The application of the OI-FMEA methodology proposed involved simply revisiting an existing DP FMEA by a DP expert armed with the concepts of the OI-FMEA methodology to test whether the methodology is effective in detecting risks not revealed by current DP FMEA practices. The exercise showed that the OI-FMEA concepts were a powerful tool that facilitated the DP expert in pointing out a serious risk scenario not covered in the FMEA being revisited.

Current DP FMEA practices, as was discussed in Section 5, do not take into account key personnel interactions, which is critical especially given that fact that in a MODU context many people come from different organizations. If DP FMEAs included critical information/knowledge communication among key personnel, they would almost certainly have weighted risk and consequence differently, instead of basically assuming an unmanned rig.

Progress has been made in the DP arena when it comes to critical communications OIs. As mentioned previously, the American Bureau of Shipping's Guide for Dynamic Positioning Systems (2012) includes the following recommendations regarding communications:

- A means of voice communication between the main DP control station, and the thruster room(s) is to be tested and confirmed to be functioning satisfactorily.
- A means of voice communication between the main DP control station, the engine control position and any operational control centers associated with DP is to be tested and confirmed to be functioning satisfactorily.

Using the OI jargon proposed in this work, these two recommendations constitute transaction surveillance and control processes (i.e., TrS&C) that vouches for maintaining appropriate number and quality of voice communication transaction routes (i.e., TrNQRt) among key stakeholders within a MODU. However, these recommendations have very subtle weakness as they do not include the frequency in which these the means of voice communication are to be tested and confirmed to be functioning satisfactorily. This reflects the need for better transaction planning quality (i.e., Tr-PlQ) as the recommendations overlooked the importance of establishing a testing schedule. The way the recommendation is verbalized could potentially be interpreted as "*testing only once*", which obviously is not the best practice.

One potential challenge for including OI weaknesses in reliability and risk assessments could be a natural reluctance to scrutinize the human element inherent to it. Transaction actors are the ones responsible for determining and/or agreeing on how to coordinate, communicate and collaborate to realize OI success. At the deep end of the accidents, incidents and undesirable events discussed in this work, the transaction actors are at the root of the events that created the conditions for these accidents, incidents and undesirable events to materialize.

The OI-FMEA methodology proposed can be used as a tool for systematic control of all critical knowledge/information communications that support a process operation. Given the significance of human involvement in most operations, it is important that interactions among people be managed and carefully coordinated to avoid incidents resulting from misunderstandings and lack of information.

Given the sensitivity and complexity of this research, limitations are not absent. One aspect of the sensitivity is due to the fact that the survey touches upon a controversial issue (OI failure) collecting empirical evidence on it is challenging as respondents may not feel encouraged to provide accurate, honest answers or may not participate at all. The survey was designed with simplicity, using binary responses (as opposed to Likert scale) to reduce the time for thinking on an answer (responding to a 2 options question is faster than several options). Also, the empirical analysis presented deviated from traditionally accepted norms of survey development, analysis, and validation. Limitations that followed these deviations were tackled and future work needed to address these limitations were presented (e.g., apply EFA to determine the underlying structure/latent factors for the survey; and testing reliability and validity).

Finally, many other potential characteristics that can also impact transaction success likelihood were not explored (e.g., organizational characteristics from the other organization – i.e., not the respondent's one) and can be topic of future research. By doing so, a more complete set of influencing factors could be factored into the simplified causal model of OI failures and broaden the level of analysis of OI failure in PRA models.

Appendix - Questionnaire

The following is the text of the questionnaire that was used to elicit expert opinions on factors affecting OI failures.

Background

Organizational Interfaces (OI) exists when two or more organizations interact with each other to exchange information, material, energy, etc. For example, an airport is a setting where various airlines and air traffic control exchange information in order to provide safe air passenger transportation. When these transactions are not successful (many of which resulting in death tolls, financial loss, environmental impact, etc.) an OI failure occurred. The purpose of this survey is to investigate correlations among organizational characteristics (i.e., design, culture, external environment) and OI failures. The words highlighted in red are questions and the ones in black are background information related to the question. Please think of any organization you have worked in the past to answer the questions.

Organizational Design

A Mechanistic design is intended to induce people to behave in predictable, accountable ways. Decision making authority is centralized, subordinates are closely supervised, and information flows mainly in a vertical direction down a clearly defined hierarchy. An Organic design is decentralized so that decision-making authority is distributed throughout the hierarchy; people assume the authority to make decisions as organizational needs dictate.

How would you describe the design of your organization?

Mechanistic ( ) Organic ( )

Back ground: Organizational Environment Uncertainty

Organizational environment consists of the set of pressures and forces surrounding the organization that have the potential to affect the way it operates and its ability to acquire scarce resources. Typical forces include: Legal, Political, Economic, Technology, Social, Cultural and Physical (e.g., need for natural resources, vulnerability to weather conditions, etc.).

There are two ways the environmental forces influence organizations:

(1) Level of uncertainty about the environmental force and amount of information needed to understand it to reduce this uncertainty

Question: How likely it is that unknown/unforeseen environmental forces can impact the organization?

Likely ( ), Not likely ( )

Question: How much uncertainty do you think your organization has regarding changes in the environmental forces?

Force	***High uncertainty***	***Low uncertainty***
Legal		
Political		
Economic		
Social		
Cultural		

Physical		
Technology		

Question: How much uncertainty do you think your organization has regarding the impact of changes in environmental forces would cause in the organization?

Force	***High uncertainty***	***Low uncertainty***
Legal		
Political		
Economic		
Social		
Cultural		
Physical		
Technology		

(2) <u>The need for resources from the forces</u>

Refers to the dependency that your organization has on the forces to acquire resources to be able to achieve goals.

Question: How much dependency do you think your organization has on the environmental forces?

High dependency ( ), Low dependency ( )

Force	***High dependency***	***Low dependency***
Legal		
Political		
Economic		
Social		
Cultural		
Physical		
Legal		

Organizational Culture

Question: how would you measure the level of participation in decision making employees within your organization have?

- *High ( )*
- *Low ( )*

Question: How much do you agree with the statement: "people in my organization in general prefer a formalized and standardized environment, where rules and regulations establish acceptable behaviors?"

- *Agree ( )*
- *Disagree ( )*

Question: How much do you agree with the statement: "people in my organization in general give precedence to relationship over tasks".

- *Agree ( )*

- *Disagree ( )*

OI Characteristics

Think about a piece of information/knowledge (1) that you think is critical to your organization, and (2) that another organization prepares and transmits to your organization. The questions below are related to this particular piece of information/knowledge transaction.

Question: How often does the transfer occur?

- *Routinely ( )*
- *Under especial circumstances (e.g., emergency, unusual, unforeseen situations) ( )*

Question: What media is used for transfer?

- *Verbal (e.g., face-to-face including video teleconference, telecommunication device, etc.) ( )*
- *Written (e.g., electronic transfer, manual/mechanical transfer ( )*

Question: Are there guides/procedures on how the information should be prepared (e.g., document templates, verbal protocol)?

- *Yes ( )*
- *No ( )*

Question: Are there guides/procedures on how the information should be transmitted (e.g., mail, e-mail)?

- *Yes ( )*
- *No ( )*

Question: Are there mechanisms to assure the transaction is successful?

- *Yes ( )*
- *No ( )*

Question: is the characteristics of the transaction dynamic or static? (i.e., does the sender and/or receiver change over time?, does the content of the information change over time? Does the media used for transfer change over time?)

- *Dynamic ( )*
- *Static ( )*

Question: How would you describe the level of collaboration with the other organization? (i.e., what is the level of commitment/dedication/allegiance of the other organization to the success of the transaction?)

- *Good collaboration ( )*
- *Poor collaboration ( )*

OI Failure Modes

How likely do you think there will be a critical information/knowledge transaction failure (e.g., critical information/knowledge is sent to the wrong receiver; critical information/knowledge is sent at the wrong time; wrong critical information/knowledge is sent, critical information/knowledge does not reach the receiver, critical information/knowledge reaches the wrong receiver, critical *information/knowledge does not reach the receiver at the right time, critical information/knowledge is dismissed by receiver, etc.)?*

- *Likely (..)*
- *Not likely (..)*

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