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Measuring Risks of Interdependencies in Enterprise Systems: An Application to Ghana’s Salt Enterprise

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MEASURING RISKS OF INTERDEPENDENCIES IN ENTERPRISE SYSTEMS: AN APPLICATION TO GHANA'S SALT ENTERPRISE

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ABSTRACT

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This dissertation describes the use of Functional Dependency Network Analysis (FDNA) for modeling risks resulting from dependencies among elements of enterprise systems with application to salt processing enterprise in Ghana. FDNA was developed to model dependencies among members of enterprise systems by highlighting two dimensions of dependency: strength and criticality. Nonetheless, the concepts and analytics for these two dimensions of dependencies needed further development and generalization in the context of project management and systems development in developing countries.

Managing risks within the interdependency in enterprise systems through integration will help improve global economic growth. Coherent theory for enterprise integration must be developed, especially in developing countries like Ghana. The significance of this dissertation is the further development of theoretical concept that can be used to analyze dimensions of dependencies in enterprise systems. This model development is contingent upon the strength and criticality dimensions of dependencies in enterprise systems as they apply to project management and the development of enterprise systems. The research covers empirical investigation of the complexities and of enterprise risk management in the Sub-Saharan region for the appropriateness of using the FDNA concept to develop the salt processing enterprise in Ghana.

This dissertation is dedicated to my parents who guided me through the rough and tumble life of being a child in a village in Ghana, West Africa. Since many children die before their first birthday, I could be considered one of the luckiest children of all because of the loving and tender care I received from them. Neither of them would live to see me accomplish this feat, yet I know that they are happy that their third child, against all odds has come of age and accomplished what most of my friends could never dream of in their lives.

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NOMENCLATURE

A	A is a chemical compound used to remove one of the components in seawater
B	One of the species of compounds in the salt water
BOL	Baseline operability level
FDNA	A method used to model entities in a system as a portfolio of capabilities
$Capi$	Is a capability portfolio of an i enterprise?
COD	Criticality of dependency is the operability level β_{ij} (utils) such that the operability level of receiver node Nj with feeder nodes *Ni* can never be more than$Pi + \beta ij$, for all $i = 1,2, \dots, h$ where $0 \leq \beta ij \leq 100$ and Pi is the operability level of feeder node *Ni*. The parameter βij is the criticality of dependency constraint between receiver node $Nj$and its feeder node Ni (Garvey and Pinto, 2009)
Ca	One of the species of compounds in the salt water
Diamond	A model developed by Porter (1990)
FOS	Federation of Systems
K	Potassium species in the salt water
Mg	Magnesium species in sea water
MEOL	Minimum Effective Operational Level
MOP	Measurement of Performance
P	Normalized output of an enterprise system, range

SOD	Strength of dependency is the operability level a receiver node relies on receiving from a feeder node for the receiver node to continually increase its baseline operability level and ensure the receiver node is wholly operable when its feeder node is wholly operable (Garvey and Pinto, 2009)
SOS	System of Systems
S	Sodium species in the salt water

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1 INTRODUCTION

1.1 BACKGROUND

Enterprise systems are collections of technology put together as a portfolio to achieve final goals and outcomes which cannot be achieved by a single system (Garvey & Pinto, 2009). Each technology is designed to perform certain tasks which may differ from other technology in the network. The parts of the network may function differently from each other, but work together as a whole, harmoniously through integration, to produce the outcome. The networks of the technological systems are put together for the purpose of achieving value-added goals and outcomes. There are inherent risks in the systems that must obviously be controlled to achieve the purpose the systems are designed to produce. These inherent risks when not properly controlled may affect the goals and outcomes of the systems or cause the whole system to fail i.e. not to achieve the goals and outcomes. When not controlled, the risk can propagate throughout the system, and can cause other systems outside its boundary to also fail. These inherent risks can have effects beyond the system boundaries when the system's outcomes are used by other systems.

Risk of interdependencies in enterprise systems, is defined as the risk between two or more interdependent systems as a result when one of the system that depends on the goals and outcomes of another which utilizes these outcomes to further produce the goals and outcomes they are set up to produce. Risk of interdependencies among enterprise systems can be analyzed by first understanding all tasks performed by portfolios of technology within the enterprise systems. Interdependency is the degree to which the action or outcome of one capability portfolio affects the action or outcome of other capability portfolios ((Albino, P, & B, 2002) (Van de Ven, Delbecq, & Koenig, 1976) (Garvey & Pinto, 2009)). Network or links between capability portfolios creates interdependencies between organizations.

Interdependency can be further described as a condition that exists between two systems or nodes when the operability of one system relies, to some degree, on the operability of another system. There are interdependencies due to flow of activities and interdependencies due to information flow. The state at which a system's performance level functions, is its level of operability. The measurement of performance achieved by the system is its measurement of performance (MOP) and the value of what the system produces, as its operability level is its measurement of effectiveness (MOE) (Garvey & Pinto, 2009).

In network analysis, a receiver node's operability level is influenced by two properties of dependency. The first is the strength with which a receiver node's operability level relies on the operability level of feeder nodes. The second is the criticality which is the contributions to a receiver node for it to achieve its operability-level objectives. These are referred to as Strength of Dependency (SOD) and the Criticality of Dependency (COD) constraints respectively. The FDNA method for identifying capabilities from which nodes are built is new. The FDNA concept has not yet been broadly applied to other engineering systems problems of an enterprise scale

Therefore, there is no clear and proven method to estimate the parameters (i.e. strength and criticality) of an FDNA model. To fully understand the impact of FDNA on systems' risks of interdependency, we need to study the time-dependent variation of system's measure of performance (MOP) and its impact on interdependency relationships.

1.2 PROBLEM DOMAIN

New approaches to sound decision making for system design and deployment are being offered due to growth in technological innovations. At the same time the acquisition of advanced knowledge and training for system design and deployment are required due to growth in complexity of technical systems. Developing countries have small to medium enterprises which lack the technical skills to develop the best and most efficient approaches to exploit their resources. Enterprise risk management through systematic ways of identifying, representing, and measuring the enterprise systems' interdependencies will improve the whole enterprise system's performance (Chapman & Ward, 1997; Garvey & Pinto, 2009). Functional Dependency Network Analysis (FDNA) can be used for modeling risks resulting from interdependencies among elements of systems of systems such as the cluster of industries created by the salt processing enterprise in Ghana. The concepts and analytics for these two dimensions of dependencies need to be further developed and generalized, in the context of project management and systems development in developing countries. The key to global economic growth is integration of the above solution approach into a coherent theory for managing risks in engineering of enterprise systems, especially in developing countries like Ghana.

The significance of this dissertation is the further development of theoretical, conceptual, and analytical dimensions of dependencies in enterprise systems. This model development is based on the strength and criticality dimensions of dependencies in enterprise systems as they apply to project management and systems development of enterprise systems. The research covers empirical investigation of the complexities of enterprise risk management in the Sub-Saharan region for the appropriateness of using the FDNA concept to develop the salt processing enterprise in Ghana.

Manufacturing enterprise systems are enterprise systems made up of several webs of users, and technologies. Manufacturing enterprise systems operate in environments that offer cross-boundary access to a wide variety of resources, information technologies, and other capabilities required for successful operation. Consider as an example a chemical enterprise or petroleum-refining enterprise system which aside from machines and technologies, is staffed by highly-trained and specialized personnel, who function in a unique atmosphere of well-coordinated, and unspoken competitiveness (Valle-Riestra, 1983).

These systems are used for producing consumer goods such as processed food, cosmetics, and medical supplies (Valle-Riestra, 1983). The technological processes and systems are necessarily scattered over large geographical locations. They may involve lengthy periods of data gathering, repetitive computations, and myriad other routine works such as troubleshooting of systems to identify risky situation. Mitigation of the risky situations will provide the goals and outcomes the systems are assembled to deliver. There are major problems involved in enterprise systems that require highly trained professionals to run them in order to produce the goals and outcomes they are designed to produce. Developing countries have no such resources to produce and create the enabling functions to grow their economies.

However, today, demand for quality consumer products requires that systems are put together to function as an enterprise system to provide the quality, productivity, efficiency, and quantity demanded. This has created a plethora of overlapping and confusing networks of systems to a higher level of complexity and risks. Consequently, new control strategies are being proposed to maintain the desired degree of success in enterprise systems. These control strategies are often based on centralized process control or distributed control systems, rendering new or amplifying old dependencies. The possible-risks impacts of these interdependencies from one system to another system are now being thoroughly investigated (Chandorkar et al., 1993).

Such enterprise systems have multidirectional dependencies at many levels in the system's capability portfolio and their program nodes may depend upon supplier nodes to achieve their required level of performance (Garvey & Pinto, 2009).

1.3 SIGNIFICANCE OF PROBLEM

There is no clear and proven method to estimate the parameters of an FDNA model (i.e. its strength and criticality). Therefore, in developing countries where data is negligible and experimentation infeasible, the use of expert opinion becomes a viable method for quantitative analysis to gain knowledge of the phenomenon. However, in this study, experimental data obtained from Morton Salt Company at the Bahamas plant makes it more reliable to bypass expert opinion for this dissertation

Using the fundamental natural law of mass, energy, and momentum, we can develop an empirical formula of interdependence systems phenomenon to show conceptual framework of feeder-receiver enterprise systems. The fundamental natural law is expressed in the form of differential equations giving the rate of change of an input quantity with respect to an independent variable. This gives the time variation of inputs and outputs of the two enterprise systems, which helps develop the time variations of observations needed for interdependency relationships.

Enterprise systems are made up of several systems which according to Keating et al. (2003), are meta-systems which consist of multiple components, autonomously embedded enterprise systems that can be diverse in technology, context, operation, geography, and conceptual framework. System of systems have their associated risks of interdependencies, which according to Balázs and Monostori (C & L, 2008) these complex systems have (a) limited knowledge about the behavior of the system, (b) have sudden or constant changes (dynamics), (c) are made up of a large number of participating elements and influencing factors (multiplicity), (d) have many types of elements (variety), (e) have interactions due to coupling in the systems, and (f) have interdependencies (i.e. feedback loops) within the network systems. In natural science problems (e.g. chemistry), graph theory is used to measure and define the complexity of structures within systems. They believe that these measures are symmetry-based, which according to them, often apply the concept of entropy, the average- or normalized-edge complexity, sub-graph count, overall connectivity, and total walk count. The theory of Enterprise Adaptive Systems is the new approach (Balázs & Monostori 2008) and may be good to measure links or complexity of structures between networks which may help identify risk of interdependencies in network systems but cannot be used to measure risks of interdependencies.

Also, the recent frameworks for measuring risk of interdependencies in enterprise systems (e.g. FDNA, and Leontief I/O model) are not fully developed as to show:

1. How to characterize types of interdependencies,
2. How to collect quantify interdependency features such as criticality relationship, and
3. How to research the analytical scalability of foundational FDNA (Garvey & Pinto, 2009) to a nation state-level enterprise.

This shows that more research studies are needed in developing the framework for measuring risk of interdependencies in enterprise systems. Identifying risks of interdependencies in enterprise network systems are difficult tasks but finding ways to study and measure risks of interdependencies are a great help to the process industries.

In interconnected enterprise systems negative impact that occurs, if not checked, could propagate into other enterprise systems that depend upon such enterprise systems to accomplish their goals and outcomes (Wiggers et al. 2006). By this reasoning, organizational units that are responsible for the goals and outcomes must view interdependency as occurring between components and all relevant systems within the enterprise systems (Rinaldi et al. 2001). According to Rinaldi et al (2001), it is important to view interdependency as arising between components and systems that achieve goals and outcomes and not organizational units because their tasks, they perform can be decoupled from the organizational unit responsible for its completion and assigned to another organizational unit. For example, a task requires a certain set of skills and knowhow to execute those (Wiggers et al., 2006). Therefore, any organizational unit that possesses those skills and knowhow may execute the task. Consequently, Wiggers et al (2006) have indicated that management has the flexibility to reassign roles and responsibilities if it adheres to the task capability constraints. Reassigning new roles would change interdependency between organizational units; but will not change the interdependency between tasks as that remain unaltered. From this reasoning, any model must represent both process constructs and organization constructs.

This paper focuses on dealing with the risk-reduction issues of enterprise systems. Modeling today's enterprise systems requires that several systems are brought together to create a single whole system. The different parts may perform differently but they all contribute towards achieving the final goal. Risk management in enterprise systems is the identification and resolution of the overall risk that impacts the effective performance of the system (Moss, 2007).

Non-stationary systems require the use of conservation principle states that input minus output equals accumulation or generation (Input - Output = Accumulation) (Douglas, 1972). For process systems in steady conditions, the accumulation terms are always equal to zero, so that total input of any conserved quantity to a unit must be equal to the total output. In this paper, only the non-stationary theoretical models are considered to minimize introducing additional complexity. Theoretical models that include the non-linear dynamic operating characteristics has been deferred to a later study. After scoping the model down to linear dynamic unsteady state condition, System dynamic Model, Leontief, and FDNA models were considered.

2 LITERATURE REVIEW

2.1 THEORETICAL RATIONAL

2.1.1 ENTERPRISE SYSTEMS

The analytical framework and computational model of Functional Dependency Network Analysis for risk assessment was first proposed by Garvey (2009). His concept and prospective was based upon general systems theory. Modern technological advances are creating a rapidly increasing number of enterprise engineering systems, products, and processes whose design, analysis, control, safety, and risk management for successful operation over their life cycles pose considerable challenges.

An enterprise system can be represented as a network of systems, infrastructures, or organizational entities that can be expressed as nodes on a graph that depict direction, strength, and criticality of a feeder-receiver dependency relationship (Garvey & Pinto, 2009). In an enterprise system, each element (or component) of the system can be regarded as a system developed to achieve an outcome that advances the goal of the whole enterprise system. Traditional Systems Engineering brings together the diverse disciplines of experts to address a wide range of problems inherent in the development of a large, enterprise "single" system (Sage 1999).

However, today's systems are not made of a single system but consist of system-of-systems (SOS) or made up of several components assembled together to form the enterprise system of systems and produce outcome the individual systems cannot achieve by themselves. As a result, the traditional Risk Management (D'Arcy, 2001) and System Engineering (Keating, Sousa-Poza, and Mun, 2004) approaches are insufficient for measuring and managing the risk of interdependencies in today's system of systems or enterprise systems. According to Maier (1998), traditional enterprise system may be regarded as system which possesses operational independence of the components and managerial independence of the component. Sage (2001b) has defined system of systems as a Federation of Systems (FOS) when there is a very limited amount of centralized control and authority (Sage, 2001b). Each system in the FOS is very strongly in control of its own destiny but these systems are assembled to participate in the Federation of Systems (FOS) as a result of their contribution to the whole enterprise system for their own good and the good of the enterprise system. A federation of systems (FOS) is generally characterized by significant autonomy, heterogeneity, and geographic distribution or dispersion (Krygiel, 1999). Traditional system engineering (TSE) approaches (Keating, 2008) have proven effective in addressing enterprise systems problems where technical requirement dominates the solution space when boundaries conditions are clearly defined. However, in the 21st century there is growing interest in a class of enterprise meta-systems, such as SOS and FOS, and have become the focus of various applications and a new class of enterprise systems problems has begun to emerge through the requirements generated by stakeholders (Sage, 2001b; Keating, 2008; Garvey & Pinto, 2009).

Chemical companies such as BASF, Procter and Gamble, Exxon, and Mobile Chemical and petrochemicals are examples of enterprise systems. Enterprise systems such as a chemical plant is an enterprise systems, petroleum-refining systems, as well as enterprise manufacturing plant is also an example of an enterprise systems such as General Foods Corporation are made up of several webs of suppliers and users of systems, technologies, and system of systems through environments that offer cross-boundary access to a wide variety of resources, information technologies, and other information systems to deliver capabilities as required by stakeholders, and are considered to be enterprise systems. A chemical-manufacturing enterprise or petroleum-refining enterprise, as well as highly involved manufacturing- enterprise systems, are staffed by highly trained specialized personnel who function in a curious atmosphere of well-coordinated corporation and unspoken competitiveness (Valle-Riestra, 1983). Such enterprise systems as the petrochemical and the chemical industries consist of enterprise components of physical systems with the seamless integration of technologies and all sorts of information flowing throughout the enterprise system (Soja, 2008).

These are used for producing consumer goods such as processed food, cosmetics, and medical supplies, and are staffed by highly trained, specialized personnel whose work functions are inter-related in a well-coordinated manner but also exhibit internal competitiveness (Valle-Riestra, 1983). According to Valle-Riestra (1983), the basic processes of analyzing and synthesizing problems are intellectually rewarding, but these processes are necessarily scattered over large geographical locations and may provide lengthy periods of data gathering, repetitive computations, and a myriad of other routine works, such as troubleshooting of systems to identify risky situations that when mitigated will provide the goals and outcomes that they are assembled to deliver. There are major problems involved in such enterprise systems that require highly trained professionals to run the enterprise systems that will produce the goals and outcomes they are designed to produce.

2.1.2 ENTERPRISE SYSTEMS AND THE TRADITIONAL SYSTEM

In the traditional system-engineering perspective, systems are designed based upon well-defined boundary conditions, customer requirements, as well as shareholders equity. Such topics as contextual, human, organizational, policy and political components were placed in the background as if the technical perspective was all that was important. There are six primary boundary conditions suggested by Keating et al (2001) for system-of-system engineering methodology that may be preferable to traditional System Engineering approaches. They are:

1. Turbulent environmental conditions - the environment for systems-engineering effort is highly dynamic, uncertain, and rapidly changing.
2. Ill-defined problem conditions - the circumstances and conditions surrounding the problem are in dispute, not readily accessible, or lack enough consensus for initial problem definition.
3. Contextual dominance - the technical aspects are overshadowed by the context within which the problem system is embedded. Success will be as much determined by adequately addressing the contextual-problem drivers as the technical-problem drivers.
4. Uncertain approach - the path of progression on how "best" to proceed with systems-engineering effort is indeterminate. Standard processes for systems engineering are either failing or highly suspect for adequately addressing the situation.
5. Ambiguous expectations and objectives - the ability to establish measures of success or system objectives for the systems-engineering effort are vague. This may be a result of inadequate understanding, hidden motives, or lack of technical competence to proceed with a systems-engineering effort.

6. Excessive complexity - the boundaries of the system are such that its complexity is beyond the capabilities of Traditional System Engineering. To proceed requires significant simplification of objectives.

It can be said that, in general, the emerging system-of-systems problems are recognized to stretch the boundaries of the traditional system engineering as indicated by Keating (Keating et al. 2003). Despite the success of the many projects in the chemical and petrochemical industries, most large engineering projects, which generally continue to follow the traditional system engineering approach, may be much less satisfactory, as suggested by Keating (2003). The reason is that there are several assumptions made to simplify the design of the system using the traditional system engineering approach. An example of these assumptions may be that new technology to be used is based upon a clear understanding of the basic principles or equations that govern the system. Another may be that the goal of the project and its specific objectives and specifications are clearly understood to use the traditional engineering approach. In the case of several chemical engineering plants, a design will be implemented and consequently the project or mission will be accomplished, based upon the specifications from the key customers' objectives and shareholders' desires.

Furthermore, according to Keating et al. (2003), although technical aspects are important, in the case of system of systems just as important as the technological context are the contextual issues such as human, organizational, policy, and political system dimensions that will ultimately change the decision space and feasible solutions for technical system problems as stated by Keating et al. (2003). Although the overall goal of the system of systems project might be clear in succinct form, the specific objectives are most likely ill-defined, unclear, and unambiguous according to Keating et al. (2003). Because of the long-term maintenance of systems of systems and pressures addressed to their evolution, one cannot consider their development to be complete, such that a solution obtained today is partial to the overall intended goal. Thus, a design will be implemented based upon the assumption of the specifications, and consequently the project or mission, which will also be accomplished, will be partially correct or incorrect.

In summary, system-of-systems engineering stretches the boundaries of traditional systems engineering in three important areas: first, traditional system-engineering has not been developed to address the high levels of ambiguity and uncertainty encountered in system-of-systems engineering. Traditional system-engineering has difficulties in adequately responding to ill-structured problems with constantly shifting requirements. This is a problem in system-of-system environments and therefore it is natural to think that problem definitions and requirements will be isolated from shifts and pressures stemming from highly dynamic and turbulent development and operational environments, according to Keating et al. (2003).

Secondly, although traditional system engineering does not ignore contextual influences (human, organizational, policy, and political system dimensions) on system problem formulation, analysis, and resolution, it certainly places the context in the background. In contrast, the problems of system of systems are evolving in ways that suggest contextual aspects must be moved to the foreground as indicated by Keating et al. (2003). System-of-systems engineers have recognized that system-of-systems problems cannot be artificially separated from their context, the circumstances and conditions within which they are embedded because the context can both constrain and overshadow technical analysis in determining system solution success, according to Keating et al (2003).

Third, traditional system engineering has been successful at deploying optimal system solutions especially through iterative development processes. However, pressures on system-of-systems design and deployment dictate that partial systems solutions must be deployed and iterated after deployment. This is contrary to the linear nature of traditional system engineering approach that aims to complete design followed by complete implementation, according to Keating et al. (2003).

Enterprise systems are like system of systems as both exhibit emergence behaviors with no specific boundaries. enterprise systems (ES) involve and evolve a web of users, technologies, systems, and system of systems through environments that offer cross-boundary access to a wide variety of resources, systems, communication, and information technologies (Garvey & Pinto, 2009).

2.1.3 ENTERPRISE SYSTEMS

Engineering systems of today have grown in complexity, made up of a network of systems that create meta-systems – systems of systems (SoS) "made up of multiple embedded and interrelated autonomous enterprise subsystems" (Keating, 2004). A system of systems is also defined to be a collection of systems that function to achieve a purpose not achievable by the individual systems acting independently of each other (White, 2006). Each system can, though, operate differently of each other to achieve some sort of goal and outcome that forms part of the overall goal and outcome.

Definition 2.1: An enterprise system is a complex system consisting of several systems put together to achieve the final goals and outputs. An example is a chemical plant.

With this definition, the term enterprise system is more appropriate than the term system because enterprise system is a complex system consisting of several systems. Enterprise systems are generally collections of elements or entities that may interact in a way that exhibit behaviors the elements or entities that constitute the systems cannot exhibit behavior by themselves. An enterprise system can also be said to be an organized collection of interdependent subsystems whose activities must be coordinated in order to achieve common enterprise goals and outcomes. Each enterprise is independent or maintains its self-rule and utilizes goals and outcome to produce different outcomes.

Enterprise systems, as described by Keating (2004) and Garvey and Pinto (2009), are made up of a large number of participating elements or entities and influencing factors. Such multiplicity of elements or entities in enterprise systems are commonly found in the chemical-process and other technologically-involved industries. Enterprise systems can grow to form a cluster of industries to serve as a country's main economic output and produce several interrelated enterprise systems such as the computer outsource in Mumbai, India, or the wine industry in France. A cluster of industries consists of enterprise systems of systems not characterized by firm and fixed specifications under the control of a centralized management or engineering organizational control, but which are interdependent through goals and outcomes they supply or receive through their network systems. Examples of enterprise systems are Dow Chemical Company, Procter and Gamble, BASF, DuPont, and Exxon Petrochemicals, or the Ghana Salt Industry.

Enterprise systems can also be described as consisting of enterprise physicals system of systems (SOS) or federation of systems (FOS) with the seamless integration of information technology, flowing through them (Soja, 2008). This information may be financial and accounting, human resources, supply chain or customer information (Davenport, 1998).

A model of a well-built enterprise system provides for integration of all inter-related systems into one core business processes' descriptions necessary to bring about the important change processes through emergence (Bernus, Nemes, & Williams, 1996).

2.1.4 RISK IN ENTERPRISE SYSTEMS

We can examine risks by observing their drivers and consequences. There are inherent risks associated with components and systems of enterprise systems, based upon their relationships with other components or systems in enterprise systems, resulting from their interdependencies. There is an increasing recognition that many risks in enterprise systems are in fact interrelated. The new approach in enterprise risk management framework is to acknowledge that the risks in enterprise organizations largely interact (Rinaldiet al. 2001). In this enterprise risk management framework, risk of interdependency must be managed together within the context of the overall enterprise mission and goal (Garbowskiet al. 2000). Thus, quantifying the enterprise system risk management framework and their extensive interrelationships between individual risk elements is a significantly important challenge.

A business enterprise system comprises several anticipated webs of users, systems, and services of technologically interdependent network systems. An analysis and assessment of business enterprise shows interactive behavior at the enterprise scale level, with a seamless integration at all levels, with information flowing through the enterprise system. Such information consists of the financial and accounting information, human resources information, supply chain information, and customer information (Valle-Riestra, 1983; Garvey & Pinto, 2009). There are inherent risks associated with each node in enterprise systems which, if not managed, will impact the performance of the supplier-receiver relationship.

Enterprise systems are classes of systems referred to as systems of systems (SOS) or federations of systems (FOS). These systems have been receiving increased attention (Sage, 2001b) in today's enterprise systems integration. They are efficient in producing a high volume of quality product at a reasonably lower cost in a short time.

However, these enterprise systems are made up of many elements or components that form the enterprise systems as found in the chemical process industries. They have variations in elements and exhibit dynamism. Some components within systems may also interact with other components and as such risks of interdependencies are found within the enterprise systems' network of systems, which must be managed for the enterprise systems to achieve goals and outcomes. Risks of interdependencies in systems involve such things as changes in processes, technologies, people, organization and, culture (Britt, 2000).

2.1.5 RISKS OF INTERDEPENDENCIES IN ENTERPRISE SYSTEMS

In the early years, most products made for the human Consumer and used by society evolved from a centrally controlled instrumentation with only a handful of regulators and were usually produced by a singular enterprise. Today, due to population growth, demand for quality consumer products and ease of usage of goals and outcomes, several systems are put together to function as enterprise system for mass production, improved product quality, and lower cost of product through efficient use of resources. This requires the use of the advanced application of technology and information systems. Therefore, new control strategies are being proposed to maintain the desired degree of system availability and efficiency. These control strategies are often based on centralized process control for individual systems or distributed control systems, rendering new or amplifying old dependencies. The possible impacts of these interdependencies on dependability of one system on another system are now being thoroughly investigated (Chandorkar et al., 1993).

In today's enterprise systems, business and technology driven by productivity, efficiency, and mass production have created a plethora of overlapping and confusing solutions, products, and standards that increase the complexity and risks. These interactions often create enterprise relationships, dependencies, and interdependencies that cross enterprise systems' boundaries. As a result, these enterprise systems or system of systems (SOS) are built to have some degree of dependencies, resulting in tighter coupling and common-mode connections. Interdependency is a condition when several programmed systems, nodes, or entities are said to depend upon other enterprise systems represented as a node which supplies capability to another enterprise system, nodes, or entities to achieve the level of performance needed by that system to reach its operating level.

The modeling and analysis of interdependencies between enterprise systems' elements is a relatively new and very important field of study (Rinaldiet al. 2001). When two systems have dynamical behavior and are observed to be coupled together, then they are interdependent with each other. The traditional test for interdependency is to determine the degree of correlation of variables between the two systems. In systems with many components, cross-correlation in the time domain and cross-spectrum or coherence in in the frequency domain has been used to detect correlation in systems (Chatfield, 1989). Cross-correlation measures the linear relationship between two variables. The measurement of cross-correlation between two variables in the time domain determines whether there is a functional relationship between the two variables.

In such enterprise systems, there exist multidirectional dependencies at many levels in the system's capability portfolio whose program nodes may depend upon supplier nodes to achieve their required level of performance (Garvey and Pinto, 2009).

2.1.6 MEASURING RISKS OF INTERDEPENDENCIES IN ENTERPRISE SYSTEMS

Enterprise systems of systems have complexity drivers defined by Balázs and Monostori (2008) to have (a) limited information (uncertainty) about the behavior of the system, (b) have sudden or constant changes (dynamics), (c) are made up of a large number of participating elements and influencing factors (multiplicity), (d) have many types of elements (variety), (e) have interactions due to coupling in the systems, and (f) have interdependencies (i.e. feedback loops) within the network systems. In natural-science problems (e.g. chemistry), graph theory is used to measure and define the complexity of structures within systems. These measures are symmetry-based, which often apply the concept of entropy, the average- or normalized-edge complexity, sub-graph count, overall connectivity, and total walk count. The new approach to this is the theory of

Enterprise Adaptive Systems (Balázs & Monostori 2008). These may be good to measure links or complexity of structures between networks, which may help identify risk of interdependencies in network systems but cannot measure risks of interdependencies.

Also, the recent frameworks for measuring risk of interdependencies in enterprise systems (e.g. FDNA, and Leontief I/O model) are not fully developed as to (1) how to characterize types of interdependencies, (2) how to quantify interdependency features such as criticality relationship, and (3) how to research the analytical scalability of foundational FDNA (Garvey & Pinto, 2009) to a nation state-level enterprise. This shows that more research studies are needed to develop the framework for measuring the risk of interdependencies in enterprise systems.

Identifying risks of interdependencies in enterprise network systems is a difficult task but finding ways to study and measure the risks of interdependencies are a great help to the process industries. In an enterprise system, interdependency is the degree to which changes in the operability of the supplier component or system affects the operability of the receiver component or system in an enterprise system (Albinoet al. 2002; Van de Venet al. 1976; Garvey & Pinto, 2009).

The negative impact that occurs in a component, if not checked, could propagate into other enterprise systems that depend upon such enterprise systems to accomplish their goals and outcomes (Wiggers et al., 2006). By this reasoning, organizational units that are responsible for the goals and outcomes must view interdependency as occurring between components and systems of enterprise systems and with other enterprise systems (Rinaldi et all, 2001). It is important to view interdependency as arising between components and systems that achieve goals and outcomes and not organizational units. This is because the tasks are systems related and can be decoupled from the organizational unit responsible for its completion and assigned to another organizational unit. For example, a task requires a certain set of capabilities in order to execute (Wiggers et al. 2006). Any organizational unit that possesses those capabilities may execute the task. Consequently, management has the flexibility to reassign roles and responsibilities if it adheres to the task capability constraints (Wiggers et al., 2006). Any reassignment would change interdependency between organizational units; however, the interdependency between tasks would remain unaltered. So, any model must represent both process constructs and organizational constructs.

This paper focuses on dealing with the risk reduction issues of process construct of enterprise systems. The theoretical models of the various process units are derived by using the fundamental principles of conservation of mass, energy, and momentum for the enterprise system. The conservation principle states that input minus output equals accumulation (Input - Output = Accumulation) (Douglas, 1972). For process systems in steady conditions, the accumulation terms are always equal to zero, so that total input of any conserved quantity to a unit must be equal to the total output. In this paper, the unsteady state theoretical models are considered since it introduces additional complexity yet provides important information about the task performance. Theoretical stationary model was developed and studied by Garvey (2009). To find the best model for this dissertation, the System dynamic Model, Leontief, and FDNA models were reviewed.

2.1.7 ALTERNATIVE MODEL DEVELOPMENT

In the design of systems, or systems of systems, the problems, associated analyses, and, the models described are dependent on a context being addressed. The context as stated by Friedly (1972) in which particular problems are found can vary by (a) purpose (e.g., detection, ranking, and prevention, etc.), (b) scale (e.g., national, regional, local, site, control system, or component), (c) audience (e.g., public, private, industry, academic), and (d) kind (e.g., random process, intelligent game, etc.). Simply stated, a change of context demands a different abstraction of the problem. A problem identified and applicable on a local site requires different thinking and solutions than those dealing with national level issues (Perrone et al., 2006).

Enterprise systems are evolving around public service and many other endeavors which are designed to improve knowledge, health, and the living conditions of people in a society or community (Dudenhoefferet al. 2006). Enterprise systems consist of series of activities or tasks that: (1) have a specific objective (scope) to be completed within certain specifications (requirements); (2) have defined start and end dates; (3) have funding limits; and (4) consume and/or utilize resources (Project Management Institute, 2000).

Enterprise systems modeling has proven challenging to enterprise systems design and management of organizations. This is largely because project conditions and performance evolve over time as a result of feedback responses, many involving nonlinear relationships, and due to accumulations of project progress and resources. This has made the application of system dynamics and other models such as FDNA to project management a fertile and productive field of study.

The research study looks for a model that can meet the requirement of providing a breakthrough project concept in risk management in both developed and developing countries. It is necessary to evaluate its progress and suggest directions for future development. Alternative models such as system dynamics, the Leontief Input-Output Model and the Functional Dependency Network System are considered in this study. While each one of these models can be used for several applications, none can be effectively applied to all systems at every stage.

2.1.8 SYSTEM DYNAMICS MODEL

System dynamics is a set of techniques for thinking and computer modeling that helps practitioners understand enterprise systems of systems such as the petroleum refining enterprise, the national transportation network, or the Earth's climate. Systems tools and network help us keep track of multiple interconnections; they help us see things wholly (Meadows, 1991). System dynamics was first conceived at the Massachusetts Institute of Technology in 1960 by Jay Forrester (Sterman, 2000) and is widely used in the private sector in many areas of the national economy, such as the petrochemicals and the oil industries. System dynamics uses software to model engineering systems, then populates the map with data and develops a method for testing solutions to design problems (Sterman, 2000). The resultant processes are simulated using assumptions, policies, and scenarios, formed by learning the patterns of the behavior in organizations.

System dynamics is the origin of whole systems thinking and it provides a wide range of skills and abilities to understand enterprise adaptive organizations. Richmond (1998) called it a set of system thinking skills and modeling tools. System dynamics has been used for learning patterns of behaviors in organizations and grounding these in the structure of organizations' operational policies and processes. Systems thinking begin with conceptualizing how organizations behave over time and how different observers will like them to behave (Richmond, 1998). After conceptualizing, the plausible explanation for the behavior of the organization over time in terms of past actions is determined. System thinking also provides a means of analyzing contributions which different operational factors make to overall behavior. Furthermore, it covers the system's closed-loop cycle and analyzes its feedback-loops, including the way results can influence causes within the enterprise system and its components.

After developing the process flow diagram (PFD), the mathematical relationships needed to model causes and effects are determined, then the models are used to construct and test hypotheses (Turton et al., 1998). In system dynamics, description of the process steps leads to the equations of a model, simulation to understand dynamic behavior, evaluation of alternative policies, education, choice of a better policy, and implementation (Forrester, 1961). Jay Forrester developed the six steps for solving problem symptoms to improvement systems, whose projects have fallen short of their potential, because of failure to gain an understanding and support necessary for implementation. The first step is to understand that there is an undesirable system behavior, which must be understood for improvement and successful implementation. The relevant system must be described and a hypothesis (theory) generated for how the system is creating the unwanted behavior or condition. The second step is to formulate the simulation model that describes the system and translate it into the level and rate equations of a system dynamics model. Creating the equations reveals gaps and inconsistencies that must be overcome. 1. After developing equations for the system dynamic model, the third step (step 3) is to develop the system dynamic software to simulate the model, always ensuring that the conditions in steps I and 2 are met. After achieving a degree of confidence in a model that is a compromise between adequacy and the time and cost of further improvement, the implementation is moved to step 4 (Forrester, 1961). The fourth step is to generate alternative policies to identify the best policy for testing. The best alternative policy may come as a result of ideas learned in several ways; (1) the first three steps, (2) as a proposal from experience gained by people from the operating system, (3) from experience system analysts, and (4) information obtained about changes in systems parameters from automatic testing. Step 5 deals with the final checkup before system implementation and involves consensus building for implementation. Experts are brought in to study the model, evaluate the method used to generate equations, and test and draw conclusions to ensure a successful implementation of the system dynamic model. Step 6 deals with implementation of the system dynamic model with all recommended improved policies. Implementation includes installation, commissioning, startup and actual running of the system. Implementation becomes critical as more ideas will be generated by people who were involved from step 1 to step 5, and others brought in to critique and recommend additional improvements. System dynamics can be used to integrate policies across organizations where behavioral feedback is important, and to analyze variation. System dynamics view algorithms developed to test process flow diagrams (PFD's) in terms of stocks and flows.

System dynamics is about learning the basis of operational processes and policies to see the patterns of behavior in organizations and grounding these in the structure of organizations (Wolstenholme, 2003). System dynamics uses software to map processes and policies at a strategic level, populate the map with data, and simulate the evolution of the processes under transparent assumptions, policies, and scenarios (Sterman, 2000). Its overall concept deals with how the whole system is put together, beginning with the initial concept development.

System dynamics is the basis for the current trend of 'whole systems thinking' in enterprise systems. It provides a set of thinking skills and a set of modeling tools, conceptualizing how organizations behave over time and how we would like them to behave (Richmond, 1998). It also enables determination of plausible explanations for the behavior of the organization over time in terms of past actions. Using system dynamic for modeling and simulation allows conceptualizing by seeing the big picture and transcending organizational boundaries (Wolstenholme, 2003). Furthermore, it allows for the use of models to construct and test hypotheses, determining the mathematical relationships needed to model cause and effect, analyze 'feedback' loops, including the way that results can influence causes, and analyze the contributions which different operational factors make to overall behavior (Hanley, 1990).

System dynamics has long been associated with modern control theory, a new approach for controlling chemical and petroleum units (Douglas, 1972). Many of these concepts are now being applied to industrial systems in a form of computer-aided approach to evaluating the interrelationships of different components and activities within enterprise systems. Many different types of models have been developed to improve project management. These models include some of the system features and characteristics addressed by system dynamics. For example, basic project models such as the critical path method explicitly model causally linked development activities and phases and cost control models used to forecast performance gaps to allocate funds, e.g. budget deficits (Douglas, 1972). More advanced models such as the computational models developed by Levitt et al. (1999) are like system dynamics, as they include linked development activities as well as feedback. System dynamics is a method to enhance learning in enterprise systems. It helps in developing a model of an enterprise system that can be used to collect data to develop the final model of the enterprise system. This is attained by using computer simulation models to help describe the dynamic complexity. The dynamic complexity has evolved as a result of accelerated changes in technology, world population growth, and the enterprise evolution of economic activities. System thinking is the ability to see the world as enterprise system in a holistic worldview whereby everything is connected to everything else and exhibits interactions between components. System dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering.

System dynamic processes identify problems, puzzles, and evaluate questions, or issues. It then develops hypotheses to explain the causes of the problems by building models of the systems at the root of the problems. System dynamic processes ensure that models of the systems reflect the behavior seen in the real world or explore similar models that have already been tested. This is done through modeling and simulation to learn what insights they produce about the issue, problem, evaluation question, or puzzle. Through such learning, conclusions can be drawn about these insights.

On the other hand, system dynamics can organize the descriptive information, retain the richness of the real processes, build on the experiential knowledge of managers, and reveal the dynamic behaviors that follow from different policy choices. System dynamics is touted to become the frontier of new developments in management education over the next several years. System dynamics is used to construct the mathematical model of the salt enterprise system in order to predict its operation (Roberts et al., 1994; Fuchs, 2002a).

However, the study of system dynamics is not easily understood as a result of its mathematical derivation. On the other hand, old mental models and decision habits are deeply ingrained; they do not change just because of a logical argument. Early system dynamics analyses were in the "consultant" mode: the practitioner would study a corporation, go away and build a model, and come back with recommendations (Roberts et al., 1994). In most cases, these suggestions would be accepted as sound, but they would not alter behavior. Under the pressure of day-to-day operations, decisions would revert to prior practice.

Recent trends in system dynamics aim to change the mental models that people use to represent the real world (Roberts et al., 1994). For this to happen, individuals must be sufficiently involved in the modeling process to internalize lessons about dynamic feedback behavior. This exposure to dynamic thinking should start at an early age before contrary patterns of thought have been irrevocably established. Apparently, students as young as ten-years-old can benefit from exposure to the cause and effect thinking and computer modeling. This can be done in the developed countries but is almost impossible for the developing countries where children do not have access to computers.

In management education we should look forward to a breakthrough in scope and effectiveness when we move beyond the case study method and fully adopt system dynamics. This is not happening in the developing countries where computer use is severely limited. The use of computers is now only beginning to make a foothold in the developing world and the application of such programs are a few years away. Also, for other enterprise systems such as the salt industry, feed-forward control systems are preferred over feedback control systems. This is because the initial feed material changes and the final product must always meet specifications. These principles and techniques are applied to develop the model for the salt enterprise systems. In order to predict the dynamic operation of the enterprise system to produce value-added outputs, the accumulation terms in the mass, energy, and momentum balances must be added to the theoretical model. However, for this study it is assumed that the systems are running at steady state condition. Enterprise systems such as large enterprise petroleum refining or enterprise chemical plant operations are made up of sets of steady state equations, derived from unsteady state equations, to describe the energy and mass transfer operation of each processing system. They may contain more than one assumption used to enable experts to produce a complete design of the system components of the enterprise system (Torton et al 1998). Equipment designed to transform raw materials into useful products using enterprise systems of systems are described by sets of nonlinear ordinary or partial differential equations which cannot be solved to give explicit relationship between input and output variables (Douglas, 1972). In many of the cases, the appropriate equations for the industrial processes are not available in analytical forms but are available through empirical correlations. These empirical correlations are expressed in continuous mathematical functions, which then can be used as system's equations for optimization procedure in pilot plant studies (Douglas, 1972). But such pilot plants data seldom give exact predictions of actual plant operation.

It is also known that specification of system parameters and some process inputs are not exact values, but are produced by approximations, and therefore can initiate some problems. Mass and heat transfer coefficients, physical properties, reaction rate constants, and other defined constants are highly suspect in terms of degree of accuracy (Douglas, 1972). As a result of these uncertain conditions, there will always be some degree of uncertainty associated with the final design, which can be a very risky operation in the long run. Also, some of the main active components and impurities in the input stream may vary, so that systems reliability can be questionable over time. Other problems include cooling water temperature variation, changes in atmospheric condition throughout the day, available steam pressure changes as demand changes, and variation in raw material and products varying with market conditions.

As a result of these problems, a system thought to be of a good design would be incapable of producing quality outcomes. A new approach in identifying interdependency risk in enterprise systems must be found to analyze and mitigate risk problems that arise during system operation. Functional Dependency Network Analysis provides a method to study such problems and develop ways to solve them.

2.1.9 LEONTIEF INPUT-OUTPUT MODEL

Leontief (1941) in “The Structure of American Economy” presented a scheme of general interdependency by describing three sets of equations under the assumption of stationary equilibrium of industrial production function (Lin, 1998). An economy in which the input requirements for production are directly proportional to the levels of production can be described by a set of linear equations. The linear equations can be expressed in terms of matrices (Oxford University Press, 1986).

Manufacturing processes in various industries, especially the chemical, automotive, electronic, and pulp and paper industries, produce adverse environmental impacts and have high energy Consumer. Efforts centered on the processes themselves have been demonstrated to be an extremely effective means for achieving the goal of reducing the adverse environmental impacts (National Academy Press, 1999). Manufacturing process innovations help to achieve improved environmental performance through a reduction in the costs associated with controlling and containing environmental impacts and thus making them more competitive. Enterprise systems will be competitive and will directly benefit from innovations to produce lower costs, higher productivity, and better-quality products. Of course, the ultimate classes of innovations are those that produce zero emissions with higher productivity.

One way of characterizing a manufacturing process is by materials flow analysis. Such an analysis can convert inputs into outputs which consist of intermediate products or final products using mechanisms, such as mechanical and chemical processing methods. For manufacturing processes, the principal environmental impacts are associated with the process methods and outputs which may take the form of solid, liquid, and gaseous emissions. Materials flow analysis identifies the amounts of inputs and outputs, associated with manufacturing systems and then relates the inputs and outputs to provide a mathematical model that can be used to explore opportunities for reduced risk impact in manufacturing systems. To establish an input-output relation, it is preferable to formulate a mathematical description based on physical, chemical, and other natural laws (Munoz & Sheng 1995).

Unfortunately, in many cases there is insufficient knowledge or process information to develop a mechanistic model of some manufacturing systems (Munoz & Sheng 1995). However, in practice, such a mechanistic understanding of the system may not be needed; this is especially true during the beginning stages of system improvement, when a simple, tractable model may be enough to identify opportunities for reduced risk impact (Choi & Kaebernick, 1997). A matrix-based input-output model represents such a model and is the focus of the effort described in this paper (Bauer et al., 1998)

Input-output analysis has traditionally been used to analyze economic activities (Oxford University Press, 1986), and it has been extended to address problems in environmental as well as manufacturing systems at the national, industry, and product levels (Breuil, 1992; Hawdon & Pearson, 1995). These analyses have provided insight into the workings of manufacturing systems policies and the manifestation of pollution at various levels (Lave et al. 1995; Miller & Blair, 1985).

In this paper, we can develop mathematical input-output at the spatial scales for such entities as manufacturing systems, manufacturing plants, and companies. For environmental input-output models developed at large spatial scales, e.g., at national or industry-wide levels, these models are highly aggregated and lack spatial resolution. They cannot be decomposed or disaggregated to acquire information about the manufacturing systems, manufacturing plants, or companies (Lave et al., 1995). Thus, according to Lave et al. (1995) there is a gap between national and process-level environmental input-output models. To bridge this gap, one needs to think in terms of aggregating process-level models to obtain a larger scale system-level material input-output model (Olsen, 1999). Common aggregation within input-output approaches is achieved by consolidating similar economic groups into a sector (Hatanaka, 1952; Caber et al. 1991). Such an aggregation requires a homogeneous input structure. Several efforts have been made to measure the effects of aggregation of sectors in input-output models (Morimoto, 1970; Theil, 1957).

The Leontief input-output model is assumed to be fundamentally a linear equation and lends itself well to rapid computation as well as flexibility to compute the effects of changes in demand. Leontief model can be applied to systems to study the effect of perturbations within well-established economic models such as the Bureau of Economic Analysis, because the data they provide is always accurate (Haimes & Santos, 2005).

Haimes and Santos (2005) studied the degree of interdependency of sectors of the U.S. economy to assess why the U.S. economy is more vulnerable to human and natural disasters. They analyzed the way inoperability caused by terrorism induced perturbations which propagated through interconnectedness of components within certain systems. Owusu et al. (2010) used input-output methodology and risk vulnerability coefficient factors to study the impact of risk transfer and their ripple effect in critical infrastructure. They looked at the recent global economic crisis and its impact on related infrastructure due to their interdependencies, and how risks propagate within various related network systems. While Nwagwo et al. (2009) used the Leontief input-output model to study how to choose the appropriate technologies that can be used to produce the amount of pollution allowed for the sector's external demand. In the salt enterprise system, instead of perturbations created by natural calamities, terrorism, or pollution allowed by a particular technology (Haimes & Santos, 2005; Nwagwo et al. 2009), the concern is the use of materials from a wide open source such as sea water to produce a very important material.

The input-output analysis cannot be used for solving problems in systems with dynamic simultaneous equations. However, it is useful in systems with matrix algebra and quantitative problems of input-output relationships. Also, the Leontief input-output model as stated, deals with input and output production function without looking into the internal production functions such as recycles.

Leontief input-output models deal with interdependency of the various industries which emphasize the exact output levels obtained from those industries which satisfy technical input-output relationships rather than market equilibrium conditions. It also assumes that each company produces a single homogeneous product. Also, Leontief input output models do not emphasize how and what technology is used to make products, nor do they address conditions to enhance technological innovations. This study is about the risk of interdependencies between components and systems of systems. Therefore, the Leontief model is inappropriate in describing risk of interdependencies described in this study.

2.1.10 FUNCTIONAL DEPENDENCY NETWORK ANALYSIS (FDNA)

In engineering enterprise systems, functional dependency network analysis (FDNA) helps in identifying, representing, and measuring risk of interdependencies between suppliers of technologies and providers of services to consumers and users (Albino et al. 2002; Van de Ven et al. 1976; Garvey & Pinto, 2009). There are inherent risks in technology whose failure may impact other enterprise systems that receive goals and outcomes as input. Risks of interdependencies as described in this study occur in systems as a result of assumptions made in the original design model, which may or may not be exact, but approximation of actual events. Also, risks of interdependencies occur in systems equipment fatigue due to age after repeated use, the effect of foreign materials that can get into instruments, and equipment supply lines that may slow down supply of information or can cause major problems to system performance.

FDNA is a unique way of engineering an enterprise system by creating capability portfolios of technology programs and initiatives that advance enterprise goals and mission outcomes in an orderly fashion. Creating a capability portfolio is enterprise engineering and management endeavor that requires expert knowledge and management to ensure its collection of technology programs and initiatives meets the required capabilities of the enterprise system.

Interdependency relationships in this paper are referred to as dependent relationships or influences between enterprise systems. FDNA has greater strength in describing the risks of interdependencies by:

1. Representing dependencies among “business” enterprise systems
2. Representing the programs and capabilities within each “business” enterprise as nodes.
3. Representing dependency programs and capabilities across “business” systems with directional arrows.
4. Establishing characteristic variables of dependencies: BOL’s, MEOL’s and the strength and criticality of dependency parameter.

However, FDNA has been developed not based on the fundamental basis of systems theory of conservation of mass, energy, and momentum. This research study will attempt to make such connection. FDNA was developed to measure risk of dependencies in an enterprise system but has not been extended to study risks of interdependencies between enterprise systems. This research focuses on studying risks of interdependencies between enterprise systems.

The way to fully analyze enterprise systems of systems in enterprise systems from the whole system perspective is to create capability portfolios of enterprise systems that when assembled together will deliver the goals and outcomes of the enterprise system (Garvey & Pinto, 2009). Functional Dependency Network Analysis (FDNA) main goal is to develop a mathematical model that provides a way to measure and trace the effects of the risks of interdependencies between the elements of capability portfolios as they affect many parts and paths in the network (Garvey & Pinto, 2009).

Functional Dependency Networks Analysis (FDNA) was developed based on network theory and network models, it is also used in identifying the presence of interdependency relationship among nodes in enterprise systems and describing the interdependencies in terms of strength and criticality (Garvey & Pinto, 2009). The FDNA approach enables users to represent ripple effects of failure in enterprise systems which when solved will allow systems to achieve the goals and outcomes they are set up to deliver.

2.1.11 CHOOSING THE FDNA METHODOLOGY

Many different types of models have been developed to improve project management. These models include some of the system features and characteristics addressed by system dynamics. For example, basic project models such as the critical path method explicitly model causally linked development activities and phases and cost control models used to forecast performance gaps to allocate funds, e.g. budget deficits (Douglas, 1972). More advanced models such as the computational models developed by Levitt et al. (1999) are like system dynamics, as they include linked development activities as well as feedback.

According to Lave et al. (1995), we can develop mathematical input-output at the spatial scales for such entities as manufacturing systems, manufacturing plants, and companies. For environmental input-output models developed at large spatial scales, e.g., at national or industry-wide levels, these models are highly aggregated and lack spatial resolution.

Therefore, they cannot be decomposed or disaggregated to acquire information about the manufacturing systems, manufacturing plants, or companies (Lave et al., 1995). Thus, according to Laveet al. (1995) there is a gap between national and process-level environmental input-output models. To bridge this gap, one needs to think in terms of aggregating process-level models to obtain a larger scale system-level material input-output model (Olsen, 1999). This research study did not choose to go that route.

FDNA was chosen over the alternatives models (example, Leontief I/O) because it provides systems approach to representing capabilities of various elements of systems as nodes in a network. Not necessarily parallel systems to be aggregates together. Aggregation is commonly done within input-output to achieve consolidating similar economic groups into a sector. Such an aggregation requires a homogeneous input structure of which several efforts have been made to measure the effects of aggregation of sectors in input-output models (Balderston, 1999; Caber et al. 1991; Morimoto, 1970)

The equation developed between enterprises E_i and E_j implies that product created in E_i is consumed by E_j or other enterprise systems along with the amount of production in an underlying cluster of enterprise systems to maintain a balance, not necessary parallel enterprise systems. FDNA highlights the technical dependencies among systems rather than economic dependencies like Leontief I/O. It can be used to model systems with limited amount of data and information or to design new systems. According to Xue et al. (2000), not all manufacturing process may be best modeled with an input-output format. Based on the analysis of process characteristics, an appropriate modeling strategy should be employed. It should also be pointed out that process changes may affect material yield, productivity, and product quality characteristics, such as the case in the Ghana Salt Enterprise Systems. As noted above, manufacturers must thoroughly investigate consequences and side-effects when input-output analysis identifies promising opportunities for emission reduction/elimination.

In using input-output model for the petroleum and chemical enterprise systems, we need to establish parallel operating processes, it might be desired to combine, or aggregate, these models to understand the collective behavior of the processes to minimize aggregation bias. The system boundary must also be selected carefully for the problem under investigation to avoid excessive aggregation that may obscure model structures that reveal insights into the underlying processes. This study is referred for further studies in future.

It can be used to study models of both linear and non-linear processing systems. It can be used to decompose or disaggregate complex systems to enhance learning in enterprise systems. It helps in developing a model of enterprise system that can be used to collect data to develop the final model of the enterprise system. In choosing a methodology for this research, we looked to the two major issues facing developing countries (Balderston,1999; Morimoto, 1970). In many cases there is insufficient knowledge or process information, and data to develop a mechanistic model of some manufacturing systems (Munoz & Sheng 1995) and the use of internal recycle to improve productivity. System dynamics and FDNA can be combined to give the methodology that can be applied in developing countries such as Ghana.

Functional dependency network analysis (FDNA) with its approach of representing portfolios as node with directed flow of information is a method used to identify whether the level of operability risk in a portfolio of engineering system is low enough to support its function to the enterprise system. These portfolios are a collection of technology programs and technology initiatives which are brought together to perform to satisfy system goal and objective. It is a tool that allows management to better utilize enterprise resources to manage programs that face high risk of failure and are also most critical to the operational capabilities of the portfolio.

2.1.12 THE TWO DIMENSIONS OF FDNA

In systems engineering, systems are designed to consist of a network of portfolios, which maintain relationship and operability levels with each other, in order to achieve the final goals and objectives of the enterprise system (Garvey & Pinto, 2009). In Functional Dependency Network Analysis (FDNA), portfolios are represented as nodes which are connected by a directional graph to depict which node of a portfolio depends on the other. To maintain the operational levels of these portfolios, each one maintains a level of operability. The two dimensions in Functional Dependency Network Analysis, the strength of dependency (SOD) and criticality of dependency (COD), are defined as the two factors that influence operability levels of these nodes. The strength of dependency (SOD) is defined as the fraction of dependency of the receiver node's operability level that it relies on from the feeder node's operability level. Strength of dependency (SOD) captures the effect of the relationship that improves the baseline operability levels. The operability level contribution from the feeder node that allows the receiver node to reach its final operability level is called its criticality of dependency. Criticality of dependency (COD), therefore, captures whether such relationship could cause their baseline to degrade. The key difficulty is how that functional dependency network analysis (FDNA) permits this loss-gain dualism approach to compete within its calculus (Garvey & Pinto, 2009). This permits negative-positive interaction to occur in the receiver-feeder nodes domain across the enterprise system.

2.1.13 INTERDEPENDENCY OF SALT NETWORK SYSTEMS

Salt enterprise system engineering design consists of a network of systems or portfolios which maintain relationship and operability levels within the network of systems, in order to achieve the final goals and objectives of the enterprise (Garvey & Pinto, 2009). An FDNA for a salt enterprise network consists of feeder-receiver relationships that are represented as nodes and are connected by directional graph to depict supplier-receiver relationships. To maintain the operational level relationship between the portfolios, each portfolio maintains a level of operability. The two dimensions in FDNA, the strength of dependency (SOD) and criticality of dependency (COD), can be defined as the two factors that influence the operability levels of these nodes. The strength of dependency (SOD) is defined as the factor that influences the receiver node's operability level and relies on the feeder node's operability level. Strength of dependency (SOD) captures the effect of the relationship that improves the baseline operability levels. The contribution to the operability level by the feeder node to the receiver node for the receiver node to reach its final operability level is called its criticality of dependency. Criticality of dependency (COD), therefore, captures whether such relationship could cause their baseline to degrade. The key difficulty is how Functional Dependency Network Analysis (FDNA) permits this loss-gain dualism approach to compete within its calculus. This permits negative-positive interaction to occur in the receive-feeder nodes' domain across the enterprise system.

The salt enterprise system will consist of petroleum production system, chlor-alkali system, salt refining system, medical manufacturing system, crude oil production system, and consumer application system. Dependency between systems (i.e. salt and chlor-alkali systems) can be defined as the reliance of the salt system on the chlor-alkali system to support a specific functionality. The chlor-alkali system E_j is said to depend on the salt system E_i to fulfill its goals and outcomes. That is E_j requires efficient operation of E_i for E_j to function correctly. The E_j will be affected, if a failure occurs to E_i such that E_i is unable to meet its goals and obligations as required byE_j. The magnitude of this effect is called strength of dependency (SOD). The impact of E_i's failure to E_j is called criticality of dependency (COD). However, in the chemical process industry, these nodes are affected by process conditions that may impact feeder nodes operability levels for both the feeder and receiver nodes. This means feeder or receiver may experience operability levels as a function of time. For example, a process flow from a tank into a heat exchanger with its temperature at T_0 and the condition of the heat exchanger is to bring the temperature of the process flow to a T_{final}. The baseline temperature will not change but the final process temperature will depend upon the process condition of the heat exchanger. Systems such as these will require dynamic modeling. More enterprise systems arise with distillation, separation, and chemical reaction systems.

2.1.14 TOOLS AND TECHNIQUES USED TO MODEL INTERDEPENDENCIES

1. Pearson, Spearman, and Kendall's tau are three common measures used to analyze statistical dependence. They are data analysis techniques designed to capture the direction and the magnitude of a correlation (Mansor, S, & Bratvold, 2007)
2. Statistical hypothesis testing approach, a method for evaluating multiple-device security systems with overlapping capabilities (i.e., dependency) (Kobza & Jacobson, 1996)
3. Inoperability input-output model (IIM) (Santos & Haimes, 2004)
4. Probability theory, a stochastic process in Markov property (Brams & Kilgour, 1995)
5. The basis of modern network theory (Barabasi, 1999)
6. Topological-complexity in graph theory (Brochev & Rouvray, 2006)
7. The fundamental theories in discrete mathematics (Barabbas, 2002)
8. Enterprise Adaptive Systems (CAS) (Holland, 1995)
9. Methodology for Probabilistic Risk Assessment of Nuclear Power Plants (Kaplan, Peria, & Bley, 1983)
10. The Dependency Structure Matrix (DSM), a transposed adjacency matrix that provides "a simple, compact, and visual representation" of system connectivity. DSMs are widely used by engineering researchers and practitioners to both analyze product architecture and project structure (Steward, 1981).

A DSM consists of identically labeled rows and columns and uses off-diagonal entries (tick-marks) to signify the dependency of one element on another. DSMs have been successfully used to model product, process, and organizational connectivity. When used to model the design process, the matrices capture dependency between different tasks and can be reordered to achieve minimum iteration. DSM product models show the connectivity between different components and organizational connections between teams and individuals.

2.2 APPLIED RATIONALE

2.2.1 PROBLEMS IN DEVELOPING COUNTRY

Enterprise systems or systems of systems enable the manufacture of needed consumer goods to be produced in large quantities with efficient use of raw materials available locally at a reasonable cost and time. This is attained by combining and utilizing different technologies to transform raw materials into outcomes that help boost economic growth. This is done in a safe and cost-effective manner, but enterprise systems require a great deal of expert knowledge. Enterprise systems enable mass production of value-added consumer goods to be produced for local Consumer and to export excess goods to neighboring countries in exchange for goods not available locally. The country then receives revenue credits for the goods exported to other countries. Developing countries must produce more food to feed the growing population, develop medicines to cure diseases, and find solutions to other numerous inefficiencies that tend to cause failure of enterprise systems and delay economic growth (World Bank, 2004). This goal is achieved by turning local raw materials into outputs needed for local Consumer. However, developing countries cannot achieve this without using enterprise systems of systems consisting of a wide variety of resources, information technologies, and other information systems to deliver capabilities as required by stakeholders.

The key is being able to supply locally produced consumer goods utilizing local raw materials, year after year, by developing enterprise systems locally. But enterprise systems that can achieve these goals are enterprise system of systems. These according to Keating et al. (2003) are meta-systems comprised of multiple, autonomously embedded enterprise systems that can be diverse in technology, context, operation, geography, and conceptual framework. This requires a skillful labor force to run the operation and a functioning research and development unit to continually find ways to improve the processes and make new products required by the economic forces within the local market system.

However, quantitative risk assessment and management processes hardly exist in developing countries, and according to Claudio (1998), this has been very costly. Because a country's annual expenditure for property insurance premiums is equivalent to a significant portion of the national government budget and is rising year after year. Claudio (1998) has also indicated that a large bulk of developing countries' annual expenditures for insurance premiums go to developed countries through reinsurance policies. Also, old and highly risky technologies that were used in the past in developed countries are still being used in agricultural and industrial activities in developing countries (Moss, 2007).

In developing countries, risk management in the public sector comes in the form of environmental protection and management, while in the private sector, risk management is narrowly focused on insurance (Claudio, 1988). Also, developing countries have long been using replicated methods obtained from the developed countries with no understanding of the context within which such practices become successful (Nightingale, 2009). The end results are silos of enterprise systems created in developing countries, whose successes are not repeatable. Therefore, applications of system engineering to enterprise systems are new to the developing countries. These countries need new approaches to solve problems facing their economic development.

Present technological innovations which have helped developed countries to improve products' characteristics in terms of quality, productivity, and efficiency of operation are being introduced to developing countries at a very slow rate. However, the lack of capital is making some developing countries accept technologies that are considered unacceptable in the developed countries, with little regard to the risks associated with these technologies on local, mostly poor, communities (Claudio, 1988). Serious and very expensive enterprise systems failures have occurred in developing countries and are some of the reasons why insurance premiums are high.

Systems engineering applications in developing countries are at their infancy and as a result they continue to struggle to grow their economies. Risk management concepts as applied to projects in developing countries, especially regarding quantitative risk management, is not well-developed (Claudio, 1988). Therefore, risk control measures are not adequately established where they are needed and more research in system engineering applications and other professional work must be done to quickly provide the goals and outcomes needed for economic growth (Moss, 2007).

Model studies of risk management research must be introduced in developing countries to develop concepts of systems integrations. Concepts of inter-related enterprise network systems such as industry clusters that could be introduced into one core business processes' descriptions, necessary to initiate the change processes through emergence must be developed (Bernus, Nemes, & Williams, 1996). This is what these countries need to jump start their economies. Developing countries need to embark heavily on research work such as enterprise systems modeling (ESM) to support knowledge preservation and deep understanding of the business process operations and system learning to transform inputs into outputs (Nocco & Stulz, 2006). But above all, how to model and capture risk of interdependencies in enterprise systems and develop ways to solve them before they become a real problem must be developed. This will lead to significant improvements in the knowledge base and confidence of the local workers and help lower system liability insurance premiums coverage as productivity improves.

It is understood that more research work will be needed to study interdependency network systems in cluster industries, to minimize risks in enterprise systems for successful transformation of inputs into outputs for developing countries, and to reverse the negative economic growth.

2.2.2 GHANA'S SALT INDUSTRY PROBLEMS

Developing countries such as Ghana face a mountain of problems and opportunities to develop will slip away, unless solutions are developed to accelerate economic growth and minimize scarcity of needed materials to fuel their economies. Developing countries still struggle to maintain growth of their countries' economies due to lack of advanced technologies, experts, and finance (Moss, 2007). Most developing countries such as Ghana have many natural resources which are unharnessed. The development of appropriate applications of system engineering principles can be developed to facilitate the efficient harnessing of the natural resources to improve goals and outcomes needed for nation-building. This in turn will improve the standard living conditions of the citizens (Moss, 2007). Ghana can recover from years of negative economic growth by developing many of the different natural resources available in the country. It requires the country to develop several advanced, technologically-related industries to serve as collaborating enterprise systems or industry clusters.

Salt is key to the industrial revolution of Ghana as a nation (Acquah, 1998). Salt is a critical raw material for various enterprise systems, e.g. medical industries and clean water processing. Salt is also used extensively for Petro-chemicals. The value of salt is dependent on support systems, e.g. transportation, higher education, mining, and others that impact the national economy, and all these areas will need improvement. Salt enterprise can give rise to a cluster of technology dependent industries, e.g. petroleum-based enterprises, medical product enterprises, and consumer goods enterprises. Such enterprise systems can use packaged and integrated software to support a wide range of organizational processes to provide a seamless control of operation at all levels and help to streamline inefficient processes (Shang & Sedon, 2003).

Ghana currently produces about 200,000 tons of crude salt annually. This is low quality grade that does not meet sanitary or physical standards recommended by the World Health Organization (WHO). Several small operators producing salt in Ghana are currently feasible, but their capacity to grow in future is limited due to inadequate capital. Other limiting factors include poor salt refining methods, low product quality control, poor transportation system, and market limitation (Dolbear, 2004). The small operators also lack the ability to compete internationally due to the above factors and inefficiencies in their operations (Dolbear, 2004).

A typical salt enterprise system consists of a system of systems made up of capability portfolios assembled together to provide the efficiency, high quality, and volume needed to fill home Consumer and export. With this approach, Ghana can successfully transform most of the local raw materials by developing industry clusters based upon the salt enterprise system.

Consequently, this will provide the presence of substantial and sustained export throughout the Economic Community of the West African States (ECOWAS), and significant inflow of foreign investment based on the skill and asset creation in Ghana (Porter, 1990). A major obstacle to this goal is that quantitative risk management applications do not exist in developing countries and more intensive research work is needed to support industrial activities in areas of the risk of interdependency network analysis in Ghana (Claudio, 1988). The FDNA methodology can be used to study the risk of interdependency network created by the cluster network of salt enterprise systems (Garvey & Pinto, 2009).

2.2.3 THE GHANA SALT ENTERPRISE

Most developing countries are producing salts using solar dehydration. The salt produced in this way does not usually meet quality standards set by the World Health Organization (WHO). The use of unrefined salt for human Consumer has adverse effects on health due to impurities that are present. For example, according to the Ghana Standard Board, locally produced solar salt does not meet the quality requirement for human Consumer (Mensah & Bayitse, 2006).

This research study utilizes functional dependency network analysis to develop a solution approach to solving these important problems. The sea water contains four components: Sodium Chloride, A; Potassium Chloride, B; Calcium Sulfate, C; and Magnesium Sulfate, D. A is the wanted material called Sodium Chloride, and the other three B, C, and D are all unwanted materials that have to be removed. A is a key material that helps us to produce so many products that are in use throughout the world today. A, the Sodium salt, is used in many applications and has helped to develop products used to control diseases and improve the quality of drinking water. According to the World Health Organization (WHO), no country can develop without a good supply of drinking water and all developed countries who have managed to have a good supply of drinking water are likely to have produced salt.

This study will take the approach of FDNA principles to help in identifying, representing, and measuring risk of interdependencies between suppliers of technologies and providers of service to consumers and users (Albino et al. 2002; Van de Ven et al. 1976; Garvey & Pinto, 2009). There are inherent risks in technology whose failure may impact other enterprises that receives goals and outcomes as input as indicated above.

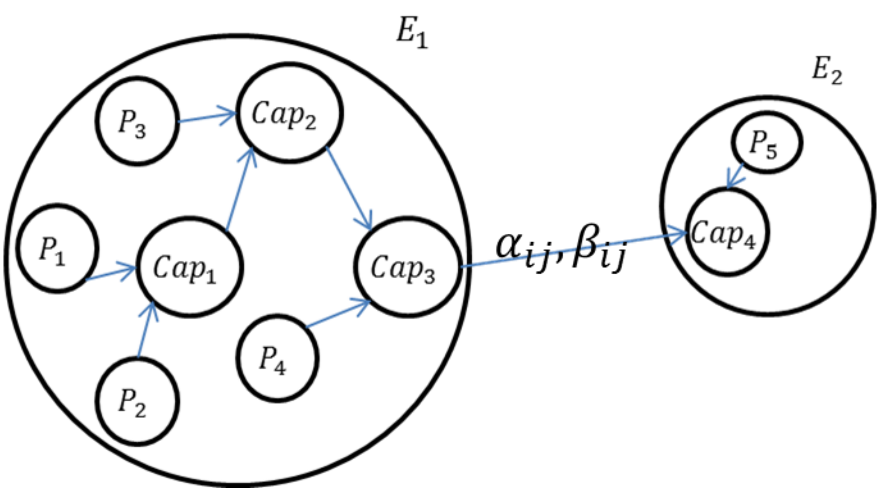

Figure 2.0: - A simple FDNA Network of Ghana Salt of E_1 and E_2 enterprise Systems

Risks of interdependencies as described in this study occur in systems as a result of assumptions made in the original design model, which may or may not be exact, but an approximation of actual events.

Figure 2.0 shows the Salt Industry E1 producing outcome for different enterprises E2, E3… E_n. In the Salt Industry, systems outputs are what bring about linkage between the interrelated networks of systems to form the whole system. Data obtained as a result of transformation through the equipment used by various processes from their input variables are evaluated for their impact in the overall result of their outputs. The salt deck has unwanted materials that must be removed to lower the consequence of a catastrophic event occurring to ensure that the outcome is an acceptable input to the receiving processes. Precise description of the processes used, the types of data obtained, and how they are collaborated with the perspective receivers' input material as their feed stocks will be examined to better understand each process' normal performance to their off-target values or deviation whenever they occur. The risk factors that prevent systems from meeting their set points and could lead to a total system failure are also assessed to know when they occur and the impacts after their occurrence. Actual data collected from Morton Salt Bahamas salt works will be used for this research study. The aggregate values of the impurities and their impacts on systems capability and performance are important to the overall ability for the clusters of industry formation.

2.2.4 IMPORTANCE TO DEVELOP THE GHANA SALT INDUSTRY

A key element in getting a good supply of quality salt for home Consumer and for application in the chemical industries is getting reliable data used in the solar salt processing. Good geological and hydrogeological data are very important for solar salt processing. Dehre Dolbar (2004) has done very extensive studies about the potential for Ghana salt development and has developed a record from review and site inspections that confirms that the area including the land leased for the solar salt projects at the Songor Lagoon in Ghana has concentrated rainfall that extends from April through June of every year. There are nine months of continuous dry weather from July through March. There are no adjoining rivers to the Lagoon and the only fresh water influx to it comes from precipitation between the months of April through June. The streams formed by the intermittent rainfall pass through the proposed solar salt sites and will need to be diverted from the proposed evaporation and crystallization ponds. The average annual rainfall for the three years of Ada-Foah weather station data is about 670 mm (26.8 inches). Also, the average day-time temperature ranges from 25oC to 40oC (75-104oF), with net evaporation rate (taking the rainfall into account) of 5.7 mm (0.23 inch). These data will need to be verified with the mathematical model approach.

Assuming such reliable data is not available, a coupled mathematical model of salt and water is used to assess the salinity of the solar salt solution across the concentration, the crystallization ponds, and the salinity of the lagoon water. The salinity of the lagoon water will have a major influence on the evaporative rates estimation of the solar ponds, from the concentration ponds to the crystalizing ponds. Also, the presence of Magnesium ions reacts with Calcium, Sodium and Potassium to form enterprise compound of different salts.

Observed compounds of Seawater at 25 ˚C			
Symbol	Name	Formula	Crystallization field
NC	Halite	$NaCl$	
KC	Sylvinite	KCl	mnpqc
MC6	Bischoffite	$MgCl_2.6H_2O$	aldz
NS	Thenardite	Na_2SO_4	shcg
MS1	Sakeite (Kieserite)	$MgSO_4.H_2O$	xykj
MS4	Leonhardite	$MgSO_4.4H_2O$	ykldr
MS6	Hexahydrite	$MgSO_4.6H_2O$	jkyx
MS7	Epsomite	$MgSO_4.7H_2O$	vijxw
	Carnallite	$KCl.MgCl_2 6H_2O$	eqrdz
N3KS	Glaserite	$Na_2SO_4.3K_2SO_4$	fgstm
NMS4	Astrakanite	$Na_2SO_4MgSO_4.H_2O$	ihstuv
KMS4	Leonite	$K_2SO_4.MgSO_4.4H_2O$	unpwv
KMS6	Schönite	$K_2SO_4.MgSO_4.6H_2O$	tumn
KMCS3	KaÏnite	$KCl.MgSO_4.3H_2O$	wpqryx

Table 2-1: Observed Compounds in seawater systems at 25℃ (IUPAC, 2002)

Van’t Hoff (1909) studied equilibrium solubility in the fivefold seawater-type system of Sodium ion ($N_a{}^+$), Potassium ion(P^+), Magnesium ion ($M_g{}^{2+}$), Chloride ion(Cl^-), Sulfate ion ($SO_4{}^{2-}$), and water (H_2O) at 25 to 85˚C, and found enterprise compounds exist in seawater solution.

Table 2: Solubility of Sodium at 25˚C in phase diagram					
	XK	XM	YS	Z	SOLID PHASE
c	0.00	0.00	20.21	802	NC+NS
h	0.00	25.29	28.9	762	NC+NS+NMS4
s	14.25	22.15	30.72	694	NC+NS+NMS4+KMS6
t	14.38	47.94	25.34	685	NC+NMS4+N3KS+KMS6
u	13.06	56.52	24.85	663	NC+NMS4+KMS6+KMS4
v	9.01	77.48	24.85	628	NC+NMS4+KMS4+MS7
i	0.00	81.79	23.55	682	NC+NMS4+MS7
w	9.04	79.85	24.2	619	NC+MS7+KMS4+KMCS3
g	14.71	0.00	21.8	722	NC+NS+N3KS
f	29.68	0.00	6.95	738	NC+N3KS+KC
m	19.37	49.06	19.38	678	NC+N3KS+KC+KMS6
n	18.62	52.93	19.50	669	NC+KC+KMS6+KMS4
p	11.38	75.89	18.31	623	NC+KC+KMS4+KMCS3
x	4.28	91.69	15.15	595	NC+MS7+MS6+KMCS3
j	0.00	94.64	14.25	596	NC+MS7+MS6+KMCS3
q	7.00	88.32	6.30	598	NC+KC+KMCS3+KMC6
z	0.34	99.02	1.04	475	NC+MC6+MS1+KMC6
l	0.00	99.10	1.25	476	NC+MC6+MS1+KMC6
a	0.00	99.25	0.00	480	NC+MC6
e	6.91	88.04	0.00	615	NC++KC+KMC6
b	30.20	0.00	0.00	770	NC+KC
k	0.00	96.95	10.60	540	NC+MS6+MS1
y	2.21	96.13	11.05	552	NC+MS6+MS1+KMCS3
r	2.25	95.31	8.08	530	NC+KMCS3+KMC6+MS1
d	0.41	98.84	0.00	473	NC+MC6+MS1+KMC6

Table 2-2: Solubility of NaCl in Observed Solid Phase diagram (IUPAC, 2002)

Kurnakow and Nikolaew (1927) discovered the existence of metastable compounds of Bloedite ($Na_2SO_4.M_gSO_4.4H_2O$), kainite ($KCl.MgSO_4.3H_2O$), and kieserite ($MgSO_4.H_2O$) in the solar diagram but no crystallization fields for them. This makes the range of which pure solar salt precipitates very narrow.

As shown in Table 2-A and Table 2-B, there are several double and enterprise Magnesium salts formed with the other salts components in the seawater which tend to remain throughout the range of specific gravity for pure Sodium salt precipitates.

The analyses of the data indicate the formation of extremely stable Magnesium compounds in the salt solutions media.

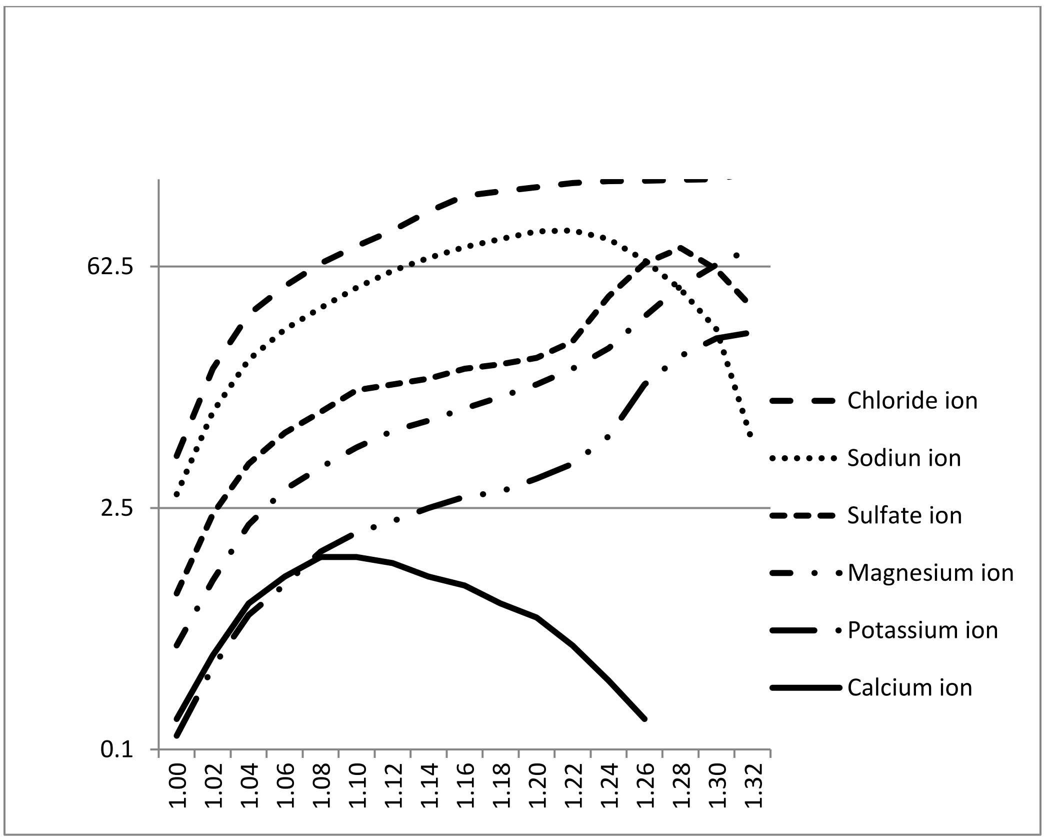

Figure 2-1: Solubility of the components of seawater

As indicated above, studies have been made about the formation of evaporative minerals deposits from seawater. Van't Hoff (1909) studied equilibrium solubility in the fivefold seawater-type system Na+, K +, Mg+, Cl-, SO42-, H20 at 25 to 83˚C. He obtained the equilibrium solubility diagram. Also, Kurnakov et al. (1938) studied the sequence for salt crystallization from seawater. Their studies resulted in the discovery of what is known as the solar sequence for salt crystallization from seawater, as well as the solar diagram of evaporation. In all, they found that the different simple Magnesium salts tend to form extremely stable supersaturated solutions. The existence of enterprise Magnesium salts do influence salt crystallization sequence from multicomponent water salt systems.

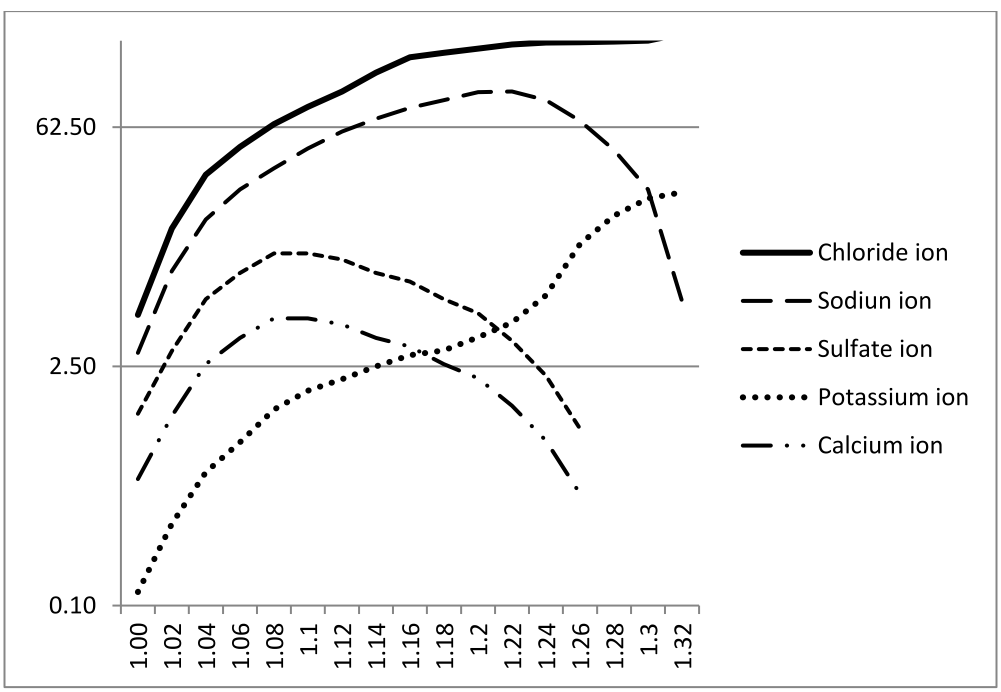

Figure 2-2: Solubility curve of seawater components without Magnesium ions at 25˚C

The presence of this stable Magnesium salt in seawater hinders the crystallization from multicomponent salt-water systems. Several of these components are found in solar salt evaporation processes, making Magnesium compounds very difficult to remove by just solar evaporation of seawater. High quality salt is produced for human Consumer and industrial use but first it is necessary to remove the Magnesium compounds by chemical precipitation before applying solar evaporation. As shown in Figure 2.1, Magnesium ion solubility curve closely follows the Sodium ion solubility curve in the same pattern, making it difficult to get pure Sodium Chloride without getting a mixture of Magnesium Chloride or Magnesium Sulfate in the specific gravity range where Sodium Chloride precipitates.

Removing nearly all the Magnesium salt content before the final salt is produced by solar evaporation. After removing Magnesium salt, the rest of the impurities are removed by solar evaporation according to the strength of their alkalinity. As water is evaporated, the specific gravity of the sea water solution increases and the components of sea water begin to precipitate in the order of their solubility curve and properties. Calcium salt has lower solubility curve and is the first ion to precipitate as the solution alkalinity increases, followed by Sodium and then Potassium salts as shown in Figure 2.3.

As water is removed, samples taken from the concentration ponds indicate that the alkalinity of the water increases until the specific gravity of the solution reaches a value of 1.09. Between $1.10\ to\ 1.21$specific gravity, the Calcium salt precipitates and continues to precipitate during evaporation process in the concentration ponds, all the way till a specific gravity of 1.21. Magnesium salt can be precipitated by chemical precipitation and when it is removed from the sea water, the rest of the of the component of sea water, Calcium salt, Sodium salt, and Potassium salt can be precipitated by solar evaporation to remove Calcium compounds before the precipitation of salt as Sodium Chloride is made (Shreve, 1955)

Trying to precipitate a greater amount of Sodium Chloride will mean getting higher amounts of Calcium and Magnesium Sulfates, as well as Magnesium Chloride. By removing Magnesium ions first by chemical precipitation, solar precipitation of the other remaining salts – Calcium, Sodium and Potassium – then becomes very straight forward. This is demonstrated and is shown in Figure 2.2 above, showing the remaining components to be precipitated. The Calcium Sulfate ions are first salt to be precipitated as water is evaporated and alkalinity of the solution increases. At about a specific gravity of 1.08, the Calcium Sulfate begins to precipitate, and Calcium Sulfate is completely precipitated before the solution reaches a specific gravity of 1.25. The concentration of Magnesium ions in the seawater coming from the lagoon is determined stoichiometrically before any precipitation processes begin in the salt enterprise system. By this approach, the amount of reagent to remove Magnesium salt will be known and must be utilized to remove Magnesium compounds before solar evaporation process to remove Calcium Sulfate and Sodium Chloride. Complete mathematical model consists of chemical precipitation of Magnesium ions in both Sulfate and Chloride compounds, one water balance, salt balance, and one evaporation model are needed for this study.

2.2.5 APPLICATION OF FDNA TO GHANA SALT ENTERPRISE

Functional Dependency Network Analysis (FDNA) enables management to study and anticipate the ripple effects of losses in supplier-receiver program contributions on a system's dependent capabilities before risks that threaten these suppliers-receiver program relationships are realized (Garvey & Pinto, 2009). An FDNA analysis identifies whether the level of operability loss, if such risks occur, is tolerable. This enables management to better target risk resolution resources to those supplier programs that face high risk and are most critical to a system's operational capabilities (Garvey & Pinto, 2009). The Ghana salt enterprise system forms industry cluster of which the slat-works supplies capabilities to down-stream enterprise systems, such as chlor-alkali enterprise, and the staple salt production enterprise for human use.

The salt enterprise systems are collection of technology programs and initiatives which are assembled together to achieve goals and outcomes of the enterprise system which cannot be achieved by a single system. FDNA provides a way through the use of graph theory to enable (1) a visual representation of enterprise interrelationships between entities of the salt enterprise systems and (2) the design of system quantitative model that provides a way to measure and trace the effects of dependencies between entities as they affect many parts and paths of the whole model (Garvey & Pinto, 2009). Figure 4 in Appendix A is an illustration of a special type of graph known as a directed graph with the arrows pointing from the feeder nodes to the receiver nodes. Imagine node N2 containing species B, C, S, and K, of which S is the specie that is needed but the B, C, and S must be removed sequentially, or else S cannot be accepted for its intended purpose. Assume B is the first to be removed by another species, D. But D has to be transformed into another species, A from node N5 into node N1. As stated above, for S to be accepted by its users, all of B, C and K must be removed to their minimum traced levels recommended by the users of S. In FDNA, operability is a measure of the value of a node's output (Garvey & Pinto, 2009). It is a measure of how much of the original quantity such as Sodium ion has been removed, in a form of Sodium

Chloride, which is expressed as a dimensionless value. A node is wholly operable if its value is 100% of its original value from the receiver node and is fully inoperable if its value is zero.

2.3 FOUNDATIONAL WORKS

The management plan for engineering an enterprise is to create capability portfolios of technology programs and initiatives that when assembled together will deliver capabilities that advance the system's goals and outcomes (Garvey & Pinto, 2009). Garvey's work on FDNA provides ways to represent capabilities of various elements of enterprise systems as nodes, then identify the presences of dependency relationship among nodes, as well as describe the interdependencies in terms of strength and criticality. Representing capabilities of various elements of enterprise systems as nodes allows risks of interdependencies to be identified and enables management to develop solutions to reduce the risk or manage it.

Also, the Ghana Salt enterprise System can be developed to form cluster of technology dependent industries whose factors of interdependencies can be identified using Porter's diamond model (1990) approach. The diamond model is comprised of four factors, namely, the factor conditions, demand conditions, related and supporting industries, and firm strategy, structure, and rivalry. Government and chance also impact these factors of the diamond model (Porter, 1990). The factors help identify the types of systems within the salt enterprise systems that creates successful systems.

Factor conditions identify the skill labor and the infrastructure that makes the enterprise system function as required (Porter, 1990). Demand conditions identify the types of products the economy of the country requires, and services rendered for economic growth. Related and supporting industries identify the systems within the salt enterprise systems that have the potential for growth and supply needed outputs for the salt enterprise systems to grow. Firm strategy governs how systems are created, organized, and managed.

This ensures continuous transformation of enterprise systems for organizational success on both strategic and tactical levels. Strategic level improvement events must be coordinated to achieve enterprise level benefits while tactical level transformation at the local improvement programs must be coordinated at the strategic level (Murman, 2002). Such understanding plays a major role in managing the cluster of enterprise network systems.

Enterprise risk management is one of the tactical level transformation programs that must be coordinated at both the strategic and tactical levels. This research will look at ways that developing countries can use quantitative risk management practices to improve business success outcomes for economic growth by minimizing the ripple effects of failure within the enterprise systems.

Applying Porter's Diamond model to develop enterprise network systems of the Ghana salt enterprise will help Ghana to create export of salt to several West African countries. Porter (1990) has indicated that the measure of global business success is the presence of substantial export to a wide array of nations and significant inflow of foreign investment based on skill and asset created in the home country (Porter, 1990).

Porter's Diamond Model approach (Porter, 1990) is used to identify factors for interdependencies among enterprise systems and allow the identification and study of the ripple effects of risks between the networks within them (Garvey & Pinto, 2009). Network theory is used to study the risk of interdependencies in the Ghana salt enterprise systems, based on enterprise network models. For example, the FDNA methodology provides a systems approach by representing capabilities of various elements of the salt enterprise system as nodes in a network system (Garvey & Pinto, 2009).

After representing capabilities of various elements in the salt system as nodes, the FDNA model is applied to help identify the presence of interdependency relationship among the nodes in the enterprise system, and then describe the interdependencies in terms of strength and criticality within the Ghana Salt enterprise. This is then followed with application of FDNA principles to study the ripple effect of failure due to risk of interdependency among the nodes that must be minimized for the enterprise system to achieve its final goals and outcomes.

2.4 SUMARY OF THEORETICAL GAPS

In systems design, specification of system parameters and some of the process inputs are produced based upon assumptions. Such parameters, for example in chemical engineering processes, mass transfer coefficients, physical properties, plate efficiencies, and reaction rates, are all produced with some assumptions made. As a result of these assumptions, there are some uncertainties associated with the final equipment designs. On the other hand, functional dependency network analysis has not yet been broadly applied to other engineering systems problems on an enterprise scale. Using FDNA methodology to help identify the presence of interdependency relationships among nodes and their capabilities in an enterprise system is new

(Garvey & Pinto, 2009). Therefore, applications of FDNA concepts need to be applied to other engineering systems problems for it to receive wide acceptance.

Also, there is no clear and proven method to estimate the parameters of an FDNA model (i.e. strength and criticality) and this research study will attempt to develop a methodology to estimate the parameters.

2.5 PROBLEM STATEMENT

There is a need to understand how to model interdependencies in large-scale enterprise systems that characterize industrial aspects of a developing nation. From this understanding, there is a need to analyze risks of interdependency in enterprise systems, in the context of industry clustering in developing countries. Population growth has made it necessary to produce large quantities of food, medicine, and several outcomes necessary to create shelter, food to feed, and protect the growing world population. To achieve this requires a series of interconnected networks of technology and information systems for an efficient and fast-paced production mode. Therefore, we need to understand how to model interdependencies in large-scale enterprise systems that characterize the industrial aspects of a developing nation such as Ghana.

3 METHODOLOGY

3.1 INTRODUCTION

This research is undertaken to find answers to a question of risk of failure in interdependent systems within a framework of a set of philosophies (approaches), by utilizing procedures, methods, and techniques that have been tested for their validity and reliability. The research method is a strategy of inquiry that begins with the underlying philosophical assumptions to the research design and data collections. The research is a structured enquiry that utilizes acceptable scientific methodology to solve problems and create new knowledge that is generally applicable to enterprise systems. Scientific methods consist of systematic observation, classification and, interpretation of data (Myers, 1997).

The research method is designed to collect data, analyze, and interpret them to answer the research questions by exploring causality in relation to two or more variables. The research is assumed to be done in a controlled environment in a rigorous and systematic manner.

Traditionally, the researcher tests to see if there is a degree of correlation between variables observed from each system. In systems with many components, cross correlation in the time domain and cross spectrum or coherence in the frequency domain have long been the mainstays of correlation detection (Myers, 1997).

However Functional Dependency Network Analysis (FDNA) can be applied to new project evaluation as well as to retrofit systems already in operation. In engineering enterprise systems, Functional Dependency Network Analysis (FDNA) helps in identifying, representing, and measuring risk of interdependencies between enterprise systems that utilize technologies to provide services to consumers and users of such services (Albino et al. 2002; Van de Ven et al. 1976; Garvey & Pinto, 2009). There are inherent risks in technology whose failure may impact other systems that receive goals and outcomes as input. Risks of interdependencies as described in this study occur in systems as a result of assumptions made in the original design model which may or may not be an exact explanation of system behavior but an approximation of actual events. Also, risks of interdependencies can occur in equipment in systems due to age fatigue after repeated use. Also, the presence of foreign materials from the receiver enterprise systems can get into instrumentations and equipment supply lines between feeder-receiver enterprise systems that hinder or slow down supply of information to the receiver enterprise systems or can cause major problems to system performance. FDNA is a unique way of engineering an enterprise system by creating capability portfolios of technology programs and initiatives that advance the systems goals and mission outcomes in an orderly fashion. Creating capability portfolio is an enterprise and engineering and management endeavor that requires expert knowledge and management to ensure its collection of technology programs and initiatives meet the required capabilities of the enterprise system.

Interdependency relationships in this paper are referred to as interdependency relationships or influences between enterprise systems. FDNA has greater strength in describing risk of interdependencies by:

1. Representing dependencies among enterprise systems
2. Representing the programs and capabilities within each enterprise system as nodes

3. Representing dependencies programs and capabilities across enterprise systems with directional arrows
4. Establishing characteristic variables of dependencies: BOL's, MEOL's and the strength and criticality of dependency parameter

However, FDNA has been developed based on the fundamental basis of systems theory and the conservation of mass, energy, and momentum for this research study with an attempt to make such connection. FDNA was developed to measure risk due to dependencies in an enterprise system but has not extended it to study risks of interdependencies between enterprise systems. This research focuses on studying risks of interdependencies between enterprise systems, with application to Ghana salt enterprise systems.

The way to fully analyze a complex system in enterprise systems from the whole system perspective is to create capability portfolios of enterprise systems that when assembled together will deliver the goals and outcomes of the enterprise system they are assembled to produce (Garvey & Pinto, 2009). Functional Dependency Network Analysis' (FDNA) main goal is to develop a mathematical model that provides a way to measure and trace the effects of risks of interdependencies between enterprise systems' capability portfolios as they affect many parts of the systems and their paths in the network (Garvey & Pinto, 2009).

Functional Dependency Networks Analysis (FDNA) was developed based on network theory (Garvey & Pinto, 2009) and based on network models to provide a systems approach to representing capabilities of various elements of an enterprise system as nodes in a network, identifying the presence of an interdependency relationship among nodes in the enterprise systems, and by describing the interdependencies in terms of strength and criticality. The approach enables Functional Dependency Network Analysis (FDNA) to represent ripple effects of failure in enterprise systems that when solved allows systems to achieve the goals and outcomes they are set up to deliver.

Also, the recent frameworks for measuring the risk of interdependencies in enterprise systems (e.g. the FDNA, and Leontief I/O models) are not fully developed as to (1) how to characterize types of interdependencies, (2) how to quantify interdependency features such as criticality relationship, and (3) how to research the analytical scalability of foundational FDNA (Garvey & Pinto, 2009) to a nation state-level enterprise. This shows that more research studies are needed to develop the framework for measuring the risk of interdependencies in enterprise systems.

Identifying the risks of interdependencies in enterprise network systems is a difficult task and finding ways to study and measure the risks of interdependencies are a great help to the process industries. In an enterprise system, interdependency is the degree to which the actions or outcome of one component or system affects the actions or outcome of another component or system in an enterprise system (Albino et al. 2002; Van de Ven et al. 1976; Garvey & Pinto, 2009).

The negative impact that occurs, if not checked, could propagate into other enterprise systems that depend upon such feeder enterprise systems to accomplish their goals and outcomes (Wiggers et al., 2006). By this reasoning, organizational units that are responsible for the goals and outcomes must view interdependency as occurring between components, systems of enterprise systems, and with other enterprise systems (Rinaldi et al. 2001).

It is important to view interdependency as arising between outputs of components and systems, which rely on information flow between systems. The information flows between them help achieve goals and outcomes, and not organizational units themselves, since tasks can be decoupled from the organizational units that have the responsibility for completing and assigning the responsibilities to other organizational units. For example, a task requires a certain set of capabilities in order to execute (Wiggers et al., 2006). Any organizational units that possess those capabilities may execute those tasks.

Consequently, management has the flexibility to reassign roles and responsibilities if they adhere to the task's capability constraints (Wiggers et al. 2006). Any reassignment would change interdependency between organizational units; however, the interdependency between tasks would remain unaltered. So, any model must represent both process constructs and organization constructs.

3.2 QUANTITATIVE RESEARCH

Quantitative research is a means for testing objective theories by examining the relationships among variables. These variables, in turn, can be measured, typically on instruments, so that numbered data can be analyzed using statistical procedures. The final written report has a set structure consisting of introduction, literature and theory, methods, results, and decision (Creswell, 2009). Researchers engaged in this form of inquiry have assumptions about testing theories deductively, building in protections against bias, controlling for alternatives explanations, and being able to generalize and replicate the findings.

Quantitative research approach can be considered positivist if there is evidence of formal propositions, quantifiable measure of variables, hypothesis testing, and deducing the inferences concerning the phenomena from representative sample to a stated population (Orlikowski, 1991). The positivist approaches assume that the relationship between social reality and human is independent, objective of the cause-and-effect type.

Deductive research approach is sometimes called top-down approach. Deductive reasoning works from the more general to the more specific and it begins from theory, through hypothesis, observation to confirmation. Arguments based on laws and rules from accepted principles are generally used by deductive reasoning. Observations tend to be used for deductive arguments. Formal logic has been described as the science of deduction while the field known as informal logic or critical thinking is regarded as the study of inductive reasoning. A variety of problems can be attacked by representing the problem description and relevant background information as logical axioms and treating problem instances as theorems to be proved (Orlikowski, 1991).

The type of reasoning concept associated with quantitative method is deductive, objectivity, and causation-based. Questions are pre-specified and outcome-oriented analytical methods are used, based on numerical estimations with statistical inferences. Though there are spectrums of research studies that encompass both quantitative and qualitative methods. This research ascribes to the quantitative research method.

3.3 THE APPROACH TO RESEARCH AND REASONING

Many of the products which are produced by different sets of projects in the chemical process industry employ the hard system methodology (e.g. the construction of chemical plant). Moreover, many of the firms are derived from these hard sciences. Therefore, it is very important to adopt a design that maintains the essential linkage between the ontology, epistemology, methodology, theoretical perspective, and the methods within the research studies. The research design adopted for this study is located within a positivist epistemology and objectivist theoretical perspective. The study justifies the selection of the empirical theory as the research methodology of choice within the context of the purpose of the research to generate a substantive theory to explain the management processes of the risk of interdependency in enterprise System inherent within a specific organizational context.

Given the exploratory nature of the study, the research method chosen for this paper was performed using the deductive reasoning methodologies, beginning with the study of the theory of the risk of interdependency in enterprise Systems. Then it moved to a more specific hypothesis to be tested. This eventually directs the research to be able to test the hypotheses developed from the original theories with specific data. The research cycle and methodology rules for quantitative analysis were observed throughout the deductive reasoning process.

This study applies a case study research of a typical enterprise System to the chemical process industry in a developing country, such as the Ghana salt enterprise system, which aims to examine the relationship between entity dependencies in the enterprise Systems.

3.4 RESEARCH METHODOLOGY

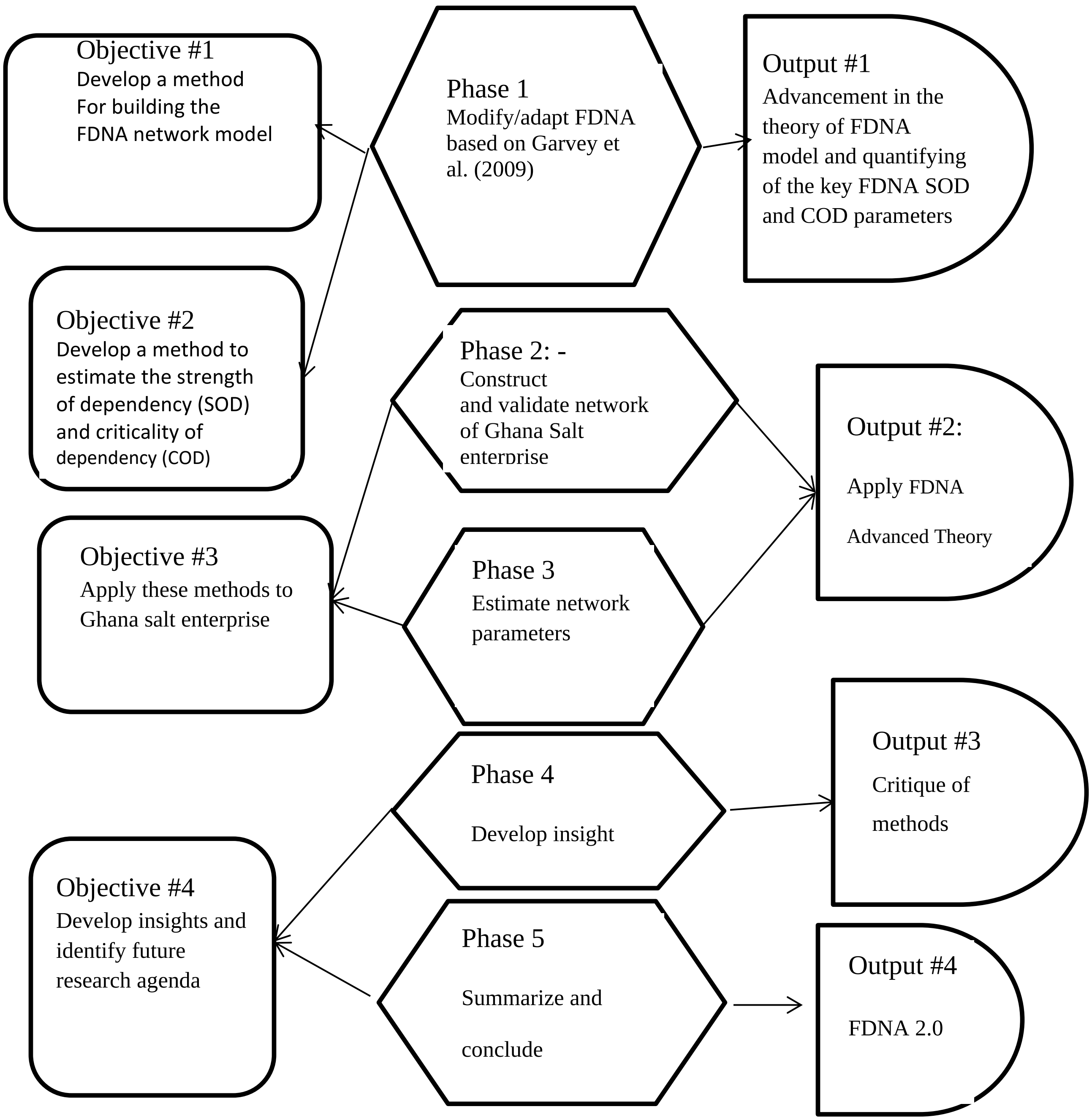

Figure 3-1: - Phases of the Dissertation & Relevant Output

Moreover, it aims to improve the study of the risk of interdependency in enterprise Systems in Ghana to achieve a high level of success of projects results and expectations. The research design as shown in Figure 3.1 is created to define the objectives and variables of the research study and describe the methods utilized to collect and analyze the data during the study in order to establish the procedures and basis for validation. The steps used for this research study are shown below as the research objectives and are shown in the Figure 3.1 above.

3.5 RESEARCH OBJECTIVES

1. Develop a method for building the FDNA network model
2. Develop a method to estimate the strength of dependency (SOD) and the criticality of dependency (COD)
3. Apply these methods to Ghana's salt enterprise
4. Develop insights and identify future research agenda

3.6 SOLUTION APPROACH

Definition 3.1 The network-topology structure is designed to depict physically or logically the complex network of enterprise system in cluster of industry network.

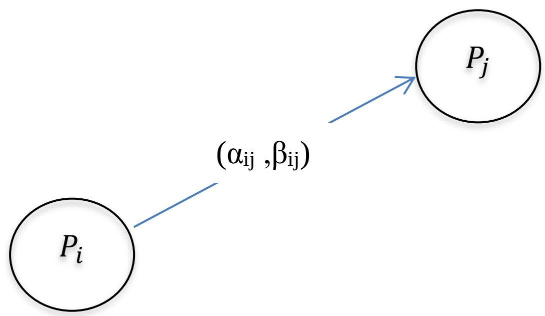

Figure 3-2: - A Simple Model for FDNA

From our definition of enterprise system, established metrics for systems network topology were not used because we want enterprise systems network topology to depict logically or physically the complex network of enterprise system in cluster of industry network being studied The Functional Dependency Network Analysis (FDNA) proposed by Garvey et al. (2009) provides a method for representing the systems in an enterprise system as nodes. Its model represents interdependencies among elements in the enterprise system with directional arrows from the feeder enterprise system to receiver enterprise system (Garvey & Pinto, 2009). Conceptual development is part of this constructive research methodology which is being employed in the current research in order to develop the formulization of the new system model as applied to enterprise systems in the chemical or petrochemical process enterprise systems. It then establishes the characteristic variables of interdependencies: baseline operability level (BOL), MEOL's, and the strength and criticality of dependency for the Ghana salt enterprise.

Garvey's model deals with stationary models which though can be used to solve risk of interdependency, it is apparent that this approach leaves out very important information in the actual operation of a system, for example, a chemical plant or auto vehicle. That is, the time behavior of processes is very important to investigate. Knowledge of the time behavior of processes allows for the understanding of what needs to take place before the system will reach its optimum performance level in the stationary state.

There are major problems encountered in the everyday operation of an enterprise system. Take, for example a chemical enterprise, which has the risk of runaway reaction, or the case of operating a motor vehicle, which includes maneuvering around curves in the road, avoiding potholes and other obstructions, and stopping and starting at traffic lights. Most of this steering and maneuvering involves non-stationary conditions which in enterprise systems deal with mass, energy, and momentum balances, and require the dynamic operation of the enterprise system.

In order to predict the dynamic operation of an enterprise system, we will need to look at the changes that occur as a function of time in the theoretical models. We will also have to specify all system inputs in order to make an accurate prediction of the speed of generation of energy, Consumer of raw materials, and production of the outcome or depletion of raw material during the system's performance.

It is necessary to investigate the Functional Dependency Network Analysis (FDNA) for modeling risks resulting from interdependencies with application to the salt systems in Ghana. Functional Dependency Network Analysis (FDNA) is a methodology that enables management to study and anticipate the ripple effects of losses in the feeder-receiver relationship of interdependent systems before risks that threatens their relationships are realized (Garvey and Pinto, 2009). Evolution of such systems approach will help pave the way for developing countries to advance economic growth by managing the risk of interdependencies in enterprise systems and advance research studies in enterprise systems in developing countries, to enable the production of the goals and outcome needs of a nation.

The research covers selected areas that focus on modeling and simulation across multiple enterprise systems of systems such as problems found in manufacturing across chemical and petrochemical industries. To achieve this, we need to understand what constitutes the systems and how they are connected to form these interdependent systems that will result in the specific outcome demanded.

3.7 FUNCTIONAL DEPENDENCY NETWORK ANALYSIS

Enterprise systems are collections of systems and components that are interconnected to form the final relationship that constitute the enterprise system, with a network of directional arrows to indicate the direction of the flow of information that allows the enterprise systems to achieve the final goals and outcomes they are specifically designed to achieve as a whole system. Garvey describes a stationary model for the systems and components as nodes and the lines connecting the nodes as vertices in a graph theory.

The operability of a node in Functional Dependency Network Analysis (FDNA) is the measure of the node's performance. A functional relationship between two nodes N_j and N_i , where

N_i , is the feeder node with operability level given as P_i and that the receiver node N_j has operability level given as P_j can be written as

$$P_j = \int (P_i, \alpha_{ij}, \beta_{ij})\, dt, 0 \leq \alpha_{ij} \leq 1, 0 \leq \beta_{ij} \leq 1, 0P_i, P_j \leq 100 \quad \ldots.. \ (1)$$

where operability level of a node allows it to achieve some level of performance, without it the node's ability to achieve its output will diminish. Operability level is influenced by two properties of interdependency. The first is the strength of dependency (SOD), the level at which the receiver node depends on the feeder node to achieve its goals and outcome. The second is how critical the contribution from the feeder node to the receiver node to achieve its operability level, and this is called the criticality of dependency. As shown in equation 1 (Garvey & Pinto, 2009), α_{ij} is the strength of dependency fraction and β_{ij} is the criticality of dependency constraint. Interdependencies within an individual system network are often well understood but looking at two or more enterprise systems, Figure 3.3.

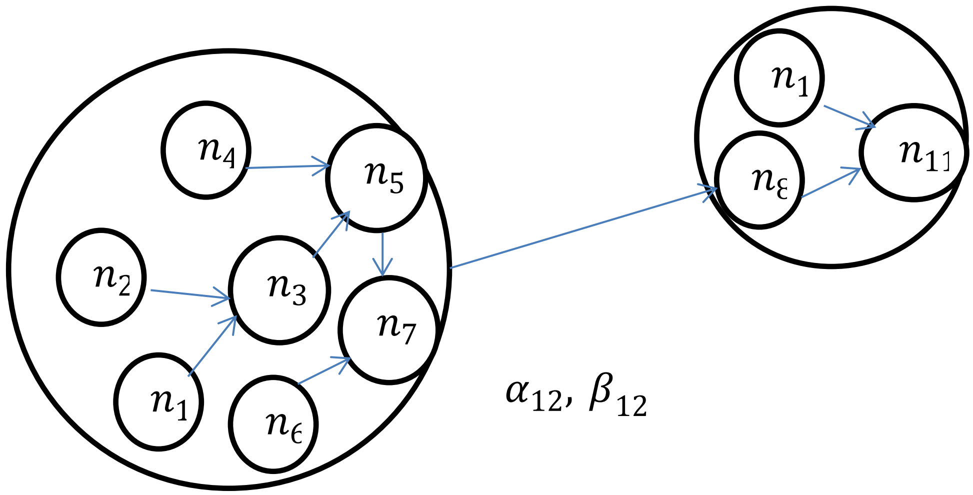

Figure 3-3: - A simple FDNA Network of Ghana Salt of E_1 and E_2 ENTERPRISE Systems

$E_1, E_2, \ \ldots\ldots \ E_n$, form a network of an enterprise system of systems, but such network is one that is of a great deal of interest in this research work. Interdependency and effect modeling measure the influence or impact that one enterprise system has over another enterprise system.

Enterprise system, E_1 supply a value to the enterprise system E_2 by going through a chain of influences indicated by the I_i network of which $n_1, n_2 \ldots . n_7 \epsilon I_i$ are all enterprise system E_1 constitute. The chains, potentially composed of multiple interdependency network systems, compose the paths and arcs between system components and systems or nodes denoted by the following relationship, $\{(n_1, n_2), (n_2, n_3), (n_3, n_4), (n_4, n_5), (n_5, n_6), . \ldots, (n_{10}, n_{11})\}$. The path represents a cascading consequence of an event of which $n_{11}{}'s$ dependency on $n1$ is derived, denoted by $n_1 \Omega n_{11}$ (Rinaldi, Peerenboom, and Kelly, 2001). The influence from multiple nodes such as (n1, n2, n3…. Ωn9) may occur over time as their behavior become cumulative in nature. The end results may be a sequence of failure of events created by the relationships of the composition of the networks systems, represented by the enterprise systems whose emergent behaviors may not be fully understood.

Functional Dependency Network Analysis has been developed to model and measure operational interdependencies in enterprise systems (Garvey & Pinto, 2009). Enterprise systems can be modeled to consist of capability nodes and program nodes, with connected arrows to indicate the direction of the flow of information throughout the enterprise systems. Shown below in Figure 3.3 is an example of an enterprise system with four capabilities nodes and five program nodes, with directional arrows to indicate the direction of informational flow throughout the enterprise system.

In the FDNA graph dependency is a condition that exists between two nodes when the operability of one node relies to some extent, on the operability of another node (Garvey & Pinto, 2009) For the capability node, Cap1 to achieve what it is intended to accomplish, it fully relies on the supply of goods and services rendered by program nodes P1 and P2. However, program nodes, P1 and P2 can supply only what capability node, Cap1 can process, which also depends on the condition's capability node Cap2 has set for capability node Cap1, and so forth, until the last stage in the process outcome is achieved. The objective of this research is to look for the effect of the dynamic behavior of processes on risk of interdependency.

We will therefore study the non-stationary model and look at the effect of failure between interdependent enterprise systems in both E_1 and E_2. This then is followed with application to the Ghana salt enterprise systems.

3.8 NON-STATIONARY ENTERPRISE SYSTEMS

Information flow and coordination of resources in effective ways within enterprise systems determine the performance of all the enterprise systems in clusters of industries. Interdependency is the degree to which the actions or outcome of one task affects the actions or outcome of a second task. The demand for the resources and the ability to supply these resources determine the effectiveness of such relationships and influence the performance of the system. Those enterprise systems where the individual response or requests for resources can be measured from the analytical point of view indicate that performance of interdependent systems is directly observable.

When systems outputs are measurable changes in the quality of the outputs may result in a decrease or increase in the performance of the feeder enterprise. It can also cause the feeder enterprise to slow down or increase as a result of those changes in the quality of the feeder enterprise. The impact of such change in the system's performance can be felt immediately or after some lag time. We cannot disregard the effect of the inherent impurities or its impacts in the performance of the receiver enterprise system. The presence of impurities in the feed stream must be addressed or completely removed to avoid consequence downstream. If the inherent impurities are not properly eliminated there could be a reduction in system's performance capabilities that could end in the system's total failure.

If a change occurs within an enterprise system that supplies an output to another enterprise system, how does it impact those enterprise systems that receive the output? The purpose for modeling the risk of interdependency is to study the factors that cause resource limitation and impede the system's performance. Modeling the risks of interdependency consists of representing enterprise systems as nodes and representing the direction of flow of information or outcome with arrows. The next step is to develop the mathematical model that links the enterprise systems together and uses the model to determine the strength of the interdependency risk parameters in enterprise systems through regression analysis modeling as shown in Figure 3.1.

Most model development for Functional Dependency Networks Analysis emphasizes stationary models. However, studying the risk of interdependency of enterprise system, using non-stationary models provides information on the relationship of systems undergoing continuous changes between the initial values of the variables P_i and P_j as they are impacted by their systems change as a function of time. Consequently, the conditions required for the existence of the derivative of the function relating the variable of the receiver enterprise system, to the variable of the feeder enterprise system, $P_j = f(\alpha_{ij} P_i)$, are fulfilled. The derivative $dP_j = f'(\alpha_{ij} P_i) dP_i$ represents the rate of change of P_j with respect to change in P_i. The use of these relations is a very important step in the formulation process systems' output with their time series variables.

We now look at the time variation of both the receiver enterprise and, the feeder enterprise variable outputs P_i and P_j. A change in the receiver node's output P_j occurs as a function of time, at the same as a change in the feeder node's output P_i also occurs as a function of time. As indicated, a change in the quantitative output of an enterprise system E_i and its effect on the quantitative input of enterprise E_j due to output supplied by E_i, over time and its impact or failure is the risk of interdependency. In this case, we can look at the change in P_j as a small change in P_i. That is

$$dP_j = f'(\alpha_{ij} P_i) dP_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (2)$$

Thus, we can examine the nature of the information flow within a system to determine the level of performance of the interdependent systems and subsystems. Using interdependency graphs to model interdependencies is one way to visualize how a flow of information from one system to another is indicated by $E_i \rightarrow E_j$, which means E_i supplies output to E_j, or means that E_j depends upon the performance of E_i to achieve the goals and outcomes of E_j, or E_j depends upon the capability of E_i to achieve its goal and outcome.

3.9 INTERDEPENDENCY MODELING OF NON-STATIONARY SYSTEM

We now begin to look at an enterprise system E_i that produces an output w_i and supply w_j to another enterprise system, E_j, which utilizes w_j to make an output w_{jk}, as shown in Figure 3.5 below.

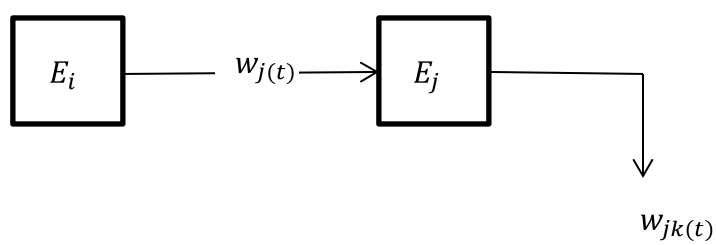

Figure 3-4: Two enterprise Systems and their outputs

Definition 3.0: W_i is the non-negative output of the enterprise system E_i. The unit of measure of W_i is expressed appropriately in the units of measure of output of the enterprise system, E_i. It is possible to have one receiver enterprise or several receiver enterprises E_i

making outputs and supplying them to a single receiver enterprise system, or a number of receiver enterprise systems, where the feeder enterprise system can be represented by E_i $(i = 1, \dots \dots \dots . ., N)$. Also, several feeder enterprise systems $E_i s'$ can supply outputs to receiver enterprise system, E_j. We measure time series of observable outputs, W_i $(i = 1, \dots \dots \dots . , N)$ given that i is a positive integer, where W_i represent the output of an enterprise system, which forms part of several feeder enterprise systems, E_i, $(where, i = 1, \dots \dots \dots . , N)$ and several receiver enterprise systems E_j, $(where,\ j = 1, \dots \dots \dots . , N)$. The outputs of both the feeder and receiver enterprise systems are time dependent and can occur in increasing or decreasing order. Therefore, we now introduce these outputs in the time domain, $W_i(t)$.

In FDNA, Garvey has defined what an enterprise system produces as its measure of performance (MOP) and the value of what is produced as its operability level or its measure of effectiveness (MOE) (Garvey, 2009). In a dependency relationship between enterprise systems, contributions to the receiver enterprise system from other feeder enterprise systems are context specific to the natures of the supplying enterprise system. Contributions result from the achievement of outputs by enterprise systems that reflect their performance. For example, suppose enterprise system E_i produces and supplies some quantity $W_j(t)$ of an output, E_j. Then the measure of performance for enterprise system E_i might be the rate with which it produces this output. A receiver enterprise system is one whose operability level relies on the operability level of at least one feeder enterprise system.

Definition 3.2: $W_i(t)$ is the non-negative output of enterprise system, E_i, from time $(t - 1)$ to a time t.

It represents the output of a feeder enterprise system that links the receiver enterprise system, and the units of measure as a function of time. For example, the value of $W_i(t)$ can be expressed in units such as tons produced in a month or the number of viewers attending a cinema show in a theater in a year. In Figure 3.3 are shown two enterprise systems E_i and E_j, as indicated by a cluster of industries. $W_i(t)$, represents the unit of measure of output the feeder enterprise system E_i can produce for the receiver enterprise system E_j.

In a cluster of industries, several enterprise systems are linked together into supplier-receiver relationships that create a web of systems of suppliers and receivers of outputs to fulfill their intended design purpose.

The outputs $W_i(t)$ of the feeder enterprise system E_i and $W_j(t)$ of the receiver enterprise system E_j are normalized with their respective maximum design capacity W_{io} and W_{jo} to obtain $P_{i(t)}$ and $P_{j(t)}$ for both enterprise systems E_i and E_j.

Definition 3.3: W_{jo} and W_{io} are the designed capacities of enterprise systems E_i and E_j. The values of $P_{i(t)}$ and $P_{j(t)}$ obtained by dividing $W_i(t)$ with W_{io} and $W_j(t)$ by W_{jo}, allow managers to know at what level of their current capacity the receiver enterprise rely on. Therefore, operability level is defined as a system's operability derived from its current and designed capacities. This is consistent with the concept of operability with the original FDNA because it measures system's performance from range zero to 100. The two systems

E_i and E_j are mutually independent and can be represented by weighted linear combination of a single dimensional value function for each criterion contained in the set. This provides us with the opportunity to express how the system performance varies from zero to one or in the range between zero and 100 percent.

We do this for the interdependent systems whose functional relationship is being studied. It provides a means to develop the interdependency relationship between dependent enterprise systems that receive outputs from an interdependent enterprise system. The value W_{io} represents the maximum design outputs of the enterprise system E_i. Using the values of W_{jo} and $W_{i(t)}$, we can define $P_{\ i(t)}$ as follows

$$p_{\ i(t)} = \frac{W_{i(t)}}{W_{io}}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

ehere $p_{\ i(t)}$ is the normalized output of enterprise system, E_i, such that $0 \le p_{\ i(t)} \le 1$ or $0 \le p_i \le 100$.

Also,

$$p_{\ j(t)} = \frac{W_{j(t)}}{W_{jo}}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

Definition 3.4: - The operability level of receiver enterprise system E_j is represented as P_j and P_i is the operability level of feeder enterprise system, E_i, and both operability levels are $(0 \le P_i, P_j \le 100)$.

Operability level is the contribution result of an achievement of output by the feeder enterprise E_i that reflects its performance at a time. The level of performance achievement of the feeder enterprise system helps the receiver enterprise system to achieve its level of performance. We can now determine the functional relationship between the enterprise systems E_i and E_j, such that

$$P_j = \psi P_i \qquad \text{……..…………………………………….. (5)}$$

If such a function ψ exists, it must be continuous, differentiable (smooth and locally linearized), and perhaps it has an inverse that is continuous and differentiable (Pecora et al. 1995). We now use the normalized data from the two systems, E_i and E_j, and the continuous function model to study the relation between P_i and P_j and determine the strength of dependency between the two outputs P_i and P_j of E_i and E_j. Using local zero order (constant) maps to check for the existence of a continuous map ψ between P_i and P_j. A first order linear map is used to verify the existence of differentiability.

We now use this relationship to develop a capability portfolio as indicated by Garvey (2009). We take Garvey's model of two nodes and turn it into two enterprise systems E_i and E_j with uncoupled boundary layers.

Garvey has developed a stationary model for two dynamical systems E_i and E_j, as shown in Figure 3.2, of which we have prior knowledge of their individual dynamics or their dynamical interdependency. For this study, we consider the non-stationary model of the two systems, E_i and E_j as shown in Figure 3.2.

We have shown how $P_i(t)$ is determined and we use the same procedure to develop $P_{j(t)}$. We now consider two enterprise systems E_i and E_j, as shown in Figure 3.4. The relationship of $P_{i(t)}$ and $P_{j(t)}$ are unknown, but we can develop a probability distribution between the two variables. We can determine the value of α_{ij} from the distribution of P_i and P_j between time t= t-1 to t = t, using the two-variable regression model to study their relationship. As the number of observations for the distribution data gets larger, the better the result for the estimator of the value of strength of dependency.

In this way, we can explore the probabilistic nature of the regression model of $P_i(t)$ and $P_j(t)$, by observing the correlation between the values of the output of the feeder enterprise system E_i and the receiver enterprise system, E_j. Garvey has answered the question about the existence of a functional relationship ψ for a stationary model between the reconstructed systems outputs, P_i and P_j as:

$$P_j = \alpha_{ij}P_i - 100\big(1 - \alpha_{ij}\big), 0 \leq P_i, P_j \leq 100, 0 < \alpha_{ij} \leq 1\ 0 \quad \ldots\ldots\ldots \quad (6)$$

We look to answer the question about the existence of a functional relationship ψ or correlation between the reconstructed outputs $P_{i(t)}$ and $P_{j(t)}$ of a time dependent non-stationary two interdependent models of the enterprise systems E_i and E_j as:

$$P_j(t) = \alpha_{ij}(t)P_i(t) + 100(1 - \alpha_{ij}(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (7)$$

Such model development and application require the use of system dynamics and other models such as time variation of FDNA models to develop and study the behavior of non-stationary systems in real time situations.

3.10 QUANTIFYING STRENGTH OF DEPENDENCY PARAMETER

Garvey's model showing the relationship between the receiver and the feeder nodes can be expressed as:

$$P_j = \psi P_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where the ψ indicates the relationship between P_j and P_i of equation 7

$$P_j = \{\alpha_{ij} P_i + 100(1-\alpha_{ij}\}, 0 \leq \alpha_{12} \leq 1, 0 \leq \beta_{12} \leq 100, 0 \leq P_1, P_2 \leq 100 \ \ldots\ldots \quad (9)$$

From equation 7, the non-stationary form of this functional relationship can be written by using equation 6. The changes in the value of α_{ij}, the strength of dependency, reflects the variations between P_j the output of enterprise E_j and P_i the output of enterprise E_i in a receiver-feeder relationship. Observing a small perturbation ΔP_i of the output P_i of enterpriseE_1, we can also observe a small change in the performance of P_j as ΔP_j. We can compare this change in P_j with the change in P_i given as ΔP_i. Therefore; the strength of interdependency of P_j on P_i can be represented by the derivative in the form

$$\alpha_{ij} = \lim_{\Delta P_i \to 0} \frac{\Delta P_j}{\Delta P_i} = {dP_j}/{dP_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

Definition 3.5: - α_{ij} is the strength of dependency fraction between the operability level P_j of the receiver enterprise E_j and the operability level P_i of the feeder enterprise E_i. The greater the value of α_{ij}, the greater the strength of dependency of the receiver enterprise E_j on feeder enterprise E_i. Also, the lesser the value of α_{ij}, the lesser E_j's dependency on E_i.

Also from the equation developed for continuous regression model by Garvey (2009), we can determine the value of $\alpha_{ij}(t)$ of a time series regression analysis of N observations in a time variation of both P_j and P_i as:

$$\alpha_{ij}(t) = \frac{dP_j(t)}{dP_j(t)}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

This is done by multiplying both the numerator and the enumerator of the right of equation 9, by dt, and it can be expressed as:

$$\alpha_{ij}(t) = \frac{dP_j}{dP_i}\frac{dt}{dt} = \left(\frac{dP_j}{dt}\Big/\frac{dP_i}{dt}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Since, $\frac{dP_i}{dt}$ cannot be equal to zero, and $\frac{dP_j}{dt} \leq \frac{dP_i}{dt}$, then, the value of $\alpha_{ij}(t)$ is found to be greater than zero and less than or equal to 1, expressed as $0 < \alpha_{ij}(t) \leq 1$, and is the time variation of the strength of interdependency function between P_j and P_i as both change with time. The value of $\frac{dP_j}{dt}$ is always equal to or less than $\frac{dP_i}{dt}$ since E_1 enterprise system with performance capability P_i will always supply performance capabilities P_j, to enterprise system, E_2 to advance its goals and mission outcomes.

The relationship between the two enterprise systems is seen as from two different environments with their own boundary conditions. This means, in the non-stationary FDNA model, $\alpha_{ij}(t)$ changes with changes in both the capability level P_j of the receiver enterprise and the capability level P_i of the feeder enterprise system, as they both change with respect to time variation. In system analysis, interactions and influences on a system are always studied within the same boundary. However, these studies are about two enterprise systems with their own two different environments and their own boundary conditions, and have influences separate from each other as well as from each other. This is the interdependency between the two enterprise systems, as shown in Figure 3.5.

3.11 THE TWO-VARIABLE REGRESSION MODEL

This paper looks for a model that can meet the requirements of providing a breakthrough project concept in risk of interdependency in enterprise systems in both developed and developing countries. It is necessary to evaluate its progress and suggest directions for future development.

Outputs	$P_{i(t)}$	$P_{j(t)}$
1	$P_{1(t)}$	$P_{1(t)}$
2	$P_{2(t)}$	$P_{2(t)}$
.		
.		
N	$P_{n(t)}$	$P_{n(t)}$

Table 3-1: Non-Stationary Regression Model of $\boldsymbol{P_{i(t)}}$ and $\boldsymbol{P_{j(t)}}$

The first question we should ask from the perspective of interdependent enterprise systems is what kind of functional relationship, or is there correlation between the output P_i of the feeder enterprise system E_i, and the input P_j of the receiver enterprise system E_j?

In the feeder-receiver relationship between enterprise systems, there can exist unidirectional and bidirectional, coupled or uncoupled relationships between enterprise E_i and E_j (information only flow from E_i and E_j) by which the outputs P_i of enterprise E_i will be supplied to P_j of the receiver enterprise E_j, as shown in Table 3.1 above.

In order to use a regression analysis to determine the value of the parameter for interdependency in the regression model, we must determine the best-fit continuous model for the time series data. The outputs from different enterprise systems will in general not contain the same range of values, but its relationship should be continuous.

$$P_j \overset{=}{?} \psi P_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

However, to explore the probabilistic nature of the regression model, we allow that for the given regression model observed value of P_i (the feeder enterprise output variable), there can exist many possible values of P_j (of the receiver enterprise input variable) (Garvey & Pinto, 2009; Pindyck & Rubinfeld, 1998). Garvey (2009) has proposed that there is a relationship between the feeder enterprise's output P_i, and the receiver enterprise's output P_j, as shown in Figure 3.2 above.

Therefore:

$$P_j = \psi P_i \qquad \text{.................................} \qquad (14)$$

From equation 11, the continuous function then becomes the model equation given in equation 13 above. We can explore Garvey's model equation for dependent systems in equation 14:

$$P_j = f\left(\alpha_{ij}, \beta_{ij}, P_i\right), 0 \leq \alpha_{ij} \leq 1, 0 \leq \beta_{ij} \leq 100, 0 \leq P_i, P_j \leq 100 \qquad \text{..............} \qquad (15)$$

How does the value of α_{ij} change as P_j and P_i changes as a function of time? We now must find how α_{ij} changes as both P_j and P_i change with time. We begin with the following, by showing Garvey's stationary model equation, with the relationship between P_j and P_i which is given as $P_j = \alpha_{ij}P_i + 100(1 - \alpha_{ij})$. We express the time variation of this equation as a function of time as shown in equation 14:

$$P_j(t) = \text{f}\{P_i(t), (t), \alpha_{ij}(t)\beta_{ij}(t)\} \quad \text{……………………} \quad (16)$$

How do P_j and P_i changes as a function of time affect a change in α_{ij}? We look at the time function of equation 15 below and differentiate both sides with respect to time and do not leave α_{ij} as constant. For example, we set the Garvey's linear equation to a time function as follows, change in the receiver enterprise P_j occurs as a function of time, as a change in the feeder enterprise P_i also occurs as a function of time. Therefore, from the stationary model developed by Garvey and Pinto (2009), we can develop a time series function, such that

$$P_j(t) = \alpha_{ij}(t)P_i(t) + 100(1 - \alpha_{ij}(t)) \quad \text{……………………………………} \quad (17)$$

So that by differentiating both sides with time, we get:

$$\frac{dP_j}{dt} = \alpha_{ij}\frac{dP_i}{dt} + P_i\frac{d\alpha_{ij}}{dt} - 100\frac{d\alpha_{ij}}{dt} \quad \text{………......................} \quad (18)$$

Rearranging like terms, we get:

$$\frac{dP_j}{dt} = \alpha_{ij}(t)\frac{dP_i}{dt} + (P_i - 100)\frac{d\alpha_{ij}}{dt} \quad \text{…………………} \quad (19)$$

The value of P_i is far greater than the value of α_{ij}, therefore the quantity $\frac{d\alpha_{ij}}{dt}(P_i - 100)$ is considered small compared to the other two terms and can be neglected. Therefore, we neglect the last quantity on the right-hand side of equation 17. This allows for the determination of the value of the strength of dependency parameter, α_{ij} by observing the variations of P_j and P_i as a function of time. Because of interdependency among enterprise systems, we can relate the risk of failure to the feeder system's inability to fulfill its obligation of providing its output to the receiver enterprise system. Given that $\frac{d\alpha_{ij}}{dt} \ll \frac{dP_i}{dt}$, we can neglect the term on the right of equation 18. We then approximate equation 17 to be:

$$\frac{dP_j}{dt} = \alpha_{ij(t)} \frac{dP_i}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

We also know that for the time series shown in Table 3.0 has outputs P_{it} and P_{jt} of enterprise systems E_i and E_j where the time t varies from1, $\ldots\ldots, n$. Then, using the script notation given such that the observations of P_{it} can be written:

$$P_{i1}, P_{i2}, P_{i3}. \ldots\ldots\ldots\ldots, P_{in} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

They represent the outcomes of the feeder enterprise regression of N observations of outcome of enterprise E_i.

Then the sum of the outcomes of the enterprise E_i output observation is:

$$\sum_{t-1}^{N} P_{it} = P_{i1} + P_{i2} \ldots\ldots\ldots\ldots + P_{iN} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

The mean of the observations of outputs P_{it} and P_{jt} of the two enterprise systems E_i and E_j can be determined as

$$\bar{P}_i = \frac{1}{N}\sum_{t=1}^{N} P_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

Also

$$\bar{P}_J = \frac{1}{N}\sum_{t=1}^{N} P_{Jt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (24)$$

We also know that for the time series, the unbiased variance of the observations P_i and P_j of the two enterprise systems E_i and E_j can be determined as

$$Var(\hat{P}_i) = \frac{1}{N-1}\sum_{t=1}^{N}(P_{i(t)} - \bar{P}_i)^2 \quad \ldots\ldots\ldots\ldots\ldots \quad (25)$$

Also

$$Var(\hat{P}_j) = \frac{1}{N-1}\sum_{t=1}^{N}(P_{j(t)} - \bar{P}_j)^2 \quad \ldots\ldots\ldots\ldots\ldots \quad (26)$$

We can study the variation in both P_j and P_i as a function of time to determine the values of α_{ij} as a function of time. Using statistical data analysis for the time series of P_j and P_i we apply the central limit theorem, which states that the distribution of the sample mean of independently distributed variables will tend toward normality as the sample size gets infinitely large. The normal value of α_{ij} is the expected value of α_{ij}, which is shown below in equation 26:

$$E(\acute{\alpha}_{ij}) = \alpha_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (27)$$

such that the correlation ψ may be continuous, differentiable (smooth and can be locally linearized), and perhaps has a continuous and/or differentiable inverse. Pecora et al. (1995) have shown in their work that we can seek a statistical measure of confidence that such a function exists. We now consider a two-variable regression model such that in equation 7 $i = 1\ and\ j = 2$. Then, equation 7 becomes equation 20 shown below. We also assume that P_1 and P_2 are time series functions. From a given values of P_1, the feeder out variable, we observed several values of the output variables and likewise the P_2, the receiver output variable. Form Garvey's model (2009) we can be expressed a general equation of the model as follows:

$$P_2 = \alpha_{12}P_1 + \gamma_{12} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (28)$$

From equation 7, the value $100(1 - \alpha_{12}) = \gamma$ as shown in equation 24 and include a random error term ε_{12}, whose value is based upon an underlying probability distribution. Then equation 24 becomes:

$$P_2 = \alpha_{12}P_1 + \gamma_{12} + \varepsilon_{12} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (29)$$

The error may arise through interaction of several forces, such as impurities in the raw materials short-falls in the design of operational processes, errors associated with instruments used to measure and collect data, technician's sampling error or other changes that affect performance of the enterprise systems.

3.12 DETERMINATION OF PARAMETERS FOR TWO VARIABLE REGRESSIONS

Our concern here is the estimation of parameter α_{12}, the strength of interdependency between the feeder enterprise and the receiver enterprise systems, and the least square method is one of a number of possible means by which a curve can be fitted to a data (Pindyck & Rubinfeld, 1998). We begin with statistical testing of the least-square regression model of a two-variable regression analysis of observation from the outputs of the receiver and the feeder enterprise systems.

It is important to describe the assumption underlying the regression model first then analyze the statistical properties of the least-square estimators. The first assumption of two-variable regression model suggests that there is a relationship between the output P_1 of the feeder enterprise and the output P_2 of the receiver enterprise systems. That they form a continuous regression is suggested by equation 20 and Figure 3.4. The next assumption is to suggest that the outputs P_1s' of the feeder enterprise have values that are non-stochastic variables and are fixed. It is also suggested that the error ε_{12} has zero expected values $\epsilon(\varepsilon_{12}) = 0$, and also the errors term ε_{12} has constant variance for all observation, i.e. $\epsilon({\varepsilon_{12}}^2) = {\sigma_{12}}^2$. Also, the random variable ε_{12} is considered statistically independent so that the expected value, given by the $\epsilon(\varepsilon_{12}\varepsilon_{13}) = 0$, for all $\varepsilon_{12} \neq \varepsilon_{13}$. The final assumptions are that the error term ε_{12} is normally distributed.

The first five assumptions are based upon the Gauss-Markov Theorem, which states that the estimators $\hat{\alpha}_{12}$ and $\hat{\gamma}_{12}$, are the best linear unbiased estimators of α_{12} and γ_{12}, for the enterprise systems E_2 and E_1, given as:

$$\epsilon(\acute{\alpha}_{12}) = \alpha_{12} \quad \text{………………………} \quad (30)$$

And

$$\epsilon(\acute{\gamma}_{12}) = \gamma_{12} \quad \text{………………………} \quad (31)$$

Sample observation from the receiver enterprise E_2 and feeder enterprise E_1 variables outputs P_1 and P_2 respectively are studied for the characteristics of the least-squares parameter estimates. Randomly distributed samples of stochastic model γ_{12} and α_{12} can be estimated based upon sample size. The values of $\hat{\gamma}_{12}$ and $\hat{\alpha}_{12}$ can be estimated, using the formulas for the regression involving the summation and the expected operators of the regression.

To estimate the parameters $\hat{\gamma}_{12}$ and $\hat{\alpha}_{12}$, we begin with equation 16 for interdependent system E_2 and E_1. We can recall from equation 25 that the model equation for interdependent system E_2 and E_1 is given as $P_2 = \alpha_{12}P_1 + \gamma_{12} + + \varepsilon_{12}$. Summing up the P1's and the P2's over the total number of observations, N and dividing the sum of the observations by N in both the outputs of enterprise systems E_2 and E_1, we obtain the following:

$$\bar{P}_1 = \frac{1}{N}\sum_{t=1}^{N} P_{i(t)} \quad \text{………………………..} \quad (32)$$

$$\bar{P}_2 = \frac{1}{N}\sum_{t=1}^{N} P_{2(t)} \quad \text{………………………..} \quad (33)$$

Then

$$\bar{P}_2 = \alpha_{12}\bar{P}_1 + \gamma_{12} + \bar{\varepsilon}_{12} \quad \text{……………….…………..} \quad (34)$$

Subtracting equation 30 from equation 27, we get

$$p_2 - \bar{p}_2 = \alpha_{12}(p_1 - \bar{p}_1) + (\varepsilon_1 - \bar{\varepsilon}_1) \quad \text{……………………} \quad (35)$$

Letting $\acute{P}_2 = (p_2 - \bar{p}_2)$, $\acute{P}_1 = (p_1 - \bar{p}_1)$, and $\acute{\varepsilon}_1 = (\varepsilon_1 - \bar{\varepsilon}_1)$, we can simplify equation 31 by writing the following:

$$\acute{P}_2 = \alpha_{12}\acute{P}_1 + \acute{\varepsilon}_1 \quad \text{…………..……………………..} \quad (36)$$

The true regression line is for the expected value of P_2 given as $\epsilon\left(\acute{P}_2\right) = \alpha_{12}\acute{P}_1$. Therefore, the estimated strength of dependency of the regression line is

$$\acute{\alpha}_{12} = \frac{\sum \acute{P}_1\acute{P}_2}{\sum(\acute{P}_1)^2} \quad \text{……………..………………} \quad (37)$$

And since $\acute{\alpha}_{12}$ is the unbiased estimator of α_{12}, then the expected value of α_{12} is

$$\epsilon(\acute{\alpha}_{12}) = \alpha_{12} \quad \text{……..……….…………} \quad (38)$$

The variance of the strength of dependency of the model depends solely on the error variance of the observed distribution, the variance of P_1's, and the number of observations, so that the expected value of the variance of α_{12} is

$$Var(\acute{\alpha}_{12}) = \frac{\sigma^2}{\sum \acute{P_1}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (39)$$

We can now determine the mean and the variance estimator of γ_{12} the intercept for the regression as:

$$\epsilon(\gamma_{12}') = \gamma_{12} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (40)$$

$$Var(\gamma_{12}') = \frac{P^2{}_1}{N \sum (P_1 - \bar{P}_1)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (41)$$

Also, we can determine the covariance between α_{12} and γ_{12} as:

$$Cov\,(\acute{\alpha}_{12}, \gamma_{12}') = -\frac{-\bar{P}_1 \sigma^2}{\sum P_1{}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (42)$$

3.13 MULTIPLE-VARIABLES REGRESSION MODEL

Shown in Figure 3.6 are three enterprise systems E_1, E_2, and E_3 of which the last two enterprise systems receive inputs from the first enterprise system E_1. In this case, by Garvey's model (2009), the operability level of receiver node E_2 depends on the operability level of the feeder node E_1. Likewise, the operability level of the receiver node E_3 depends on the operability level of the feeder node E_1.

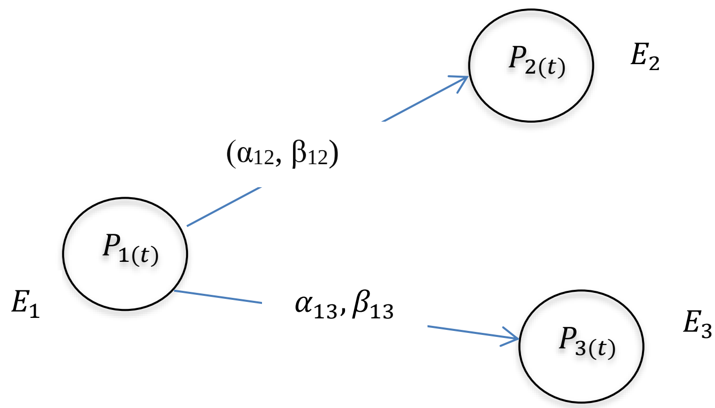

Figure 3-5: Modeling Interdependency between Multiple enterprise systems

We now deal with multiple-variable regression analysis. Shown in Figure 3.6 is a condition where three interdependent systems have one enterprise supply output to two dependent enterprise systems, such as the Ghana salt enterprise system. It consists of a Salt Winning enterprise E_1, a Chlor-alkali enterprise system E_2, and a Staple Salt enterprise system E_3.

In a two variable regression analysis, the model equations can be expressed generally by the functions expressed by Garvey (2009) as follows:

$$P_2 = ⨍(\alpha_{12}, \beta_{12}, P_1), 0 \leq \alpha_{12} \leq 1, 0 \leq \beta_{12} \leq 100, 0 \leq P_1, P_2 \leq 100 \quad \ldots\ldots\ldots\ldots\ldots \quad (43)$$

$$P_3 = ⨍(\alpha_{13}, \beta_{13}, P_1), 0 \leq \alpha_{13} \leq 1, 0 \leq \beta_{13} \leq 100, 0 \leq P_1, P_3 \leq 100 \quad \ldots\ldots\ldots\ldots \quad (44)$$

From a given value of P_1, the feeder enterprise system output variable, we observed several values of the receiver variable outputs form Garvey's model (2009),

where

$$P_2 = \alpha_{12} P_1 + 100(1 - \alpha_{12}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (45)$$

we set the $100(1 - \alpha_{12}) = \gamma$ and included an error term ε_{12}. Then equation 25 becomes,

$$P_2 = \alpha_{12} P_1 + \gamma_{12} + \varepsilon_{12} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (46)$$

Therefore, equation 40 becomes:

$$P_3 = \alpha_{13} P_1 + \gamma_{13} + \varepsilon_{13} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (47)$$

The error may arise through interplay of several forces, such as the impurities in the salt solution, or from the type of instruments used to measure and collect data, technician's sampling error, or weather changes during operation such as wind speed, sun's radiation, and rain fall effect. As shown in the two-variable regression model from equation 25 and 40, are also true that we can determine the values of α_{12} and α_{13} as:

$$\alpha_{12} = (\frac{\frac{dP_2}{dt}}{\frac{dP_1}{dt}}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (48)$$

and

$$\alpha_{13} = (\frac{\frac{dP_3}{dt}}{\frac{dP_1}{dt}}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (49)$$

Therefore, both α_{12} and α_{13} are nonnegative values and both lie between zero and 1.

$$0 < \alpha_{12}, \alpha_{13} \leq 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (50)$$

Furthermore, since P_1 produces resources or performance capability for both P_2 and P_3, we can postulate the total resources produced by E_1 is equal to the sum of outcomes supplied to both E_2 and E_3, such that $\alpha_{12} + \alpha_{13} = \left(\frac{dP_2}{dP_1}\right) + (\frac{dP_3}{dP_1})$, then

$$\alpha_{12} + \alpha_{13} = \left(\frac{dP_2 + dP_3}{dP_1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (51)$$

If the change in both P_2 and P_3 is the result of the change in P_1 then it is possible that $dP_2 + dP_3$ will sum to dP_1. Therefore, from equation 41 then gives

$$\alpha_{12} + \alpha_{13} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (52)$$

It has been shown from the two-variable linear regression models, that the following assumptions about errors play a crucial role in the accuracy of results. We have shown in equations 32 through 40 that the value of α_{12} and its variance for the regression between P_1 and P_2 can be determined using the summation and the expected operator. We can also do the same for enterprise E_1 and E_3 by studying the relationship between the outputs P_1 and P_3.

The first assumption is to suggest that the relationship between P_1 and P_3 is continuous and linear as indicated in equation 46 and shown in Figure 3.6. Next is to suggest that $P_1's$ values are non-stochastic variables and are fixed. We also suggest that that errors ε_{12} and ε_{13} have zero expected values: $\epsilon(\varepsilon_{12}) = 0$ and $\epsilon(\varepsilon_{13}) = 0$. We also suggest that the error term ε_1 has constant variance for all observation, i.e. $\epsilon({\varepsilon_{12}}^2) = {\sigma_{12}}^2$ and $\epsilon({\varepsilon_{13}}^2) = {\sigma_{13}}^2$. Also, the random variables ε_{12} and ε_{13} are considered statistically independent of each other. Thus, the expected value is given as $\epsilon(\varepsilon_{13}\varepsilon_{31}) = 0$, such that $\varepsilon_{13} \neq \varepsilon_{31}$.

The final assumptions are that the error term ε_{12} and ε_{13} are normally distributed. The first five assumptions are based upon the Gauss-Markov Theorem, which states that the estimators $\hat{\alpha}_{12}$, $\hat{\alpha}_{13}$, $\hat{\gamma}_{12}$ and $\hat{\gamma}_{13}$, are the best linear unbiased estimators of α_{12}, α_{13}, γ_{12}, and γ_{13}, for interdependent systems E_1 and E_2, E_3 and E_1 respectively.

Sample observation from the feeder output and the receiver output variables P_1 and P_2 as well as P_1 and P_3 are studied for the characteristics of the least-squares parameter estimates. Randomly distributed samples of the stochastic model γ_{12} and α_{12}, as well as γ_{13} and α_{13}, can be estimated based upon their sample sizes. The values of $\hat{\gamma}_{12}$, $\hat{\gamma}_{13}$, $\hat{\alpha}_{12}$, and $\hat{\alpha}_{13}$ can be estimated from their formulas consisting of the continuous regression analyses given in equations 45 and 46.

To estimate the parameters $\hat{\gamma}_{12}, \hat{\gamma}_{13}, \hat{\alpha}_{12}$, and $\hat{\alpha}_{13}$, we begin with equations 46 and 47 for interdependent systems of $E_2 - E_1$ and $E_3 - E_1$. We can recall from the two-variable regression analysis, given by the equation:

$$P_3 = \alpha_{13} P_1 + \gamma_{13} + + \varepsilon_{13} \qquad (53)$$

Summing over all the total observation N and dividing the total observations by N in $E_2 - E_1$ interdependent enterprise system, we obtain the mean values of the regression as follows:

$$\bar{P}_3 = \alpha_{13} \bar{P}_1 + \gamma_{13} + \bar{\varepsilon}_{13} \qquad (54)$$

Subtracting equation 53 from equation 52, we get:

$$p_3 - \bar{p}_3 = \alpha_{13}(p_1 - \bar{p}_1) + (\varepsilon_{13} - \bar{\varepsilon}_{13}) \qquad (55)$$

Letting $\acute{P}_3 = (p_3 - \bar{p}_3)$, $\acute{P}_1 = (p_1 - \bar{p}_1)$, and $\acute{\varepsilon}_{13} = (\varepsilon_{13} - \bar{\varepsilon}_{13})$, we can write the following:

$$\acute{P}_3 = \alpha_{13} \acute{P}_1 + \acute{\varepsilon}_{13} \qquad (56)$$

The true regression line is $\epsilon\left(\acute{P}_3\right) = \alpha_{13} \acute{P}_1$. The estimated slope of the regression line is

$$\acute{\alpha}_{13} = \frac{\sum \acute{P}_1 \acute{P}_3}{\sum (\acute{P}_1)^2} \qquad (57)$$

and since $\acute{\alpha}_{13}$ is the unbiased estimator of α_{13}, then

$$\epsilon(\acute{\alpha}_{13}) = \alpha_{13} \qquad \text{..} \qquad (58)$$

The variance of the model depends solely on the error variance, the variance of P_1's, and the number of observations, so that

$$Var(\acute{\alpha}_{13}) = \frac{\sigma^2}{\sum \acute{P_1}^2} \qquad \text{..} \qquad (59)$$

We can now determine the mean and the variance estimator of the intercept for the regression as:

$$\epsilon(\acute{\gamma}_{13}) = \gamma_{13} \qquad \text{..} \qquad (60)$$

$$Var(\acute{\gamma}_{13}) = \frac{P^2{}_1}{N \sum (P_1 - \bar{P}_1)^2} \qquad \text{......................................} \qquad (61)$$

Also, we can determine the covariance between $\acute{\alpha}_{12}$ and $\acute{\gamma}_{12}$ as:

$$Cov\,(\acute{\alpha}_{13}, \acute{\gamma}_{13}) = -\frac{-\bar{P}_1\sigma^2}{\sum P_1{}^2} \qquad \text{....................................} \qquad (62)$$

3.14 CLUSTER OF INTERDEPENDENT SYSTEMS

We have developed the strength of interdependency between interdependent enterprise systems E_1 and E_2, and E_1 and E_3 above. We now apply the same approach to several interdependent enterprise systems as follows, E_1 and E_2, and E_1 and E_3, …., E_1 and E_n, and continue to higher levels such as E_4 and E_{41}, and E_4 and E_{42} as shown in Figure 3.7. The value of the alpha parameters in $E_4 \rightarrow E_{441}$ and $E_4 \rightarrow E_{442}$ interdependent enterprise systems can be determined by setting up a time series regression analysis to develop a statistical solution.

In this cluster of industry networks, the more enterprise systems that receive supply of resources from a single enterprise system as show in Figure 3.6, the less the value of their individual α's become. An example for this is also shown in Figure 3.7. In this case, the feeder enterprise output is supplied to five or more receiver enterprise systems, such that enterprise system E_1 supplies performance capabilities to all E_2, E_3, E_4, E_5, and E_6 as shown in Figure 3.7:

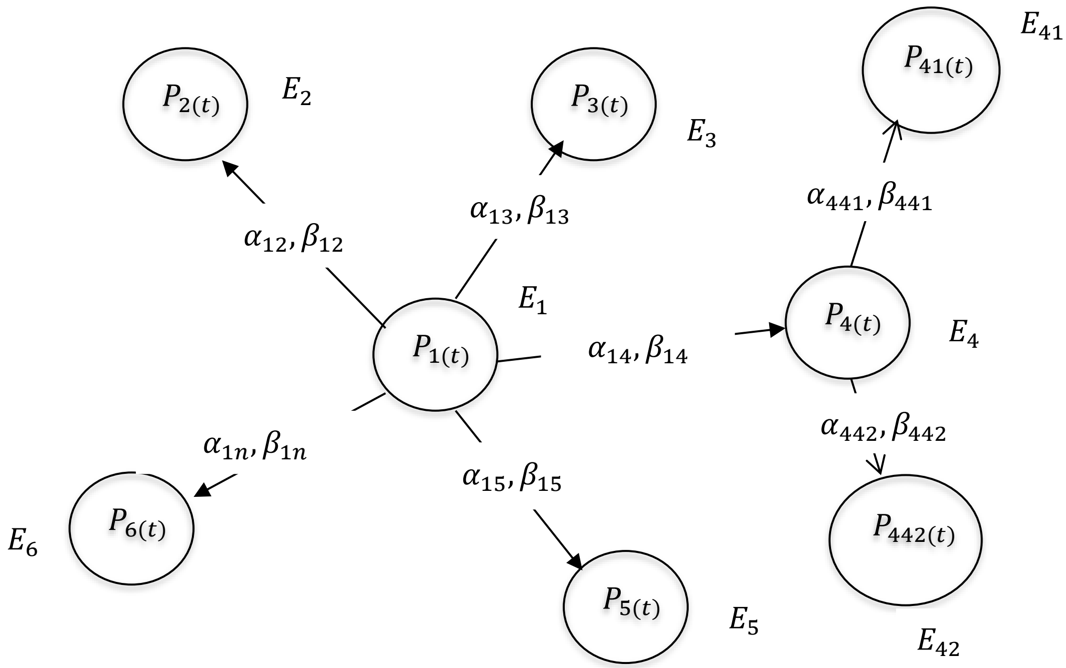

Figure 3-6: Interdependency between several enterprise systems

See Definition 3.1 for network-topology

Then

$$\alpha_{12} + \alpha_{13} + \alpha_{14} + \alpha_{15} + \alpha_{16} \leq 1 \quad \text{……………………………..} \quad (63)$$

Therefore, performance capability produced by E_1 is supplied to all the enterprise systems, E_2, E_3, E_4, E_5, and E_6 . As indicated above all the strength of interdependencies have non-zero values and all lie between zero and 1.

Therefore,

$$0 < \alpha_{12}, \alpha_{13}, \alpha_{14}, \alpha_{15}, \ldots, \alpha_{1n} \leq 1 \qquad \ldots\ldots\ldots \quad (64)$$

Also, we can determine α_{441} and α_{442} to be in the range as:

$$0 < \alpha_{441}, \alpha_{442} \leq 1 \qquad \ldots\ldots\ldots \quad (65)$$

The values of α_{12} and the others are determined by using statistical regression analysis from the two time series data from the two enterprise systems.

4 APPLICATION OF FDNA TO GHANA SALT SYSTEM

4.1 PROBLEM SPACE

Ghana and most of the developing countries have operated as stand-alone several enterprise systems or silos of enterprise systems. Such operations are costly and are not manageable. However, it is mostly understood that the output they require to grow their economies can be set up in clusters of interdependent enterprise systems, sharing resources and creating technologies and knowhow that fit their sectors of the economic outputs. An example of this is the Ghana salt enterprise systems, shown in Figure 4.1 below.

The Ghana salt enterprise consists of a salt winning that produces Sodium Chloride. The Sodium Chloride is supplied to a Chlor-alkali enterprise or to an enterprise that produces staple salt for human Consumer. The Chlor-alkali enterprise produces outputs for the Bauxite, Mining, Textile, Pulp and Paper, Water Treatment, Soap and Detergent enterprise systems. Thus, given this realm of analysis for interdependency enterprise systems, modeling and simulation efforts for the Ghana salt enterprise system are intended to achieve growth in Ghana's economic output. In manufacturing fields, interdependency occurs through combinations different of technology, or it can be of different types of systems. Society demands quality products made at lower cost and abundantly available.

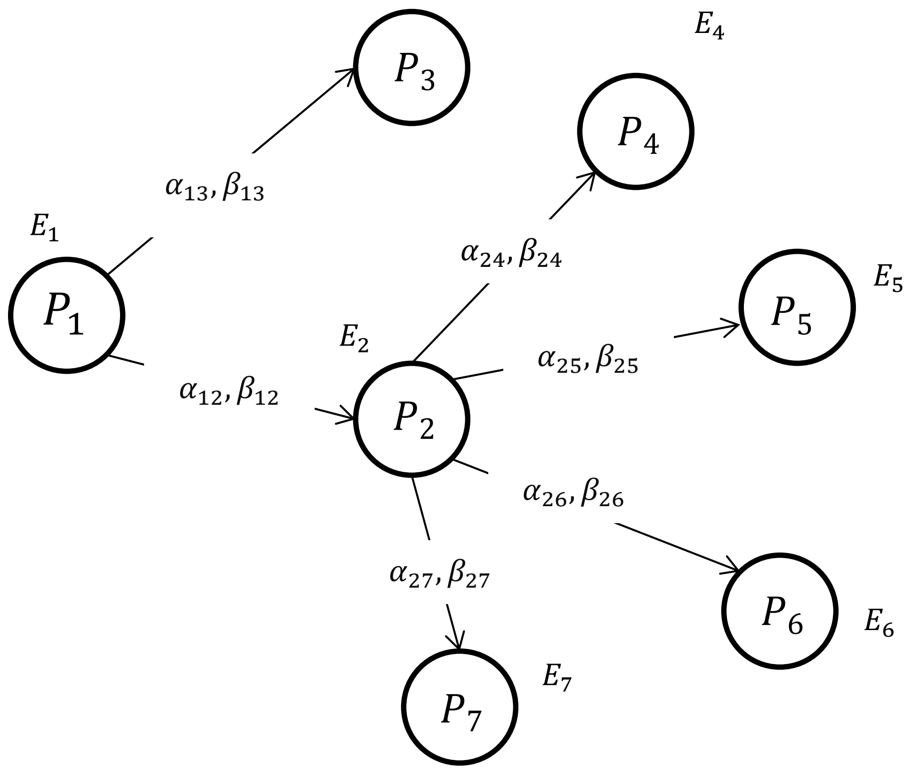

Figure 4-1: The Ghana Salt ENTERPRISE System

Making abundant and quality products at a low enough price for consumer acceptance can be achieved using enterprise systems modeling that utilize risks of interdependency methodology in the enterprise systems design, and their subsequent emergent behavior. Enterprise systems modeling and simulation efforts for the Ghana salt enterprise system are intended to achieve a real growth in Ghana's economic output. In manufacturing fields, interdependency can come from different combinations of technology, or it can be of different types of systems. Society demands quality products made at lower cost and abundantly available.

Enterprise systems risk of interdependency include the following initiating events, which are similarly described by Rinaldi et al. (2001) in terms of their general categories shown within their boundaries so that making abundant and quality products at a low enough price for consumer acceptance is an enterprise model that can involve risks of interdependencies in the enterprise systems and in the subsequent emergent systems behavior. Enterprise systems within two different environments have influences separate from each other as shown below:

1. Physical – a physical reliance on material flow from one enterprise system to another enterprise or enterprises system
2. ICT – a reliance on information transfer between enterprise systems components to other enterprise systems and their components
3. Geographic – how the local environmental events affect components across multiple external and internal components of enterprise systems due to physical proximity of an area, state, region, or country
4. Logical – some interdependency that exists between enterprise systems which does not fall into one of the above categories such as systems instrumentation and their programing impacts

And lastly, in developing countries where many languages are spoken, cultural differences also become a major problem when running an enterprise system. The interdependencies or influences that network component events may have on cultural issues or public confidence include:

Cultural - beliefs, values, norms, and tangible signs (artifacts) of organization members and their behaviors (Suda, 2006). According to Suda (2006), understanding the culture of an organization is critical to running successful enterprise systems. Culture resides in every fold of an enterprise, influencing the dynamics of how people perform, relate, and perceive the organization's impact on their lives.

4.2 THE GHANA SALT ENTERPRISE SYSTEM NETWORK

The Ghana salt enterprise system as shown above consists of the salt work or the salt winning E_1 which produces pure salt for the chlor-alkali enterprise system E_2 and salt for human, or staple salt, Consumer, E_3. The chlor-alkali enterprise system produces Hydrogen, Sodium Hydroxide, and Chlorine for downstream enterprise systems, which have many applications.

The Ghana salt enterprise system, consisting of the salt winning E_1, the Chlor-alkali salt enterprise systems E_2, and the staple salt enterprise system E_3 are developed based on state space elements given above and rely on how well Ghana develops its vast natural resources to grow the economy. Ghana needs to develop key enterprise systems, such as Sodium Hypo-chlorate for water and wastewater treatment, Caustic Soda for the Bauxite and other minerals refining industries, and pulp and paper products that will form clusters of enterprise systems to develop a technology that fits the local content. With all its related technology, information and communication systems and training of the workforce, managing such technologically related enterprise systems is a huge undertaking. Such industries are now taking shape in Ghana today, as results of the oil find.

As shown above in Figure 4.1, there are several other products that can be developed by Ghana if the pure salt production is seriously constructed and managed by Ghana to improve the country's economy. Examples of other enterprise systems that would be developed in the chemical enterprise systems consist of the petro-chemical products, pulp and paper, textile, cosmetics, leather, medical drugs, and plastics and pipes industries. Also, in the chemical industry, pure salt is used for crude oil production, petroleum refining, and there are major use Chlorine, Sodium Hydroxide, and Hydrogen from the Chlor-Alkali industry to produce several products for economic development.

In Ghana, the lead enterprise systems are the Petroleum and Gas, Salt, Bauxite, Textiles, Water treatment, Pharmaceutical, Pulp and Paper and the Chlor-Alkali and other mineral ores enterprise systems. The salt enterprise E_1 consists of three capability portfolios with five program nodes to form an enterprise system as shown in Figure 4.2.

A fourth capability portfolio node could be installed if Potassium compound from the seawater were also needed. To produce Sodium Chloride salt, only three capability portfolio nodes are required. The Chlor-Alkali downstream products are found in several applications in the petrochemical and chemical industries.

Therefore, 60 percent of Sodium Chloride salt produced from the Chlor-Alkali enterprise is used by the petrochemical and the chemical industries, while 30 percent is used for staple salt production and other small applications, mostly for food, available in several sources in different qualities such as table, are used for cooking, and food preservation salt.

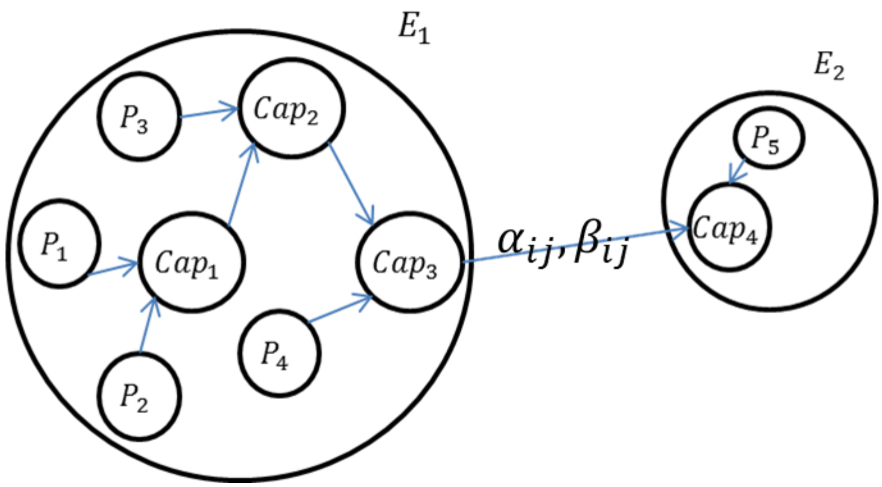

Figure 4-2: A simple FDNA Network of Ghana Salt of E_1 and E_2 enterprises

As indicated above, the highest amount of salt Consumer is by the chemical industry, which is a business decision.

Therefore, the business decision set by the chemical industry as the industry standard is used for this study. The solar salt produced by the Ghana salt enterprise system must be according to the chemical industry standard. This means producing salt that meets the Chlor-alkali specifications. The present salt produced by the Ghana salt enterprise does not meet this requirement. This means that the outcome of the third capability portfolio of the salt winning enterprise system must produce the outcome that becomes an input product for the Chlor-alkali enterprise system as a base standard for the other enterprise systems. All receiving enterprise systems, such as the Chlor-alkali and the stable salt enterprise systems, would receive salt that meets the Chlor-alkali salt requirement. In this study, we will look at the salt enterprise and the chlor-alkali enterprise as two key interdependent enterprise systems, E_1 and E_2, whose risk of interdependency is being studied. Interdependencies between other enterprise systems such as $E_1 - E_4, E_2 - E_3, \ldots\ldots E_{n-1} - E_n$ can be studied at another time.

Interdependent enterprise systems $E_1 - E_2$ are two key functions that can offer great opportunity for Ghana's industrial development because of the cluster of the enterprise system that will be borne by creating that initial network of enterprise systems. In figure 4.2, we look at Cap_3 and Cap_4 as the two nodes in the $E_1 - E_2$ interdependent enterprise systems for the study of risk of interdependency. The risk of interdependency for stationary models in a single enterprise system E_1 has been studied by Garvey (2009) but more studies about interdependent network systems between two enterprise systems E_1 and E_2 and the effect of the risk of interdependency between nodes in the enterprise systems are needed.

While Cap_1 and Cap_2 are important functions to perform within E_1 before Cap_3 is produced, the stationary work of such studies is covered by Garvey. In this work, it is assumed that the risks of interdependency between elements of enterprise systems are well understood and that the final goals are successfully implemented. We must then look at the interdependency between E_1 and E_2 as shown in Figures 4.2 above.

5 THE GHANA SALT ENTERPRISE SYSTEM

5.1 THE KETA AND SONGOR LAGOONS

Hourly samples taken from the Morton Salt Company Plant in the Bahamas from the concentration and crystallizing ponds are shown in Appendix A. The seawater concentration and summer temperatures in the Bahamas are like that of Ghana. Therefore, the data from the Morton Bahamas Salt Company fits well with the conditions for salt winnings in Ghana, where solar evaporation also occurs at 30˚C. The component solutes and the seawater density increase as water evaporation occurs similarly in Ghana. Calcium concentration peaks at seawater density of 1.084 gm.(cm)-3 and begins to precipitate in the concentration ponds. Therefore, the concentration pond must be designed to completely remove all Calcium ions from the solution.

Other component ions such as Potassium, Magnesium, and Sodium concentrations continue to increase as water evaporates and the solution density and alkalinity increases. Shown in Figure 5.1, the Magnesium-ion concentration increases as the density increases as a result of water evaporation and Magnesium ions will continue to remain in the solution until most of the Sodium ions are removed at its peak level. As shown in Figure 5.2, removing Magnesium ions first from the solution by chemical precipitation improves water evaporation and the Sodium salt quality as well as the quantity recovered (Balarew, 1993; Voigt, 2001). As water evaporates and both the solution density and alkalinity increase, Magnesium forms several enterprise ionic compounds with the component elements in the seawater that are very difficult to remove.

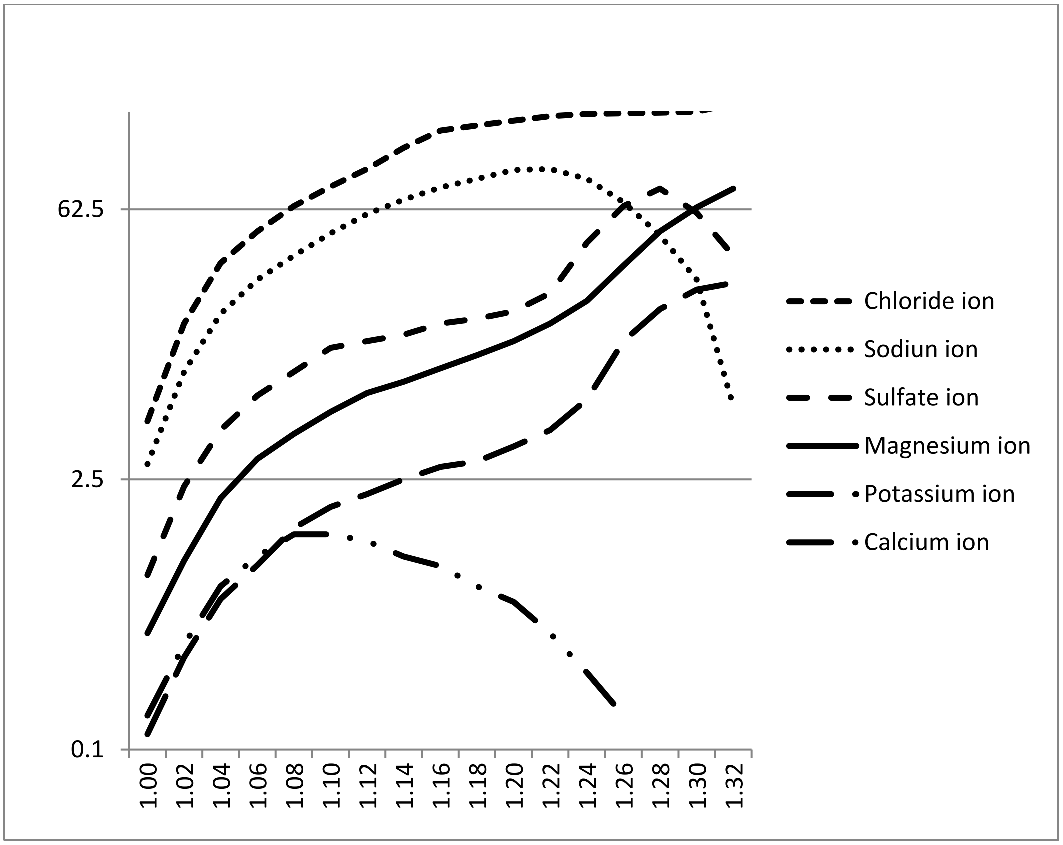

Figure 5-1: Solubility of the components of Seawater for Ghana Salt enterprise

When the salt water density reaches 1.214, as seen in both Figure 5.1 and 5.2, fewer Calcium-ions remains as Sodium-ions concentration peaks and begins to precipitate.

Figure 5.2 is without the Magnesium-ion as it has been removed by chemical reaction. In Figure 5.2, water evaporates quickly, and the Calcium-ion concentration increases and peaks at a density of 1.06 and starts to precipitate. Fewer Calcium ions remain in the solution as the salinity increases.

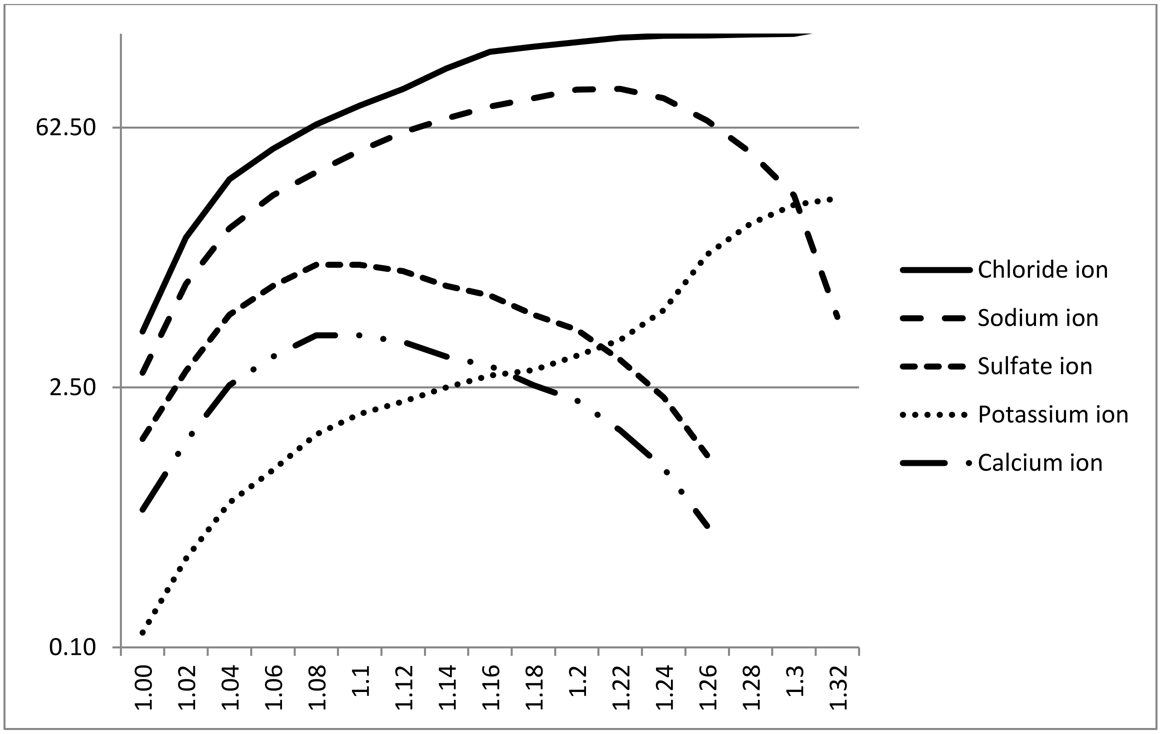

Figure 5-2: Solubility curve of seawater components without Magnesium ions at 25˚C

At a density of 1.21, the Sodium-ion concentration peaks and begins to precipitate. At this point the solution is transferred to the crystallizing ponds for Sodium salt to precipitate. In a salt rich solution of Sodium and Potassium ions, the Sodium Chloride salts precipitate very quickly and at appreciable levels as the solution density reaches 1.218 in the crystallization ponds.

Crystallization is aided by water evaporation as a result of heat energy brought to the pond's surface by the sun's radiation. The latent heat of water evaporation at 30˚C is 0.675 kWh (kg)-1 of water evaporated. Also, the Earth's solar energy budget in West Africa where cooling provides a minimum energy lost due to wind velocity, solar energy available for water evaporation is found to vary between 7.6 – 8.7 kWh (day)-1 at the earth's surface (Sedivy, 2009). The expected water evaporation in West African's tropical zone is 11.259 – 12.89 kg/day.

The result of experimental studies and data obtained from solar evaporation of seawater in the crystallizing ponds are shown in Appendix B, Table B. The changes in Sodium-ion concentration as the density and alkalinity of the solution increases, indicates the quantity of salt precipitated in an hour of any typical average summer day in Ghana.

It is assumed that Magnesium is removed by chemical precipitation to improve salt precipitation as shown in Figure 5.2, and in Table B2 in Appendix B, with Calcium salt already precipitated in the concentration ponds before sending the solution to the crystallizing ponds. Equation 58 is used to determine the amount of Sodium Chloride salt precipitated and the daily rate of salt production is shown in Figure 5.2. The precipitated Sodium Chloride salt is fed to the Chlor-alkali and the food grade manufacturing enterprise systems after several cleaning steps to remove the remaining impurities and sand.

This research interest is on the risk of interdependency between the salt winning enterprise system, the chlor-alkali enterprise, and the table salt enterprise system that package salt for human Consumer. From this analysis and the rate of production, a crystallizing pond with a surface area of 150 m2 will produce 8,000 tons of salt per year. Using the same Consumer ratios between industry supply and that of food Consumer, it will require 32 equal size crystallizing ponds to meet both industrial use of salt and to supply for food additives in a year. Dolbear (2003) has confirmed that the government of Ghana has allocated more land for this project and the analysis shows that the project is equally feasible.

In an experimental setting, the systems were constructed to dynamically link the two systems. We conclude that a function exists between the feeder and the receiver enterprise systems that map the values from the feeder enterprise system into the receiving enterprise system.

In this situation, it is known that there exists between the two enterprise systems a degree and direction of coupling within their elements and that there is the existence of dynamical interdependency. We then record the observable variables of both systems and apply statistics time series analysis to check the existence of dynamic interdependency. Equation 58 and Figure A3 were used to determine the amount of Sodium Chloride precipitated in the crystallization ponds as a function of time. Samples were taken from both the concentration and crystallization ponds in two hour intervals over a two-day period.

Water evaporation takes place across the ocean by utilizing the sun's solar energy and the water condenses in the atmosphere and falls to the earth's surface as rain water. Throughout this circle of change, the solute concentration remains virtually constant.

Figure 5.1 indicates the solubility curve of seawater. As water vaporizes the alkalinity of the water increases as a function of the water's specific gravity and the components in the seawater begin to precipitate.

We then look at the interdependency between E_1 and E_2 as shown in Figure 4.2 below. The primary salt-works E_1 consists of three capability portfolios and is designed to remove first Magnesium salts by chemical reaction before sending the Magnesium free filtrate to the main holding pond. The concentration ponds are designed to increase the solution alkalinity to the level where the Calcium salt will precipitate. The filtrate is then flowed by gravity to a series of shallow (40 – 60 cm) concentration ponds to evaporate most of the water and precipitate the Calcium salt.

The high alkalinity salt solution is then transferred to the series of crystallizing ponds (40 – 60 cm) to precipitate the Sodium Chloride salt.

As stated, the first capability portfolio is the removal of soluble Magnesium ions by chemical precipitation from water taken from the Keta or Songor Lagoons. Suitable locations for a salt production site require a climate with low monthly and annual rainfall, with continuous and vigorous winds, a low concentration of organic and inorganic nutrients, and a low content of sand, soil and silt and microorganisms. Normally if seawater is used, a series of shallow ponds are made to hold seawater in a reservoir to remove debris and to provide for an additional evaporation mechanism. The water in the reservoir has a higher density and alkalinity than the seawater and can supply debris-free water to the concentration ponds at a higher water temperature than the seawater and at a higher density and alkalinity for increased water evaporation. The initial salt water from the sea enter the ponds at a 3.5 °Be (between 1.025 - 1.08 specific gravity). The shallow concentration ponds occupy 60% of the salt winning area for the greater amount of water evaporation. Salt concentration continues up to 1.225 before transferring the concentrated salt solution to the crystallizing ponds.

5.2 MAGNESIUM SALTS PRECIPITATION BY CHEMICAL REACTION

Magnesium Sulfate and Magnesium Chloride compounds are first removed by chemical precipitation before solar evaporation to remove Calcium and Sodium salts. Calcium Carbonate is first calcite to give Calcium Oxide, which is dissolved in water to from the Calcium Hydroxide.

The resultant solution is added to the salt solution as it flows into a holding tank. The reaction that takes place is as follows:

$$C_aO + H_2O \rightarrow C_a(OH)_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(66)}$$

$$2C_a(OH)_2 + M_gCl_2 + M_gSO_4 \rightarrow 2M_g(OH)_2 \downarrow + C_aSO_4 + C_2Cl_2 \quad \ldots\ldots \text{(67)}$$

The soluble Magnesium compounds are precipitated as Magnesium hydroxide and are recovered by filtration. The remaining solution which is made up of mainly Calcium, Sodium and Potassium salts is pumped into the holding pond to further precipitate any additional solutes before being sent to the concentration ponds. The design of the salt work is done to provide minimum pumping from the lagoon to the initial reservoir. Throughout all the chemical precipitation steps, from the reservoir through the concentration ponds to the crystallizing pond, the salt solution is transferred by gravity flow.

5.3 SOLAR PRECIPITATION OF CALCIUM SULFATE

The salt solution from the holding pond (the reservoir) is then directed through a mixing tank containing Calcium Hydroxide for removing the Magnesium ions from the salt solution. After removing Magnesium compounds from the salt water solution through chemical reaction, the resultant solution is filtered and transferred to the low salt concentration holding pond, where the water is then directed to the initial concentration pond for water evaporation and Calcium salt precipitation.

Solar salt works use energy from the sun and wind to evaporate seawater in outdoor ponds to precipitate Calcium and Sodium salts from sea water. In Ghana, solar salt can be produced semi-continuously though it should be shut down during the rainy season. The solution in the crystallizing ponds could be directed to secured reservoirs and held there during the rainy season. The water in the concentration ponds should remain there during the rainy season.

During the dry season, the solar salt works maintain continuous flow of water at desired salinity gradients throughout the series of concentration ponds (Davis, 2000). The Ghana coastal area lies in a tropical climate zone north of the equator, suitable for solar salt production. As the concentration of the salt solution increases, the water moves to other concentration ponds. At 13.2 °Be (between 1.162 – 1.215) Calcium Sulfate precipitates. Above 1.215, the brine solution is transferred to the crystallizing ponds.

The non-stationary model for the Calcium precipitation is expressed as follows:

$$\frac{dM_{C_a salt}}{dt} = -P_{C_a s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (68)$$

where $M_{C_a salt}$ is the mass of Calcium ions in solution in the concentration pond?

$P_{C_a s}$= the sum of all large salt precipitated fluxes

As the water in the concentration in the ponds evaporate and the density of the solution increases and the precipitation of Calcium salt begins between 1.162 and 1.215. Calcium is precipitated in the concentration ponds as Calcium ions in the concentration ponds decrease. From equation 61, the change in ion concentration represents the amount of Calcium salt precipitated. In solution, there exist Calcium (Ca2+) ions and Sulfate (SO42-) ions which combine to form the salt as follow:

$$Ca^{2+} + SO_4^{2-} = CaSO_4\downarrow \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (69)$$

Therefore,

$$\int_{Ca_{(0)}}^{Ca_{(t)}} M_{Ca_{ion}} = -\int_0^t P_s dt = -P_s \int_0^t dt \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (70)$$

$$M_{Ca_{ion}}(t) - M_{Ca_{ion}}(t-1) = -P_s t \quad \ldots\ldots\ldots\ldots\ldots \quad (71)$$

As Calcium salt precipitates, Calcium ions in solution decrease, making the left-hand side of equation 64 negative. Continuous solar evaporation increases the alkalinity of the salt water, and Calcium ions decrease to less than five percent of the original Calcium-ion concentration, the Sodium-ion increase and reaches near its peak at the water density of 1.25.

5.4 WATER MASS BALANCE EQUATION

The water from the lagoon has no water discharges nor does ground water flow to it. Therefore, precipitation and evaporation are the predominant components of the water mass balance equation. Solar radiation supplies solar energy to vaporize water in the pond in both the concentration and crystallization ponds. The change in total mass of water in both concentration and crystallization ponds can be expressed as

$$\frac{dm}{dt} = (Evap - P_c - C)s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (72)$$

where

$m = mass\ of\ water\ lost\ from\ the\ pond\ per\ hour$

$Evap = amount\ of\ water\ evaporated\ per\ hour$

$P_c = Precipitation, rain\ fall\ in\ a\ day$

$C = amount\ of\ condensation$

$S = Surface\ area\ of\ pond\ (\ m^2)$

The modified Penman formula used to determine the evaporation and condensation fluxes is (Calder and Neal, 1984):

$$Evap. = \left[\frac{\frac{M_W Le_S}{RT_a^2}}{\left(\frac{M_W Le_S}{RT_a^2} + \frac{\rho Cp}{qL_W a}\right)}\right]\frac{H}{L_w} + \frac{\rho C_p}{qL_w^2}\left[\frac{P_w - \frac{P_S}{a}}{\left(\frac{M_W Le_S}{RT_a^2} + \frac{\rho Cp}{qL_W a}\right)}\right](0.036 + 0.025u) \quad \ldots\ldots \quad (73)$$

The formula used to estimate the activity of water (Garrels and Christ, 1990) is:

$$a = 1 - \frac{0.017 \sum_{i=1}^{n} \frac{(Ms)_i}{M_i}}{M_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (74)$$

where

$a\ =\ the\ activity\ coefficient\ of\ water\ in\ solution$

$C_p\ =\ the\ specific\ bulk\ heat\ of\ air\ at\ constant\ pressure\ =\ 0.24\ (Btu/lbm^{\circ}F)$

$H = the\ sum\ of\ latent\ and\ convection\ heat\ fluxes$

$L_w =\ the\ evaporation\ enthalpy\ of\ water\ at\ 30\ ^{\circ}C\ is\ 0.675\ kWh\ /kg$

M_{wi} = Molecular weight of the ion i

$M_s = the\ corresponding\ mass\ of\ the\ ion\ i$

$M_w = molecular\ weight\ of\ water$

$P\ =\ the\ atmospheric\ pressure\ \ = 14.7\ psig$

$q\ =\ the\ molecular\ weight\ ratio\ of\ water\ to\ air\ 18.0153/29$

$P_s =\ the\ observed\ partial\ pressure\ of\ water\ vapor$

$P_w =\ partial\ saturation\ pressure\ of\ water\ vapor\ in\ air$

$T_a =\ the\ temperature\ of\ air\ at\ the\ earth's\ surface\ \ =\ 30°C$

$u\ =\ the\ surface\ wind\ velocity$

$a\ =\ activity\ coefficient\ as\ a\ function\ of\ salinity$

Also, during evaporation as salinity increases the seawater components with the lower solubility will begin to precipitate. In this case, the Calcium ions will precipitate as Calcium Sulfate between specific gravity of 1.10 and 1.15. Evaporation will continue until the alkalinity of the solution reaches almost 25.7 °Be, specific gravity of 1.215, and ionic strength of 6.42. At this point, the salt solution, almost free of Calcium, is transferred to the crystallization ponds.

5.5 SOLAR SALT ($NaCl$) PRECIPITATION

The dynamics of solar precipitation is very important to this research. At this point, it is assumed that both the Magnesium and Calcium compounds are removed. Sodium salt precipitation begins at 25.7 °Be (between 1.215 - 1.218 specific gravity). Since there is no external flow into the ponds, we look for the water mass balance as it is shown above, and the salt balance equation as shown below.

While Sodium salt precipitates, Sodium ions in the solution decrease, making the left-hand side of equation 68 negative. Continuous solar evaporation increases the alkalinity of the salt water and Calcium ions decrease to less than five percent of the original content at the peak of Sodium ion concentration.

The non-stationary model for the Sodium Chloride precipitation is expressed as follows:

$$\frac{dM_{N_a salt}}{dt} = -P_{N_a s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (75)$$

where $M_{N_a salt} = the\ total\ mass\ of\ desolved\ solutes\ in\ the\ concentration\ ponds$

$P_{N_a s} = the\ sum\ of\ all\ large\ scale\ salt\ precipitated\ fluxes$

From equation 77, the change in ionic concentration gives the amount of Sodium salt precipitated. In solution, there exists Sodium (Na^{+}) ions and Chloride (Cl^{-}) ions react to form the salt as follows:

$$N_a^{+} + Cl^{-} = N_a Cl \downarrow \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (76)$$

Therefore,

$$\int_{Na_{(0)}}^{Na_{(t)}} M_{Na_{ion}} = -\int_0^t P_s dt = -P_s \int_0^t dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (77)$$

$$M_{Na^{+}{}_{ion}}(t) - M_{N^{+}a_{ion}}(0) = -P_s t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (78)$$

The amount of Sodium ions precipitated is obtained as a function of time as shown in equation 76. The Sodium ions react with Chlorine ions in the solution and are converted into Sodium Chloride as follows:

$$N_a^+ + C_l^- \rightarrow NaCl \downarrow \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (79)$$

More Sodium Chloride is precipitated in the crystallizing ponds as more water is evaporated by the solar radiation.

5.6 HEAT FROM SOLAR RADIATION

In enterprise E_1 solar energy from the sun is used to precipitate both Calcium and Sodium salts. Calcium Sulfate is less soluble in water than Sodium as such it is the first salt to precipitate out at between the density of 1.10 and 1.15. Solar salt needed by E_2 precipitates at a higher density, between 1.22 and 1.25. Solar salt is produced by utilizing the solar energy from the sun. One hundred percent of the incoming solar energy provides between 1,412 and 1291Wm^{-2} amount of energy (Mottershead, 2006). However, only 51% of the energy, equivalent to 658 to 705 Wm^{-2} of energy reaches the earth's surface. This averages to 329 to 353 Wattsm^{-2} of energy for a typical area in the West African coastal area, where the coastal area receives direct radiant energy from the sun over an average of 12 hours daily.

Latent heat of water evaporation at 30oC is 0.675 kWhkg^{-1}. This is equivalent to 7.9 to 8.5 kWhm^{-2}d^{-1} of surface insolation. If all the energy was to be absorbed, it could evaporate between 11 and 12.59 kg of seawater (1029 kg of seawater occupies 1m^3 of volume). Due to the cooling of brine by wind, and reradiating into the atmosphere and space, only 23% of the solar energy is absorbed. Therefore, the amount of water evaporated per day is between 2.53 and 2.90 kg of seawater per day. The depth of the concentration and crystallizing ponds are set, and the only variables are the surface area.

5.7 FDNA MODELING OF THE GHANA SALT ENTERPRISE SYSTEM

Salt as Sodium Chloride was originally used in the human diet and was found to have significant properties for food preservation. At present, salt has become one of the most important commodities in the modern world. Salt can only be compared to that of petroleum for its significant as a commodity which is greatly used in industrial applications to produce other commodities needed to achieve economic development. Large quantities of salt are needed in all sectors of Ghana’s economy: for water treatment, industrial applications for industrial mineral ores refining, for the petroleum refining and crude oilfields applications, medical applications, as well as the production of consumer products.

Salt exists in rock caves, lakes, and most abundantly in seawater. In Ghana, salt from the sea enters the lagoons where the salt concentration grows higher due to the evaporation of water from the lagoons. The seawater and the lagoon salts contain additional components such as Magnesium Sulfate, Calcium Carbonates, Potassium Chloride, as well as the required Sodium Chloride. These components of Sodium Chloride can be used for other applications, but their presence in the seawater makes obtaining pure Sodium Chloride for use in commercial, dietary products, and for medical applications very difficult. Therefore, these components in the seawater are unwanted products which must be removed to obtain a pure form of Sodium Chloride.

In the Chlor-alkali plant, Magnesium Sulfate is a by-product that when found in large concentration will create a very explosive mixture that can lead to loss of lives and property. Calcium Carbonate compounds forms scales in processing equipment that reduces the efficient use of much equipment.

Continuously operated salt-works are designed to maintain water flow from one pond to another, from the concentrated ponds to the crystallizing ponds.

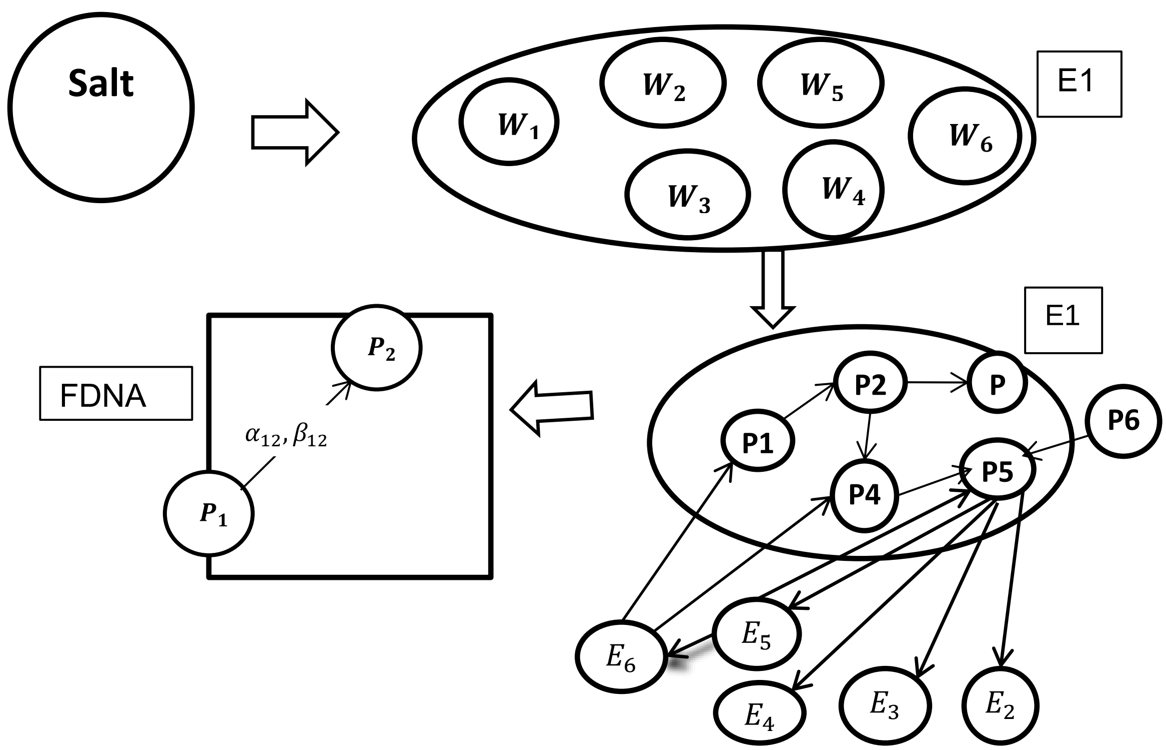

Figure 5-3: Developing FDNA Network System

The FDNA methodology of identifying, representing, and measuring dependencies between enterprise systems in suppliers-receivers relationships will make it possible to obtain the pure salt that Ghana's Economy needs. We begin the Ghana salt model with the identification of a system that can be put together to represent the flow of information from the start of the salt winning to the precipitation of the final pure salt.

The measuring and sizing of the interdependent systems, from the salt winning throughout the final component of the enterprise systems will enable the study of a ripple effect of failure from one capability portfolio to the other interdependent capability portfolio, as shown in Figure 4.2 (Garvey & Pinto, 2009).

Developing a non-stationary FDNA model to study the ripple effects of failure in the Ghana salt enterprise systems will provide for time varying changes between interdependent enterprise systems throughout the Ghana salt enterprise. The ripple effects of failure are best understood by studying the non-steady state equation of the Ghana salt enterprise systems shown in Figure 4.4 where the capability is from P_1 of the feeder enterprise, E_1, and P_2 the capability of the receiver enterprise E_2, and P_3 of enterprise E_3.

In most systems in the petroleum and the petrochemical enterprise systems, as well as many other enterprise systems where the objective is to add value to the outcome, the dynamic effect of failure in interdependent systems can be catastrophic in nature. Examination of their ripple effects in interdependent systems output variables or outcomes will mean a safer and more profitable operation of the systems. The study of the non-stationary behavior of processes enable scientists the opportunity to know at what speed and time a system brought down by the failure of its component systems can be brought up and reach stationary conditions after start-up, and what it costs the systems to do so.

In non-stationary consideration, both P_i and P_j, are all functions of time. Both the strength of dependency and criticality of dependency can vary as well as a function of time and/or as a function of both P_i and P_j. Enterprise systems can be represented by a time domain model shown in equation (1) and can be represented as shown in Figure 3. Consider the time-varying dynamic system given below in equation 72. The accumulation term can be expressed as the change in mass as a function of time

This paper seeks to provide an understanding of an outcome of an enterprise system going through a cascading effect due to a time-varying perturbation of some elements in the receiver enterprise system. If given that node P_i produces an outcome that node P_j needs, there is an event which produces a change in the outcome produced by E_i, whether positive or negative, we need to understand that change and its impact to the final outcome, in order to respond to the consequence of its effect. In the most general form, the conservation principle of mass, energy and momentum, states that

$$\text{Input} - \text{Output} = \text{Accumulation} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (80)$$

Accumulation is regarded as the amount of salt precipitated during solar evaporation. A system which is at steady state (stationary) condition as described by Garvey (2009) where there is no change in the system output as a function of time cannot predict the instantaneous impact of failure. Therefore, the total input of any conserved quantity to any unit must be equal to the total output.

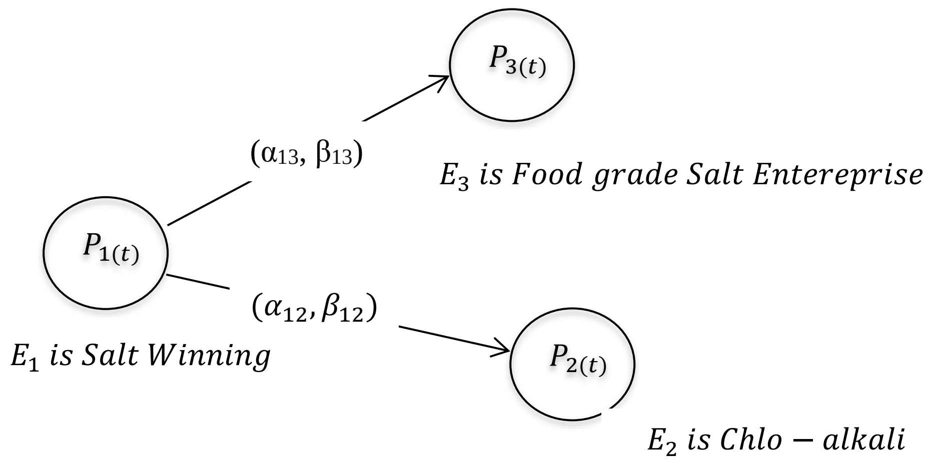

Figure 5-4: Interdependency Modeling of enterprise Systems in Ghana Salt

We now want to extend our theoretical models to include the dynamic operating characteristics by including the time variation of both the receiver and the feeder enterprise variables, $P_{j(t)}$ and $P_{i(t)}$ as shown in equation 4 and Figure 3.5. The time variations of both the dependent and independent variables introduce a tremendous amount of additional complexity into the model equations.

For a three nodes graph, let us assume that $i = 1$ and $j = 2$ and $k = 3$. Then the model can be shown in Figure 5.4 as a three nodes graph below. Following a standard convention (Bird et al., 1960), we look at the impact of the change on $P_2(t)$ and $P_3(t)$ as a result of the change occurring at node $P_1(t)$ at time t and $t + \Delta t$. The accumulation term can be expressed as

$$P_2(t)I_{t+\Delta t} - P_2(t)I_t = \int \left(P_1(t), \alpha_{12}(t), \beta_{12,}(t)\right) \Delta t \quad \text{……...……} \quad (81)$$

$$\frac{dP_2}{dt} = \frac{Limit}{\Delta t \to 0} \frac{P_2(t)|_{t+\Delta t-} P_2|_t}{\Delta t} \quad \text{…………………} \quad (82)$$

But, as the two enterprise systems are not within the same boundary,

$$\frac{dP_2}{dt} = \alpha_{12} \frac{dP_1}{dt} \quad \text{…………………..……………} \quad (83)$$

$$\alpha_{12} = (\frac{dP_2}{dt})/(\frac{dP_1}{dt}) \quad \text{……………………………} \quad (84)$$

where,

$$0 < \alpha_{12} \leq 1 \quad \text{…………………………...} \quad (85)$$

Also,

$$P_3(t)I_{t+\Delta t} - P_3(t)I_t = \int \left(P_1(t), \alpha_{13}(t), \beta_{13,}(t)\right) \Delta t \quad \text{……………} \quad (86)$$

where,

$$\frac{dP_3}{dt} = \frac{Limit}{\Delta t \to 0} \frac{P_3(t)|_{t+\Delta t-} P_3|_t}{\Delta t} \quad \text{…………………} \quad (87)$$

Therefore, since the two enterprise systems are not within the same boundary,

$$\frac{dP_3}{dt} = \alpha_{13} \frac{dP_1}{dt} \quad \text{…………………..…………...} \quad (88)$$

Therefore,

$$\alpha_{13} = (\frac{dP_3}{dt})/(\frac{dP_1}{dt}) \quad \text{……………………………} \quad (89)$$

where,

$$0 < \alpha_{13} \leq 1 \quad \text{………………………} \quad (90)$$

6 NUMERICAL DETERMINATION OF PARAMETERS

6.1 SAMPLES FROM MORTON SALT COMPANY

Hourly samples taken from the Morton Salt Company Plant in the Bahamas were taken from the concentration and crystallizing ponds as shown in Appendix A. The seawater concentration and summer temperatures in the Bahamas are like those of West Africa and therefore the data fit well to the conditions in West Africa, where solar evaporation occurs at 30˚C. The component solutes concentration increases as the seawater density increase during water evaporation due to solar radiation. Calcium concentration peaks at seawater density of 1.084 gm. (cm)-3 and begins to precipitate in the concentration ponds on further water evaporation.

Other component ions such as Potassium, Magnesium, and Sodium concentrations continue to increase as water evaporates and the density of the salt solution increases. As shown in Figure 2.2, removing Magnesium ions first from the solution by chemical reaction improves water evaporation and solutes precipitation of salt recovery quality as well as quantity (Balarew, 1993; Voigt, 2001).

Sodium-ion concentration peaks as the salt water density reaches 1.214, only a minimum amount of Calcium ions remains. At this point the solution is transferred to the crystallizing ponds for Sodium salt to precipitate. In a salt rich solution of Sodium and Potassium ions, the Sodium salt precipitates very fast and precipitation begins at a density of 1.218 in the crystallization ponds.

Crystallization is aided by energy from the sun. The latent heat of water evaporation at 30˚C is 0.675 kWh (kg)-1 (Sedivy, 2009). Also, the Earth's solar energy budget in West Africa, where cooling provides a minimal energy loss due to wind velocity, energy available for water evaporation is between 7.6 and 8.7 kWh (day)-1 at the earth's surface. The expected water evaporation in West Africa's tropical zone is 11.259 to 12.89 kg/day.

The experimental data in the crystallizing ponds and the result are shown in Appendix A, Table A1. The change in Sodium ions as the density increases indicates the quantity of salt precipitated in an hour in an average summer day. It is assumed that Magnesium is removed by chemical precipitation and Calcium salt is precipitated in the concentration ponds at a lower solution density before sending the solution to the crystallizing ponds.

This research interest is in the risk of interdependency between the salt production enterprise system, the chlor-alkali enterprise system, and the salt Consumer enterprise system. From this analysis and the rate of production, a crystallizing pond with a surface area of 150 m2 will produce about 8,000 tons of salt per year. Using the same Consumer ratios between industry supply and that of food Consumer, 32 equal size crystallizing ponds will be required to meet both industry and supply demand for food additives in a year. Dolbear (2003) has confirmed that the government of Ghana has allocated more land for this project and their analysis shows that the project is equally feasible.

In an experimental setting, the systems were constructed to dynamically link the two systems. Since the feeder node supplies performance capability to the receiver node, we conclude that a function exists that maps the values from the feeder enterprise system into the receiving enterprise system. In this situation, it is known that there exists between the two enterprise systems a degree and direction of coupling within their elements and that there is the existence of dynamical interdependency.

We then record the observable variables of both systems and apply statistics to check the existence of dynamic interdependency. Equation 28 and Figure A3 were used to determine the amount of Sodium Chloride precipitated in the crystallization ponds as a function of time. Samples were taken from both the concentration and crystallization ponds at two-hour intervals over a two-day period.

6.2 SODIUM CHLORIDE SALT ($NaCl$) PRODUCTION

Equation 89 is the model to determine the amount of Sodium salt precipitated as a function of time to determine production of salt in the Salt Winning as shown in Figure 6.1. Sodium Chloride is salt that feeds the Chlor-alkali enterprise System E_2 and the Table Salt enterprise system E_3. The Sodium ions precipitate from crystallization ponds as water evaporates from the crystallizing ponds of the Salt Winning System. The negative sign on the right side of equation 89 indicates that the left side is also negative. That is $[M_{{Na^+}_{ion}}(t) \leq M^+_{{Na}_{ion}}(0)]$ is always true. Therefore:

$$M_{{Na^+}_{ion}}(t) - M_{{N^+a}_{ion}}(t-1) = -W_i(t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (91)$$

The daily rate of salt production by the salt winning and supplied to the two enterprise systems, E_2 and E_3 are shown in Figure 6.2 for a single pond. To produce enough for human

Consumer on the national level and to supply the demand for salt in chemical-industry use will require several ponds in parallel and in series to constitute the concentration and crystallization ponds of the Salt Winning system.

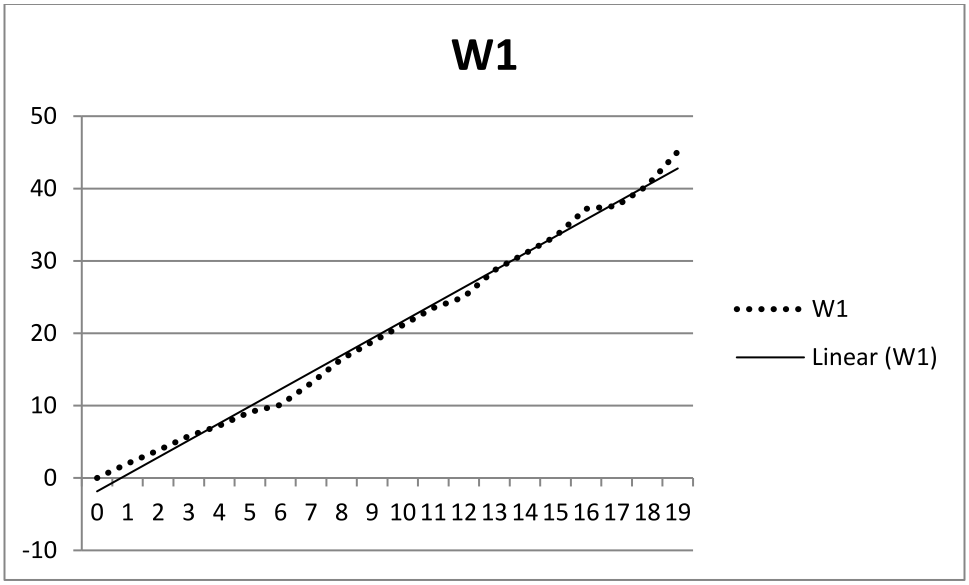

Figure 6-1: Precipitation of Sodium Salt in the Crystallization Pond (Norton Salt)

How does the production of salt in the crystallization ponds relate to the supply of salt to the Chlor-alkali enterprise system and that of the national human Consumer level? Salt produced by the Salt Winning system has two major users, the Chlor-alkali system E_2 and the Table salt systemE_3. Norton salt data in Appendix A was used to determine the hourly salt precipitated in the crystallization ponds of the Salt Winning system E_1 shown in Figure 6.1.

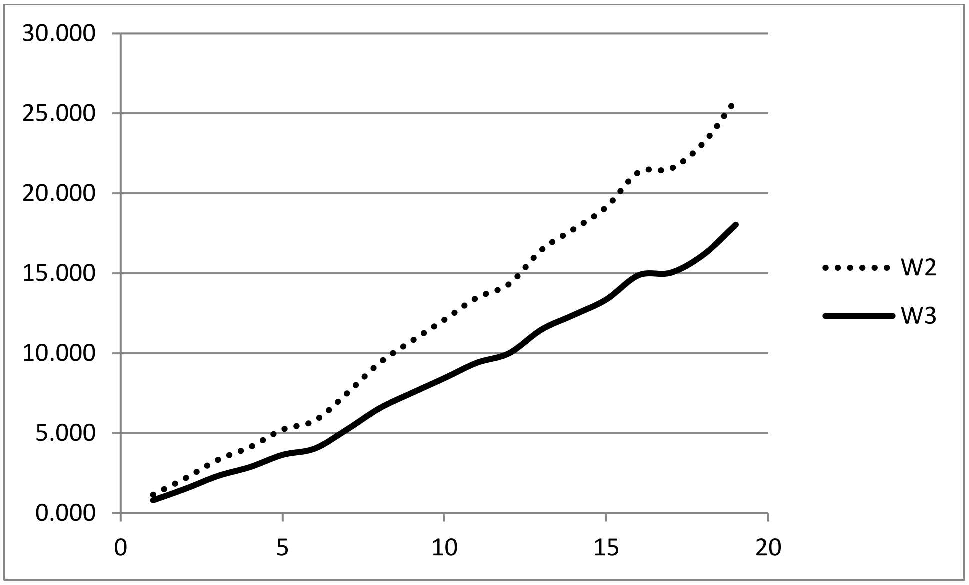

Figure 6-2: Solar Salt Precipitation in the Crystallizers

The salt produced by Salt Winning enterprise E_1 is split into two according to the Chemical Industry's Consumer ratio for the Chlor-alkali enterprise system $E_2's$ Consumer W_2 and the Table Salt manufacturing enterprise system $E_3's$ Consumer W_3. Chemical Industry's Consumer ratio from the salt winning is about 60 percent of total production of salt from the Salt Winning Company. Salt Winning production of salt and the distribution of salt outcome among the two enterprise systems E_2 and E_3 are used to construct an interdependency relationship between them. The values of W_2, W_2, and W_3 were normalized to generate P_1, P_2, and P_3 and they were plotted as function of time and are shown in Figure 6.3. The salt winning is designed to produce solar salt, utilizing the solar energy. Hourly data were taken from the concentration and crystallization pond and are shown as non-stationary set of observations.

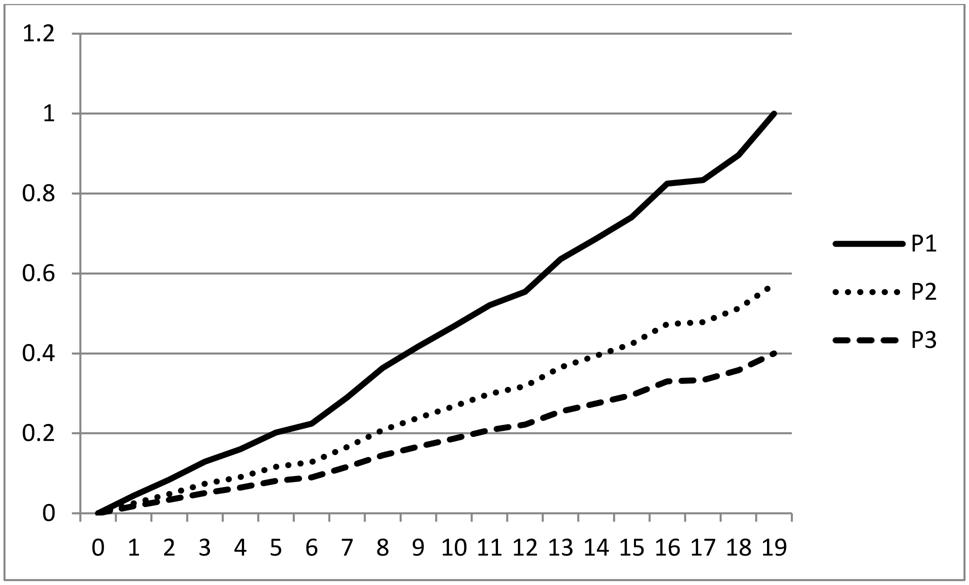

Figure 6.3: - Normalized $P_1 = Production, P_2 = Chlor - alkali, and\ P_3 = Table\ Salt$

From equation 45, we have shown the interdependency relationship between $E_2 - E_1$ as:

$$P_2 = \alpha_{12} P_1 + \gamma_{12} + \varepsilon_{12}$$

Also, from equation 46, we have shown the interdependency relationship for $E_2 - E_1$ enterprise system, the outcome P_3 of E_3 is plotted against the outcome P_1 of E_1 and the result is also shown in Figure 6.4

$$P_3 = \alpha_{13} P_1 + \gamma_{13} + \varepsilon_{13}$$

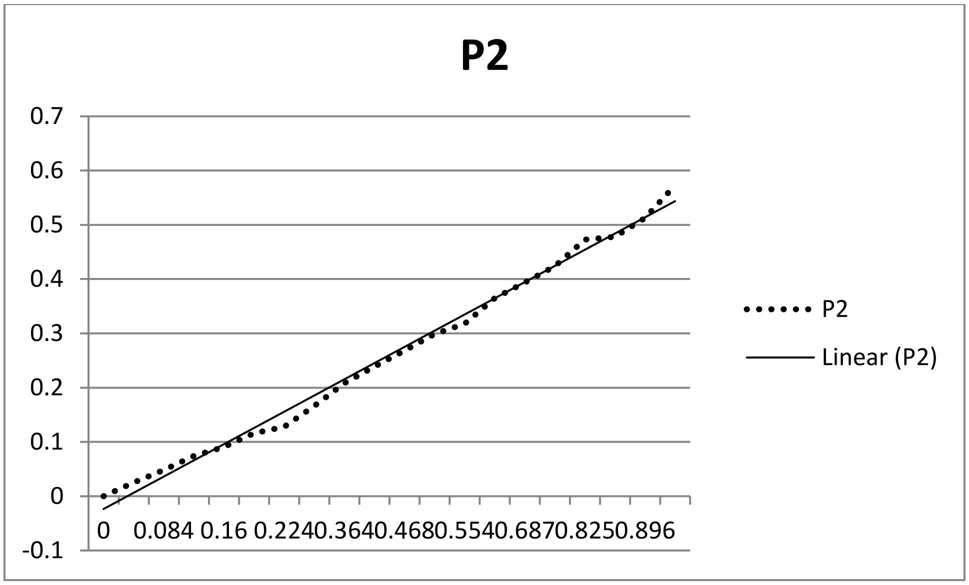

Figure 6-4: The Relationship between $P_2 - P_1$ of E_2 and E_1 enterprise systems

Therefore, the two models can be represented by the enterprise E_2 and E_1 model and can be represented as

$$P_2 = \alpha_{12} P_1 + \beta_{12} \qquad \text{……………..……….} \qquad (92)$$

where, α_{12} is the strength of dependency P_2 on P_1 and β_{12} is the intercept of the model in equation 84. Also, for E_3 and E_1, the model equation can be represented as: -

$$P_3 = \alpha_{13} P_1 + \beta_{13} \qquad \text{…………………………….} \qquad (93)$$

where, α_{13} is the strength of dependency P_3 on P_1 and β_{13} is the intercept of the model in equation 85. Both Figures 6.3 and 6.4 are linear models with slopes and intercepts.

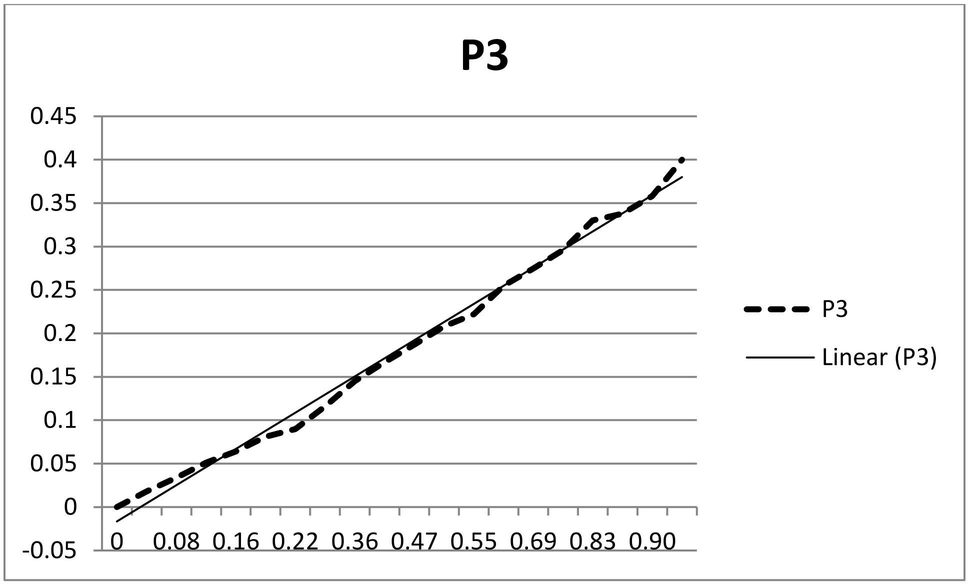

Figure 6-5: The Relationship between $P_3 - P_1$ of E_3 and E_1 enterprise systems.

6.3 DATA ANALYSIS

By the central limit theorem, the distribution of the sample mean of independently distributed variables will tend toward normality as the sample size gets infinitely large (Pindyck & Rubinfeld, 1998). This applies to $\acute{\alpha}_{12}$ because $\acute{\alpha}_{12}$ is a linear combination of $\acute{P}_2's$.

$$\acute{\alpha}_{12} \sim N(\alpha_{12}, \frac{\sigma^2}{\sum P_1^2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (94)$$

$$\acute{\gamma}_{12} \sim N(\beta_{12}, \sigma^2 \frac{\sum P_1^2}{N \sum \acute{P}_1^2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (95)$$

$$Cov\ (\acute{\alpha}_{12}, \acute{\beta}_{12}) = -\frac{-\bar{P}_1\sigma^2}{\sum {P_1}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (96)$$

6.3.1 THE TWO-VARIABLE REGRESSION MODEL

From a given value of P_1, the independent variable, we observed several values of the dependent variables. From Garvey's model (2009),

where

$$P_2 = \alpha_{12}P_1 + \gamma_{12} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (97)$$

We set the $100(1 - \alpha_{12}) = \gamma$ and include an error term ε_{12}. Then equation 89 becomes,

$$P_2 = \alpha_{12}P_1 + \gamma_{12} + \varepsilon_{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (98)$$

Also, the interdependency relationship between $P_3 - P_1$ of E_1 and E_3 enterprise system is:

$$P_3 = \alpha_{13}P_1 + \gamma_{13} + \varepsilon_{13} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (99)$$

The error may arise through interplay of several forces, such as impurities in the salt solution, the type of instruments used to measure and collect data, technician's sampling error, or whether changes during operation related to wind speed, the sun's radiation, and rain fall have an effect.

6.3.2 DETERMINATION OF MODEL PARAMETERS

For the two-variable linear regression models, the following are the assumptions as to how errors play a crucial role in the accuracy of the results.

Time, t	$P_{i(t)}$	$P_{j(t)}$
1	$P_{i(1)}$	$P_{j(1)}$
2	$P_{i(2)}$	$P_{j(2)}$
.	.	.
.	.	.
n	$P_{i(n)}$	$P_{j(n)}$

Table 6-1: Time Series Regression Model of $\boldsymbol{P_{j(t)}}$ and $\boldsymbol{P_{i(t)}}$

The first assumption is to suggest that the relationship between P_1 and P_2 and P_1 and P_3 are linear as shown in Figure 5.2 and Figure 5.3. Next is to suggest that the P_1's values are non-stochastic variables and are fixed. We also suggest that that the errors ε_{12} and ε_{13} have zero expected values: $\epsilon(\varepsilon_{12}) = 0$ and $\epsilon(\varepsilon_{13}) = 0$. We also suggest that the errors terms ε_{12} and ε_{13} have constant variance for all observation, i.e. $\epsilon({\varepsilon_{12}}^2) = {\sigma_{12}}^2$ and $\epsilon({\varepsilon_{13}}^2) = {\sigma_{13}}^2$. Also, the random variables ε_{12} and ε_{13} are considered statistically independent. Then, the expected values for ε_{12} and ε_{13} are given as $\epsilon(\varepsilon_{12}\varepsilon_{13}) = 0$, for all values of ε_{12} and ε_{13} where $\varepsilon_{12} \neq \varepsilon_{13}$. The final assumptions are that the error terms ε_{12} and ε_{13} are normally distributed. The first five assumptions are based upon the Gauss-Markov Theorem which states that the estimators $\hat{\alpha}_{12}$ and $\hat{\beta}_{12}$ are the best linear unbiased estimators of α_{12} and β_{12} for interdependent systems E_2 and E_1.

Sample observations from the dependent and independent variables P_1, P_2, and P_3 are studied for the characteristics of the least-squares parameter estimates. For randomly distributed samples of stochastic model β_{12} and α_{12} can be estimated based upon sample size. As an estimate of strength of interdependency α_{12} and the criticality of dependency β_{12} $0 \leq \beta_{12} \leq 100(1-\alpha_{12})$, the formulas for the regression criticality of dependency and strength of dependency are given as $\hat{\beta}_{12}$ and $\hat{\alpha}_{12}$.

To estimate the parameters $\hat{\beta}_{12}$ and $\hat{\alpha}_{12}$, we begin with equation 45 for interdependent system E_2 and E_1. We can recall from equation 45 that $P_2 = \alpha_{12}P_1 + \gamma_{12} + \varepsilon_{12}$, where $\gamma_{12} = 100(1-\alpha_{12})$. Summing over all the total observation, N and dividing the total observations by N in enterprise systems E_2, and E_1, we obtain the following:

$$\bar{P}_2 = \alpha_{12}\bar{P}_1 + \gamma_{12} + \bar{\varepsilon}_{12} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (100)$$

Subtracting equation 98 from equation 96, we get

$$p_2 - \bar{p}_2 = \alpha_{12}(p_1 - \bar{p}_1) + (\varepsilon_{12} - \bar{\varepsilon}_{12}) \ldots\ldots\ldots\ldots\ldots\ldots \quad (101)$$

Letting $\acute{P}_2 = (p_2 - \bar{p}_2)$, $\acute{P}_1 = (p_1 - \bar{p}_1)$ and $\acute{\varepsilon}_{12} = (\varepsilon_{12} - \bar{\varepsilon}_{12})$, we can write the following

$$\acute{P}_2 = \alpha_{12}\acute{P}_1 + \acute{\varepsilon}_{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (102)$$

The true regression line is $\epsilon(\acute{P}_2) = \alpha_{12}\acute{P}_1$. The estimated slope of the regression line is.

$$\acute{\alpha}_{12} = \frac{\sum \acute{P}_1\acute{P}_2}{(\acute{P}_1)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (103)$$

And since $\acute{\alpha}_{12}$ is an unbiased estimator of α_{12}, then

$$\epsilon(\acute{\alpha}_{12}) = \alpha_{12} \quad \text{………………..……………} \qquad (104)$$

The variance of the model depends solely on the error variance, the variance of P_1 and the number of observations, so that

$$Var(\acute{\alpha}_{12}) = \frac{\sigma^2}{\sum \acute{P_1}^2} \quad \text{…..……………………} \qquad (105)$$

We can now determine the mean and the variance estimator of the intercept for the regression as

$$\epsilon(\gamma'_{12}) = \gamma_{12} \quad \text{...………………………....} \qquad (106)$$

$$Var(\gamma'_{12}) = \frac{P^2{}_1}{N\sum(P_1 - \bar{P}_1)^2} \quad \text{…………………} \qquad (107)$$

Also, we can determine the covariance between $\acute{\alpha}_{12}$ and γ'_{12} as

$$Cov\,(\acute{\alpha}_{12}, \acute{\gamma}_{12}) = -\frac{-\bar{P}_1\sigma^2}{\sum P_1{}^2} \quad \text{……………..……} \qquad (108)$$

6.3.3 THE REGRESSION PARAMETERSS

The strength of dependency determines the relationship between two varying outputs such as P_2 and P_1, where their strength of interdependency relationship α_{12} is found to vary between $0 \le \alpha_{12} \le 1$. For multiple enterprise systems, if the receiver enterprise receives outputs from a single feeder enterprise then the sum of their strength of dependency is $\alpha_{12} + \alpha_{13,} \dots \dots \dots ., + \alpha_{1N} = 1$ as indicated in equation 42.

We have shown that $\bar{P}_1 = \frac{1}{n}\sum_{i=1}^{N} P_1$ and $\bar{P}_2 = \frac{1}{n}\sum_{i=1}^{N} P_2$. Also, we determined $\acute{p}_1 = P_1 - \bar{P}_1$ and $\acute{p}_2 = P_2 - \bar{P}_2$. We also know that the linear curve of the regression is given by

$\hat{P}_2 = \hat{\alpha}_{12}\acute{P}_1 + \hat{\gamma}_{12}$ and therefore the error $\hat{\varepsilon}_{12} = \acute{P}_2 - \hat{P}_2$ and $\hat{\alpha}_{12}$ = 0.571. We can now evaluate the variance of the standard error $s^2 = \frac{1}{N-2}\sum \hat{\varepsilon}^2{}_{12}$.

$\acute{P}_1$	$\acute{P}_2$	$\hat{P}_2 = \hat{\alpha}_{12}\acute{P}_1$	$\hat{\varepsilon}_{12} = \acute{P}_2 - \hat{P}_2$	$\hat{\varepsilon}^2{}_{12}$	$\acute{P}^2{}_1$
-0.41819	-0.23718	-0.23874	0.00156	0.00000143	0.17488
-0.38007	-0.21533	-0.21698	0.00165	0.00000272	0.14445
-0.33772	-0.19107	-0.19280	0.00173	0.00000299	0.11405
-0.30808	-0.17408	-0.17588	0.00180	0.00000324	0.09491
-0.26785	-0.15103	-0.14082	-0.01021	0.000104	0.07174
-0.24667	-0.13887	-0.14082	0.00195	0.0000038	0.06085
-0.18315	-0.10247	-0.10456	0.00209	0.00000437	0.03354
-0.11328	-0.06243	-0.06467	0.00224	0.00000502	0.01283
-0.06245	-0.03327	-0.03565	0.00238	0.00000566	0.00390
0.06959	-0.00538	0.03972	-0.0451	0.002034	0.00484
0.03707	0.02373	0.02116	0.00257	0.0000066	0.00137
0.06884	0.04194	0.03930	0.00264	0.00000697	0.00474
0.14719	0.08720	0.08403	0.00317	0.0000100	0.02166
0.19589	0.11477	0.11183	0.00294	0.00000864	0.03837
0.2467	0.14388	0.14084	0.00304	0.00000924	0.06086
0.32717	0.19000	0.18678	0.00322	0.0000104	0.10704
0.33564	0.19485	0.19162	0.00323	0.0000104	0.11265
0.39493	0.28588	0.22547	0.06041	0.003649	0.15597
0.49445	0.28588	0.28228	0.0036	0.0000130	0.24448

Table 6-2: Estimation of the variance of the standard error $\boldsymbol{\hat{\varepsilon}_{12}}$

Therefore, the variance can be estimated as follows:

$$s^2 = \hat{\sigma}^2{}_{12} = \frac{1}{N-2}\sum \hat{\varepsilon}^2{}_{12} = \frac{\sum(\acute{P}_2 - \hat{\gamma}_{12} - \hat{\alpha}_{12}\acute{P}_1)}{N-2} \qquad \text{.........} \qquad (109)$$

where (N-2) value is called the degree of freedom, with the minus two coming from the constraint resulting from the calculation of the strength of interdependency and the value of receiver enterprise before any contribution from the feeder enterprise.

Since $\hat{\alpha}_{12} = 0.571$, as shown in the result of the output in Table 6.2, then

$$\hat{P}_2 = \hat{\alpha}_{12}\acute{P}_1 = 0.5709\acute{P}_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (110)$$

The variance of the estimate $\hat{\alpha}_{12}$ varies directly with the variance of the standard error $\hat{\varepsilon}_{12}$.

We need to estimate the variance of the standard error of the regression to obtain a more precise estimate of $\hat{\alpha}_{12}$. The equation to determine the variance is shown as

$$s^2 = \hat{\sigma}^2{}_{12} = \frac{1}{N-2}\sum \hat{\varepsilon}^2{}_{12} = \frac{\sum(\acute{P}_2 - \hat{\gamma}_{12} - \hat{\alpha}_{12}\acute{P}_1)^2}{N-2} = \frac{\sum\{\acute{P}_2 - \hat{P}_2)^2}{N-2} \quad \ldots\ldots\ldots \quad (111)$$

Then the sum of the error square is equal to $\sum \hat{\varepsilon}^2{}_{12} = 0.04491$ and the degree of freedom for the N equal to 19 observations is $N - 2 = 17$. Therefore,

$$s^2 = \hat{\sigma}^2{}_{12} = \frac{1}{N-2}\sum \hat{\varepsilon}^2{}_{12} = \frac{0.04491}{17} = 0.002642 \quad \ldots\ldots\ldots \quad (112)$$

As a result, the variance of the standard error $s = 0.051397$.

We apply t distribution to construct 95 percent confidence intervals for the estimated parameters α_{12} and γ_{12}. For the null hypothesis we set $\alpha_{12} = \alpha_0$. we then calculate the t statistic is:

$$t_{N-2} = \frac{\hat{\alpha}_{12} - \alpha_0}{s_{\hat{\alpha}_{12}}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (113)$$

The critical value is defined so that

$$Prob\left(-t_c < \frac{\hat{\alpha}_{12} - \alpha_0}{s_{\hat{\alpha}_{12}}} < t_c\right) = 0.95 \qquad \ldots\ldots\ldots\ldots \qquad (114)$$

Equation 106 can be rearranged to form

$$Prob(\hat{\alpha}_{12} - t_c s_{\hat{\alpha}_{12}} < \alpha_0 < \hat{\alpha}_{12} + t_c s_{\hat{\alpha}_{12}}) = 0.95 \qquad \ldots\ldots \qquad (115)$$

We can obtain the 95 percent confidence interval for α_{12}:

$$\hat{\alpha}_{12} \pm t_c s_{\hat{\alpha}_{12}} \qquad \ldots\ldots\ldots\ldots\ldots \qquad (116)$$

For this study, $\hat{\alpha}_{12} = 0.5709$ and $s = 0.051397$ and for the 19 observations with two degrees of freedom, the t statistic gives a value of $t_c = 2.110$. Therefore, from equation 113, the 95 percent confidence interval for the estimated strength of dependency for $E_1 - E_2$ enterprise systems:

$\hat{\alpha}_{12} \pm t_c s_{\hat{\alpha}_{12}} = 0.57089 \pm (2.110 * 0.051397)$

$= 0.5709 \pm 0.01964$

Therefore, for ENTERPRISE systems $E_2 - E_1$, α_{12} was found to be in the range of

$$0.57089 < \alpha_{12} < 0.59053 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (117)$$

Also, for enterprise systems $E_3 - E_1$, α_{13} was found to be in the range of

$$0.41054 < \alpha_{13} < 0.43977 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (118)$$

This study is about obtaining a useful measure of the fit between the estimated regression line and data between two variables of the feeder enterprise output P_1 and the receiver enterprise output P_2 to determine the Goodness of Fit of the data. If the regression equation is a good fit it will help explain a large proportion of the variance in P_2. However, a large residual between the estimated line and the data will imply a poor fit, while a small residual will imply a good fit.

R^2 is the value used in analyzing a causal relationship between the outputs of interdependent enterprise systems E_1 and E_1 (Pindyck & Rubinfeld, 1998). Pindyck and Rubinfeld have stated that R2 is the measure of the interdependency relationship between two variables, the outputs of a feeder and receiver enterprise system:

$$R^2 = \frac{\sum(\hat{P}_2 - \bar{P}_2)^2}{\sum(P_2 - \bar{P}_2)^2} \qquad \text{…………………………..} \qquad (119)$$

where $\sum(\hat{P}_2 - \bar{P}_2)^2$ is the sum of square of the explained variation of P_2 of the receiver enterprise system $E_{2.}$ Also, $\sum(P_2 - \bar{P}_2)^2$ is the sum of squares of the total variation of P_2 of the receiver enterprise System E_2. The R^2 value was obtained using excel basic regression analysis and the result indicated as 0.9955 in Table 7.3A, which is a good fit.

6.4 GHANA SALT REGRESSION ANALYSIS $(\boldsymbol{E_2 - E_1})$ AND $(\boldsymbol{E_3 - E_1})$

Garvey developed the interdependency relationship between P_2 and P_1 seen in Figure 6.7, for the Ghana Salt enterprise System interdependency between E_2 and E_1 as follows:

$$P_2 = \alpha_{12}P_1 + 100(1 - \alpha_{12})$$

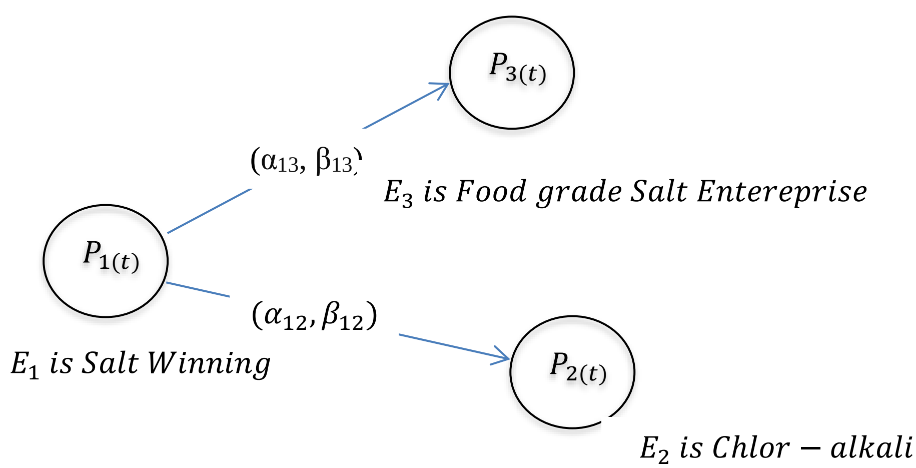

Figure 6-6: Interdependency between Feeder-Receiver enterprise systems in Ghana Salt

The value of α_{12} is constant and equal to 0.571, then β_{12} is the criticality of dependency between P_1 and P_2 within the range of $0 \leq \beta_{12} \leq 100(1-\alpha_{12})$, and therefore $0 \leq \beta_{12} \leq 42.91$.

In the case of $E_2 - E_1$ enterprise system, P_2 has neither maximum strength of dependency nor maximum criticality of dependency on P_1.

$$P_2 = \alpha_{12}P_1 + 100(1 - \alpha_{12}) \ldots\ldots\ldots\ldots \quad (120)$$

Then with the value α_{12} determined to be α_{12} =0.5709, the above equation becomes

$$P_2 = 0.5709P_1 + 42.91 \quad \ldots\ldots\ldots\ldots \quad (121)$$

If E_2 is the receiver enterprise and E_1 is the feeder enterprise, then for $E_2 - E_1$ enterprise systems P_2, the output of enterprise E_2, has a dependency relationship with P_1, the output of enterprise E_1 and P_2 has a baseline operability level, such that BOPP_2 result in a family of linear curves given as

$$\text{BOP}P_2 = 100(1 - \alpha_{12}) \quad \ldots\ldots\ldots\ldots \quad (122)$$

From equation 115, we can now study how P_2 changes with changes of P_1 in Table 6.3.

P_1	$0.5709P_1$	100(1-α_{12})	$SODP_2$	$CODP_2$
0.0	0.0	42.91	42.91	42.91
10	5.709	42.91	48.62	52.9
20	11.418	42.91	54.33	62.9
30	17.127	42.91	60.04	72.9
40	22.836	42.91	65.75	82.9
50	28.545	42.91	71.46	92.9
60	34.254	42.91	77.16	100.9
70	39.963	42.91	82.87	112.9
80	45.672	42.91	88.58	122.9
90	51.381	42.91	94.29	132.9
100	57.090	42.91	100.00	142.9

Table 6-3: P_2 Dependency Relationship of P_1 in $E_2 - E_1$ enterprise

Also, the

$$BOLP_2 = 100(1 - \alpha_{12}) = 42.91 \quad \ldots\ldots\ldots\ldots\ldots \quad (123)$$

$$P_2 = F(\alpha_{12}, \beta_{12}, P_1) = Min(SODP_2, CODP_2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (124)$$

where $SODP_2 = \alpha_{12}P_1 + BOLP_2$

And $CODP_2 = P_1 + \beta_{12}$

The value of β_{12} is what P_2 needs before receiving a contribution from the feeder enterprise and is defined as the criticality of dependency. It is the minimum effective operability level (MEOL) of P_2 before receiving a contribution from the feeder enterprise output P_1.

Therefore, the value of β_{12} is given as:

$0 < \beta_{12} \leq 100(1 - \alpha_{12})$

Given that $0 < \alpha_{ij} \leq 1$ and $0 < \beta_{ij} \leq 100(1 - \alpha_{ij})$

Since α_{ij} =0.571, then $\beta_{ij} = 100(1 - 0.571)$ $therefore,\ \beta_{ij} = 42.91$

For the salt enterprise system, the interdependency relationship between $E_2 - E_1$ gives the value of β_{12} = MEOLP_2 = 42.91

Therefore, from Table 6.3,

$SODP_2 = \alpha_{12}P_1 + BOLP_2 = 0.571P_1 + 42.91$

Also,

$CODP_2 = P_1 + MEOLP_2 = P_1 + 42.91$

The COD/SOD cross-over point is expressed as

$$p_i = 100 - \frac{\beta_{ij}}{1-\alpha_{ij}}$$

For the $E_1 - E_2$ enterprise system, $p_1 = 100 - \frac{\beta_{12}}{1-\alpha_{12}} = 0$

Therefore, the cross-over point occurs where the $p_1 = 0$ or where $CODP_2 = SODP_2 = 42.91$.

$SODP_2$	$CODP_2$	P_2 operability level determined by
42.91	42.91	COD/SOD
48.62	52.91	SOD
54.33	62.91	SOD
60.04	72.91	SOD
65.75	82.91	SOD
71.46	92.91	SOD
77.16	100.91	SOD
82.87	112.91	SOD
88.59	122.91	SOD
94.29	132.91	SOD
100.00	142.91	SOD

Table 6-4: Determination of P_2 Operability Level

We have indicated above in equation 116 that $P_2 = Min(SODP_2, CODP_2)$. Therefore, for the interdependency relationship between $E_3 - E_1$, the COD/SOD crossover point occurs where $P_1 = 0$. Also,

$$P_2 = F(\alpha_{12}, \beta_{12}, P_1) = \min\,(SODP_2, CODP_2) \qquad …….. \qquad (125)$$

6.5 INTERDEPENDENCY BETWEEN $\boldsymbol{E_3}$ AND $\boldsymbol{E_1}$

The value of α_{13} is constant and equal to 0.429, then β_{12}, the criticality of dependency between P_1 and P_2, is within the range of $0 \leq \beta_{13} \leq 100(1-\alpha_{13})$, and therefore, we express the value of β_{13} to be between $0 \leq \beta_{13} \leq 57.46$.

$$P_3 = \alpha_{13}P_1 + 100(1 - \alpha_{13}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (126)$$

Then with the value α_{13} determined to be α_{13} =0.429, the above equation becomes

$$P_3 = 0.4291P_1 + 57.1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (127)$$

From equation 125, we can now study how P_3 changes with changes of P_1 in Table

Also,

$$BOLP_3 = 100(1-\alpha_{13}) = 57.1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (128)$$

Since the value of α_{13} is constant and equal to 0.4291, then β_{13} the criticality of dependency between P_1 and P_3, is within the range of $0 \leq \beta_{13} \leq 100(1-\alpha_{13})$, therefore $0 \leq \beta_{13} \leq 57.1$.

Given that $0 < \alpha_{ij} \leq 1$ and $0 < \beta_{ij} \leq 100(1-\alpha_{ij})$

Since α_{13} =0.4254, then $\beta_{13} = 100(1-0.4254)$

Therefore, $\beta_{13} = 57.46$

And

$$SODP_3 = \alpha_{13}P_1 + BOLP_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (129)$$

Also

$$CODP_3 = P_1 + \beta_{13} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (130)$$

In the case of the $E_3 - E_1$ enterprise system, P_3 has neither maximum strength of dependency nor maximum criticality of dependency on P_1. Therefore

$$P_3 = F(\alpha_{13}, \beta_{13}, P_1) = \min\,(SODP_3, CODP_3) \quad \ldots\ldots\ldots\ldots \quad (131)$$

and

$$SODP_3 = \alpha_{13}P_1 + 100(1 - \alpha_{13}) \quad \ldots\ldots\ldots\ldots \quad (132)$$

where $0 \leq P_1, P_3 \leq 100$ and $0 \leq \alpha_{13} \leq 1$.

Also

$$CODP_3 = P_1 + \beta_{13} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (133)$$

where

$0 \leq \beta_{13} \leq 100(1 - \alpha_{13})$. Therefore, the range of β_{13} can be expressed as $0 \leq \beta_{13} \leq 57.46$

where $0 \leq \beta_{13} \leq 100(1 - \alpha_{13})$. Therefore, the range of β_{13} can be expressed as $0 \leq \beta_{13} \leq 57.1$. For the salt enterprise system, $\beta_{13} = 57.71$

The COD/SOD cross-over point is expressed as

$p_i = 100 - \frac{\beta_{ij}}{1-\alpha_{ij}}$

P_1	$0.4252P_1$	100(1-α_{13})	$SODP_3$	$CODP_3$
0.0	0.0	57.46	57.46	57.46
10	4.252	57.46	61.71	67.46
20	8.504	57.46	65.96	77.46
30	12.756	57.46	70.22	87.46
40	17.008	57.46	74.47	97.46
50	21.26	57.46	78.72	107.46
60	25.512	57.46	82.97	117.46
70	29.764	57.46	87.22	127.46
80	34.016	57.46	91.48	137.46
90	38.268	57.46	95.73	147.46
100	42.52	57.46	99.98	157.46

Table 6-5: P_3 Dependency Relationship with P_1 in the $E_3 - E_1$ enterprise

For the $E_3 - E_1$ enterprise system, $p_1 = 100 - \frac{\beta_{13}}{1-3} = 0$

Therefore, the cross-over point occurs where the $p_1 = 0$ or where $CODP_2 = SODP_2 = 57.46$ as shown in Table 6.6.

$SODP_3$	$CODP_3$	P_3 operability level determined by
57.46	57.46	COD/SOD
61.71	67.42	SOD
65.96	77.46	SOD
70.22	87.46	SOD
74.47	97.46	SOD
78.72	107.46	SOD
82.97	117.46	SOD
87.22	127.46	SOD
91.48	137.46	SOD
95.73	147.46	SOD
99.98	157.46	SOD

Table 6-6: Determination of the P_3 Operability Level

The COD/SOD crossover point in both $E_2 - E_1$ and $E_3 - E_1$ enterprise systems is given by

$$P_1 = 100 - \frac{\beta_{13}}{1-\alpha_{13}} = 100 - \frac{\beta_{13}}{1-\alpha_{13}} \quad \text{…………..…} \qquad (134)$$

In the interdependency relationships between $E_2 - E_1$ and $E_3 - E_1$ the COD/SOD crossover points occur at where $P_1 = 0$ in both $E_2 - E_1$ and $E_3 - E_1$ enterprise systems.

We now can show that enterprise systems E_1 and E_2

As shown from the equation $P_j = \alpha_{ij} P_i + 100(1 - \alpha_{ij})$, the enterprise systems are bounded by their baseline operability levels.

6.6 DETERMINATION OF BASELINE OPERABILITY LEVEL

Pi	j0.9	Pj0.8	Pj0.7	Pj0.6	Pj0.5	Pj0.4	j0.3	Pj0.2	Pj0.1
0	10	20	30	40	50	60	70	80	90
10	19	28	37	46	55	64	73	82	91
20	28	36	44	52	60	68	76	84	92
30	37	44	51	58	65	72	79	86	93
40	46	52	58	64	70	76	82	88	94
50	55	60	65	70	75	80	85	90	95
60	64	68	72	76	80	84	88	92	96
70	73	76	79	82	85	88	91	94	97
80	82	84	86	88	90	92	94	96	98
90	91	92	93	94	95	96	97	98	99
100	100	100	100	100	100	100	100	100	100

Table 6-7: How $\boldsymbol{P_j}$ varies at various values of $\boldsymbol{P_i}$

In Table 6.8, the Baseline Operability level is determined when P_i = 0, for all values of $P_j = f(P_i)$. Equation 117 represents the value of the baseline operability level. We consider the baseline operability level, B_{ij}, is given as $0 \leq \beta_{ij} \leq 100(1-\alpha_{ij})$ as shown in the Table 6.8, if $\alpha_{ij} = 100(1-\alpha_{ij})$. A plot of the above Table 6.8 is shown below.

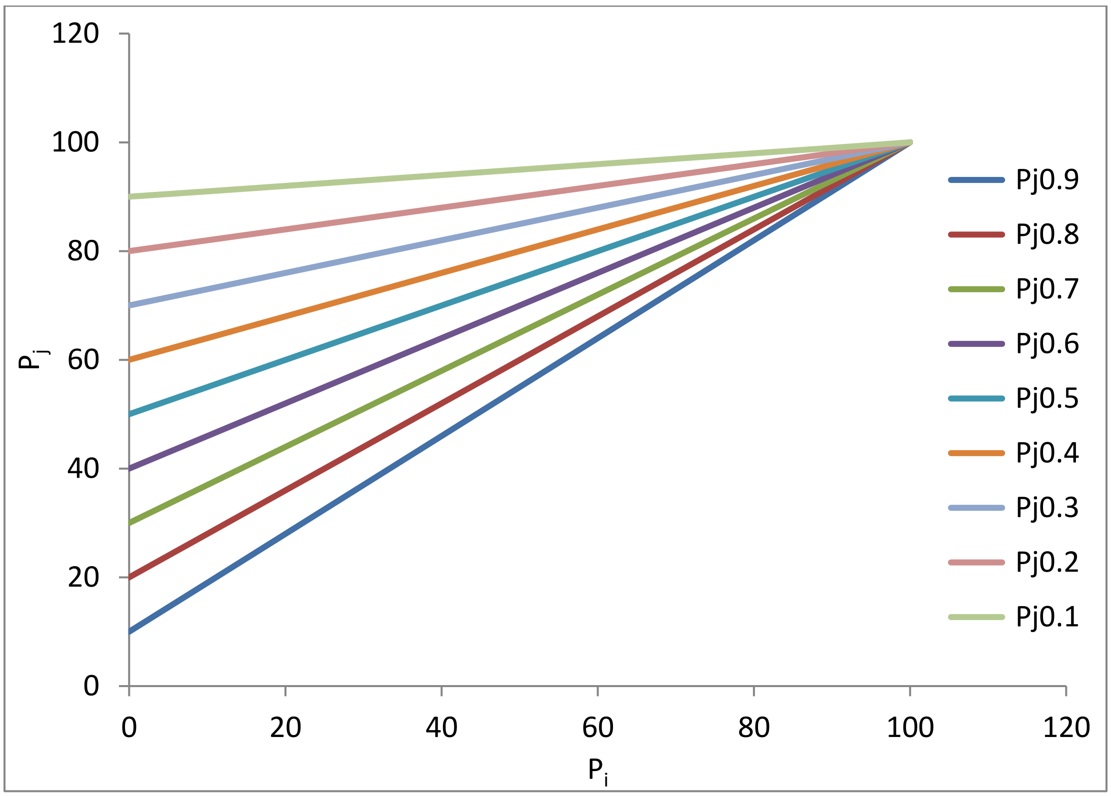

Figure 6-7: A plot of $\boldsymbol{P_j{}'s}$ as a function of $\boldsymbol{P_i}$ at different values of $\boldsymbol{\alpha_{ij}}$

The limitation of this research is based upon the value of α_{ij}. The value of α_{ij} is determined by the design capacity of the systems being considered (i.e. chlor-alkali). Figure 6.8 shows how P_j changes with changes in P_i and they are bounded by the value of α_{ij}. For example α_{ij}= 0.2, then for $P_j = \alpha_{ij}P_j + 100(1 - \alpha_{ij}) = 0.2P_i + 80$. For this case, the baseline operability level is 80 and P_j will vary from 80 to 100. Therefore, the size of the enterprise system cannot be changed at any moment in time. In the Food Processing, Chemical, Petrochemical, and the Petroleum Industries, design capacity usually uses design capacity as a primary planning factor. All other enterprise systems, such as those in technology, education, banking does not pay important attention to design capacities.

For the case of the Ghana salt enterprise, as shown in Figure 6.9, the Salt Winning and the Chlor-alkali enterprise systems, $E_1 - E_2$, the baseline operability level 42.9.

While in the case of the Salt Winning and the Processed Consumer Salt, the baseline operability is 57.1.

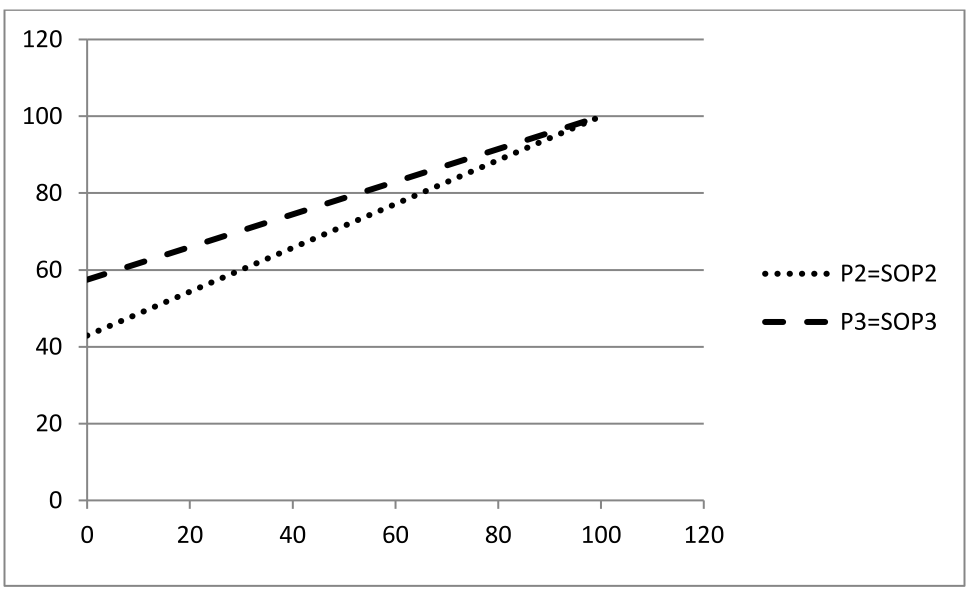

Figure 6-8: A plot of $P_j's$ as a function of P_i bounded by α_{ij} values

For $E_1 - E_2$ enterprise systems, α_{ij}=0.571, therefore, $P_j = \alpha_{ij}P_i + 100(1 - \alpha_{ij})$. In this case, substituting the value of α_{ij}= 0.571, then $P_j = 0.571P_i + 42.7$. This plot of P_j verses P_i is shown by the dotted line in Figure 6.9.

7 RISK MANAGEMENT OF GHANA SALT ENTERPRISE

In the Ghana Salt enterprise, risk is a measure of the probability and consequence of not achieving the defined product quality requirement of the receiver enterprise. The presences of several impurities associated with the solar refined salts can cause a major disaster or explosion in the chlor-alkali systems or too much of impurities in the solar salt make it unhealthy for Consumer. Impurities present in large quantities induce a hazardous situations and risk increases with hazard but decreases with proper safeguards. The implication of this is good project manager should design ways to identify hazards and provides safeguards to overcome them. By providing suitable safeguards, risks that can cause hazardous situations can be eliminated or reduced to acceptable levels.

The implication of this research to project management is that FDNA methodology can be used for risk analysis to identify and analyze the project or enterprise system in terms of risk issues that has been approved by stakeholders for further evaluation. The objective is to judge their likelihood of occurrence, cost, and technical performance. FDNA methodology can be used to design activities and analysis to estimate the likelihood, and to predict the impact on the project of identified risks in the petrochemical enterprise systems as shown in the Ghana Salt enterprise study.

Risk management can be set-up as a continuous, disciplined process of planning, assessing, handling, and monitoring, which supplement other processes such as planning, budgeting, cost control, quality, and scheduling. Analysis begins with identifying the potential problem then developing a profile of the fundamentals for each system in the enterprise systems, both the feeder and the receiver enterprise systems. These profiles should consist of answering the following four questions.

1. What function(s) is this supposed to accomplish? What output(s) is it supposed to deliver (to the next enterprise system)?
2. What unneeded/undesired function output(s) accompany these?
3. What input(s) environment must be provided in order to accomplish these functions/deliver these outputs?
4. What unneeded, undesired input(s) /environment accompany these?

If an enterprise accomplishes everything it is supposed to do, as is defined in question1, it is error free; potential problems arise from failure to properly accomplish functions or deliver outputs. Therefore, the next step is to judge the probability (High, Medium, and Low) of failure to accomplish each function, to deliver output.

When the probability is judged to be high or medium, we subsequently define the resultant potential problem and proceed to determine its likely cause(s) and each of their probabilities (High, Medium, and Low). If the probability is judged to be low, the project manager chooses to accept the risk.

Determining the likely cause of the high and medium risks, we look to the responses to question 2, 3, and 4 for clues. For likely causes with high or medium probability, preventive actions or safeguards are developed with the intent that taking these actions will reduce the residual probability of the original high or medium probability problems happening to low probability.

8 RESEARCH FINDINGS AND DISCUSSIONS

8.1 STRENGTH OF DEPENDENCY MEASUREMENT

The strengths of dependency α_{12} of the $E_1 - E_2$ enterprise systems and α_{13} of the $E_1 - E_3$ enterprise systems were determined through regression analysis. And the results were as follows, for the $E_2 - E_1$ enterprise systems based upon the expected value of α_{12}:

$$\alpha_{12} = \frac{\sum(P_1 - \bar{P}_1)(P_2 - \bar{P}_2)}{\sum(P_1 - \bar{P}_1)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (135)$$

We obtained the value of α_{12} for the Salt Winning/Chlor-alkali systems, $E_2 - E_1$ to be in the range given below.

$0.57089 < \alpha_{12} < 0.59053$

Also, for the $E_3 - E_1$ enterprise systems based upon the expected value of α_{13} the results were:

$$\alpha_{13} = \frac{\sum(P_1 - \bar{P}_1)(P_3 - \bar{P}_3)}{\sum(P_1 - \bar{P}_1)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (136)$$

And the value of α_{12} was found to be between the range below.

$0.41054 < \alpha_{13} < 0.43977$

As shown above in Table 7.2, the strength of dependency can be determined using the time dependent strength of the dependency relationship between P_2 and P_1 and also that of P_3 and P_1, as shown below in equations 128 and 129.

$$\alpha_{12} = \left(\frac{dP_3}{dt}\right) / \left(\frac{dP_1}{dt}\right) = 0.5709 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (137)$$

Also,

$$\alpha_{13} = (\frac{dP_3}{dt})/(\frac{dP_1}{dt}) = 0.4252 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (138)$$

8.2 REGRESSION SUMMARY OF OUTPUTS FOR $E_2 - E_1$ ENTERPRISE

Regression Statistics	
Multiple R2	0.99774759
R2	0.99550025
Adjusted R2	0.99523555
Standard Error	0.01126023
Observations	19

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.4768654	0.47687	3760.98	2.1543E-21
Residual	17	0.0021555	0.00013		
Total	18	0.4790208			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.0014662	0.0050053	-0.29294	0.77312	-0.01203	0.009094
P2 Variable 1	0.57088708	0.0093089	61.3269	2.15E-21	0.5512470	0.590527

Table 8-1: Summary of outputs from Regression Model $P_2 - P_1$

8.3 SUMMARY OF OUTPUTS $E_3 - E_1$ ENTERPRISE

Regression Statistics						
Multiple R2	0.99775					
R²	0.99551					
Adjusted R²	0.99524					
Standard Error	0.00838					
Observations	19					
ANOVA						
	df	SS	MS	F	Significance F	
Regression	1	0.26448	0.26448	3767.215	2.12436E-21	
Residual	17	0.00119	0.00007			
Total	18	0.26568				
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.00110	0.00372	-0.2944	0.77203	-0.00895	0.00676
X Variable 1	0.42516	0.00693	61.3776	2.12E-21	0.41054	0.43977

Table 8-2: Summary of outputs from Regression Model $\boldsymbol{P_3 - P_1}$

For the strength of interdependency, $\alpha_{12} = 0.5709$ was obtained from the regression analysis of the outputs for systems E_1 and E_2. For the non-stationary regression analysis for enterprise systems $E_1 - E_2$ with outputs P_1 and P_2 the 95 percent confidence level as shown in Table 7.1 gives the strength of dependency value to be

$$0.55125 < \alpha_{12} < 0.59053 \quad \ldots\ldots\ldots\ldots \quad (139)$$

Therefore, the baseline operability is 100(1 - α_{12}) = 42.91, such that

$$P_2 = 0.5709P_1 + 42.91 \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (140)$$

Also, P_2 has a dependency relationship with P_1 which is defined by

$P_2 = \min(SOPP_2, CODP_2) = \min\,[\{\,\alpha_{12}P_1 + 100(1-\alpha_{12})\}, P_1 + \beta_{12}]$.

The results from Table 6.4 give,

$SOPP_2 \leq COPP_2$

Therefore, $P_1 + 100(1-\alpha_{12}) \leq P_1 + \beta_{12}$ and $P_2 \leq SOPP_2$, and the operability level of the receiver enterprise is bounded by the measure of its strength of dependency on the feeder enterprise P_1.

And for the linear regression analysis shown in Table 6.9 for enterprise systems $E_1 - E_3$ with the outputs P_1 and P_3 the 95 percent confidence level as shown in Table 7.2 gives the strength of dependency value between P_1 and P_3 as

$$0.41054 < \alpha_{13} < 0.43977 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (141)$$

Therefore, the baseline operability level is determined as 100(1- $\alpha_{13}) = 100(0.5748) = 57.48$

In this case the model for the salt winning/Chlor-alkali systems $E_1 - E_3$ can be shown from the regression analysis of the non-stationary outputs P_1 and P_3. Therefore,

$$P_3 = \alpha_{13}P_1 + 100(1 - \alpha_{13}) = \alpha_{13}P_1 + 57.48$$

And for the Salt Wining-Consumer Salt enterprise systems $E_1 - E_3$ model, the relationship between P_1 and P_3 is given as. Also, shown in Appendix C in Tables C5 and C6, the value for the Strength of Interdependency, $\alpha_{13} = 0.4252$ for systems E_1 and E_3.

$$P_3 = 0.4252P_1 + 57.48 \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (142)$$

And P_3 has a dependency relationship with P_1 which is defined by

$P_3 = \min(SOPP_3, CODP_3) = \min\,[\{\,\alpha_{13}P_1 + 100(1 - \alpha_{13})\}, P_1 + \beta_{13}]$.

We found in Table 6.6 that

$SOPP_3 \leq\ COPP_3$

Therefore, $P_1 + 100(1 - \alpha_{13}) \leq P_1 + \beta_{13}$ and $P_3\ \leq SOPP_3$, and the operability level of the receiver output P_3 of enterprise E_3 is bounded by the measure of its strength of interdependency of the feeder output P_1 of enterprise E_1.

In both the $E_2 - E_1$ and the $E_3 - E_1$ enterprise systems, as shown in Table 6.7 and 6.9 with their strength of dependency bounded, therefore

$P_2\ \leq SOPP_2$

and

$P_3\ \leq SOPP_3$

8.4 DISCUSSION

It is well documented that any country that has an ocean boundary can produce salt through solar evaporation of the seawater by creating ponds to hold the water for some period. Yet, these countries, especially developing countries that have ocean boundaries with an abundant supply of solar radiation, cannot make salt pure enough for local Consumer and power their industries to fuel their economies.

The seawater processes other constituents which makes solar precipitation of Sodium Chloride nearly impossible. These elements also are known to causes health problems when used as food grade salt. These constituents are not easily removed as some remain throughout the evaporation process. The careful procedure outlined in this paper could make it easier to produce pure solar salt.

In a solar salt-works application, energy is the paramount requirement since a large amount of water must be evaporated. Solar salt production is highly suitable to areas where there is an abundant supply of solar energy and high dry wind with high speed to carry away the water vapor from the salt deck.

It was assumed that the relationship given that $P_2 = f(\alpha_{12} P_1)$ is a linear function. Then the derivative $dP_2 = f'(\alpha_{12} P_1) dP_1$ represents the rate of change of P_2 with respect to change in P_1. The use of these relations is a very important step in the formulation of the process systems' output with their time series variables.

Enterprise systems encounter impurities (noises) in raw material which must be minimized in the final products or outcomes. There are also design faults caused by assumptions made which may not be completely correct. The management of every enterprise system day-in and day-out makes business decisions on how to better serve their customers and at the same time satisfy their stakeholders' interest.

In this research, the ratio of salt Consumer between the chemical industry and in human use was used for the Chlor-alkali and table salt enterprise systems of the Ghana salt enterprise. With this assumption, we could be able to specify fully the two-variable linear regression model by listing its important assumptions proposed in the Gauss-Markov theorem.

Therefore $P_2 = \alpha_{12}P_1 + 100(1-\alpha_{12})$ and $P_3 = \alpha_{13}P_1 + 100(1-\alpha_{13})$ are assumed to be linear models of the outputs from enterprise systems$E_2 - E_1$, and $E_3 - E_1$. And the assumption of linearity to the model allows the use of regression analysis to obtain the values of α_{22} and α_{13} through the assumptions of the classical linear regression model. The estimated strength of dependency of the output P_2 of the receiver enterprise E_2 and the output of the feeder enterprise E_1 is

$$\hat{\alpha}_{12} = \frac{\sum(P_1-\bar{P}_1)(P_2-\bar{P}_2)}{\sum(P_1-\bar{P}_1)^2}$$

The regression residual provides a useful measure of the fit between the estimated regression line and the data. A good regression equation is one which helps explain a large portion of the variance of the receiver outputs P_2 and P_3. A large residual implies a poor fit of the data (Pindyck & Rubinfeld, 1998). The line of best fit is said to be the line that minimizes the sum of the squared deviations of the points on the graph from the points of the straight line. The least-square criterion can be expressed as follows:

$$Minimize \sum_{j=1}^{N}(P_j - \hat{P}_j)^2$$

where $\hat{P}_j = \alpha_{ij} P_i + \gamma_{ij}$ represents the equation of the straight line with the relationship between $\hat{P}_j$ and P_i given as α_{ij} and γ_{ij} is the value of $\hat{P}_j$ when P_i is zero.

The t distribution was used to construct the 95 percent interval for the estimated parameters. The 95 percent confidence interval was found to be

$\alpha_{12} = 0.5709 \pm 0.01964$

and

$\alpha_{13} = 0.42516 \pm 0.01462$

Also, the R2 is defined as:

$R^2 = \frac{\sum(\hat{P}_2 - \bar{P}_2)^2}{\sum(P_2 - \bar{P}_2)^2}$

where, $(\hat{P}_2 - \bar{P}_2)^2$ is the regression sum of squares (RSS) and $(P_2 - \bar{P}_2)^2$ is the total sum of squares (TSS). The value of R^2 is the proportion of the total variation in P_2 or P_3 explained by the regression of P_2 or P_3 on P_1. The error sum of squares varies from zero to the total sum of squares (TSS) as follows:

$o \leq ESS \leq TSS$

The R2 of the regression equation is defined as:

$R^2 = 1 - \frac{ESS}{TSS} = \frac{RSS}{TSS}$

Therefore, when ESS/TSS is equal to 1, R2 is equal to zero and when ESS/TSS is equal to zero, R2 is equal to 1, where $0 \leq R^2 \leq 1$. R2 is equal to zero when the linear regression model does not explain the variation in the output of the receiver enterprise on the feeder enterprise output. R2 being equal to one implies a best fit of the regression model, indicating that the linear regression model does explain the variation in the output of the receiver enterprise on the feeder enterprise. On $P_2 - P_1$ regression model, R2 = 0.996 while the $P_3 - P_1$ regression model is R2 = 0.996.

The above shows proof that P_2 and P_3 have interdependency relationship with P_1 with $P_2 = SODP_2$ and with $\alpha_{12} \neq 1$, then

$$\alpha_{12}P_1 + 100(1 - \alpha_{12}) < P_1 + \beta_{12}$$

Therefore,

$$P_1 > 100 - \frac{\beta_{12}}{(1-\alpha_{12})}$$

Since the minimum effective operational level of P_2 is achieved by $SOPP_2$ then $MEOLP_2 = \alpha_{12}P_1 + 100(1 - \alpha_{12})$. Therefore, $P_1 = \frac{\{MEOLP_2 - 100(1-\alpha_{12})\}}{\alpha_{12}}$ and $MEOLP_2 < P_1 + \beta_{12}$

This implies that:

$$MEOLP_2 < \frac{\{MEOLP_2 - 100(1-\alpha_{12})\}}{\alpha_{12}} + \beta_{12}$$

Therefore

$$\beta_{12} > MEOLP_2 - \frac{\{MEOLP_2 - 100(1-\alpha_{12})\}}{\alpha_{12}}$$

By rearranging we get

$$\beta_{12} > \frac{\alpha_{12}MEOLP_2 - MEOLP_2 - 100(1-\alpha_{12})}{\alpha_{12}}$$

$$\beta_{12} > \frac{MEOLP_2(\alpha_{12}-1) + 100(\alpha_{12}-1)}{\alpha_{12}}$$

The right side of the above expression for β_{12} has a negative value and since the criticality of interdependency β_{12} is always positive, then

$$\beta_{12} > \frac{(\alpha_{12}-1)}{\alpha_{12}}(MEOLP_2 + 100)$$

Also, the Ghana salt enterprise system uses sample information to obtain estimates of best possible mean and variance, and the covariance of two random variables of the regression. Though we can draw inference on the models, the sample size of nineteen observations was below the 30-sample size recommended for the analysis. This was done to minimize the amount of impurities, if salt precipitation was allowed beyond the optimum level where Magnesium ions begin to precipitate.

9 CONCLUSION

9.1 RESEARCH CONTRIBUTIONS

In this research study, our main concern was to develop a method to estimate the parameters of the model, namely the strength and criticality of dependency, using the least-square regression model with the output of one feeder enterprise and the output of one receiver enterprise. First, we described the assumptions underlying the model, and then we analyzed the statistical properties of the least-square estimators. We concluded that under certain assumptions, the estimators of the strength and criticality were consistent and efficient. The distribution of the estimated parameters, strength and criticality were used to construct confidence intervals and to test the hypothesis about the model. The obtained parameter estimators were within the 95% confident interval. We also, computed the R2, the measure of the goodness of fit of the regression model. The R2 achieved in this research was .99 of which a value of 1.0 indicates a perfect fit.

We have shown that for a given observed value of the feeder enterprise output, we observe many possible outputs of the receiver enterprise. From the assumptions of Gauss-Markov theorem of classical linear regression model, we have developed the best estimate of the strength of dependency or degree of correlation α_{ij} and the criticality of dependency β_{ij} between the outputs P_i and P_j of the feeder and the receiver enterprise systems, E_i and E_j. The values of α_{ij} and β_{ij} are determined as follows:

$$\alpha_{ij} = \frac{\sum(P_j - \bar{P}_j)(P_i - \bar{P}_i)}{\sum(P_i - \bar{P}_i)^2}$$

$$B_{ij} = 100(1 - \alpha_{ij}) = 100\{1 - \frac{\sum(p_i - \bar{P}_i)(P_j - \bar{P}_j)}{\sum(P_i - \bar{P}_i)^2}\}$$

$$B_{ij} = 100\{\frac{\sum(P_i - \bar{P}_i)^2 - \sum(P_i - \bar{P}_i)(P_j - \bar{P}_j)}{\sum(P_i - \bar{P}_i)^2}\}$$

From the Ghana Salt enterprise system, the dynamic behavior of the two enterprise systems, the Salt Winning enterprise and the Chlor-alkali enterprise system, $E_1 - E_2$ is used to determine their functional relationship. The results obtained from the Salt Winning enterprise and the Chlor-alkali enterprise system, $E_1 - E_2$ enterprise system, and the Salt Winning enterprise and the Food Grade Salt enterprise, $E_1 - E_3$, clearly show that there are correlations between them, and that the sum of α_{12} and α_{13} equals to 1, as E_2 and E_3 are coupled to the same common driver E_1. Cross correlation in the time domain was used to detect the degree of correlation between variable observed from each of the interdependent systems.

An application of the above advancement to the Ghana Salt enterprise system and the estimation of the strength and criticality parameters, α_{12} and E_2 as indicated above for the Ghana Salt enterprise systems were as follows:

For

$$E_1 - E_2$$

$$\alpha_{12} = 0.571$$

and

$$\beta_{12} = 42.9$$

Also, for

$$E_1 - E_3$$

$$\alpha_{12} = 0.429$$

and

$$\beta_{12} = 57.1$$

Making a safe solar salt for the chemical industry requires the elimination of the component impurities that exist with Sodium salt. Over ninety percent of Calcium present in salt water is precipitated in the concentration ponds before the highly saturated water is transferred to the crystallization ponds at a specific gravity of 1.21 where all carbonates of Calcium and Magnesium ions have been removed. If the Magnesium Sulfate ions are not removed by chemical precipitation, they will exist in the specific gravity range where Sodium Chloride ions are to be precipitated. The presences of Magnesium ions in the defined range of specific gravity for Sodium ions precipitation limits the amount of pure solar salt recovered. Removing the Magnesium ions limits the risk impact of impurities on downstream enterprise systems and increases solar salt production.

In this study, the least-square criterion was applied to find the line of best fit, which minimizes the sum of the squared deviations of the points of the graph that form the straight line. Time function outputs of enterprise systems which describe the hourly movement of the variable over time called time series data were used to construct the feeder-receiver relationships of the FDNA. To determine the strength of interdependency relationship between enterprise systems E_2 and E_1, cross-sectional data of their outputs were used. To describe this relationship statistically we used a set of observations for each variable and a hypothesis that set forth the explicit mathematical model of the relationship.

Consequently, the conditions required for the existence of the derivative of the function relating the output variable of the receiver enterprise system to the variable of the feeder enterprise system written as follows, $P_j = f(\alpha_{ij} P_i)$ are fulfilled. The derivative $dP_j = f'(\alpha_{ij} P_i) dP_i$ represents the rate of change of P_j with respect to change in P_i. Since the values of P_j and P_i vary as a function of time, the ratio of their derivatives was found to be constant. The use of these relations is a very important step in the formulation process of the relationship between these systems' outputs with their time series variables. Therefore, the value of the strength of dependency relationship between the feeder enterprise and the receiver enterprise was found to be a constant value. An interesting phenomenon in this case is that the cross-over point was determined to be at the point where the feeder enterprise has not yet supplied any value to the receiver enterprise, which is $P_i = 0$.

The assumption of a linear relationship between P_j and P_i enabled the extension of the FDNA calculus to address non-stationary interdependency to analysis problems in complex systems. The derivatives of P_j and P_i with respect to time helped to determine the value of strength of dependency between P_j and P_i. Enterprise systems such as the Ghana Salt enterprise System where the cross-over point occurs at $P_i = 0$ are systems that wholly rely on the feeder enterprise to achieve their goals and outcomes.

9.2 STUDY LIMITATIONS

In the chemical process industries and the petrochemical industries, system modeling, the rate equation is determined using the elementary concept of conservation of mass, energy, and momentum. Therefore, the output of the chemical process is determined by the process input and the performance of the unit equipment or several equipment that make up the systems. Also, apart from the process systems, process flow streams and/or the utility streams, there are recycle streams, internal to the process that are critical to the operation of the process systems and must be identified and their impact on the processes understood and managed.

The effect of factors such as recycle streams and process performance of equipment limits this study to the chemical process industries and other manufacturing systems where design characteristics are important for process definition and performance. The limitation of this research is shown in the value of $\boldsymbol{\alpha_{ij}}$. The value of $\boldsymbol{\alpha_{ij}}$ is determined by the design capacity of the systems being considered (i.e. chlor-akali). Figure 6.8 shows how $\boldsymbol{P_j}$ changes with changes in $\boldsymbol{P_i}$ and they are bounded by the value of $\boldsymbol{\alpha_{ij}}$ which is obtained as a function of the system's design capacity. For example $\boldsymbol{\alpha_{ij}}$= 0.2, then for $\boldsymbol{P_j = \alpha_{ij}P_j + 100(1 - \alpha_{ij}) = 0.2P_i + 80}$. For this case, the baseline operability level is 80 and $\boldsymbol{P_j}$ will vary from 80 to 100. Therefore, the size of the enterprise system cannot be changed at any moment in time. In the Food Processing, Chemical, Petrochemical and the Petroleum Industries, design capacity is usually used as a primary planning factor. All other enterprise systems, such as those in technology, education, and banking does not pay important attention to design capacities in the same way as that characterized by fluid flows in the manufacturing industries.

9.3 FUTURE RESEARCH IN ENTERPRISE INTERDEPENDENT SYSTEMS

The study has concentrated on non-stationary, two-variable regression analysis where the receiver enterprise systems have relationships with a feeder enterprise system. In this case, it has extended the non-stationary two-variable model where P_j, the receiver enterprise system's output, is a linear function of a series of feeder enterprise systems' outputs P_i to P_j as a function of multiple feeder enterprise outputs P_{1i}, $P_{2i}, \ldots.$ P_{ni}. Then it has used statistic regression analysis to test the statistical significance of the individual strength of dependency coefficients. Finally, it has evaluated if the Gauss-Markov theorem can be extended to the multiple regression model and whether one can obtain information about the distribution of the estimated regression parameters, the strength of dependency coefficients.

Most engineering enterprise systems are made up of non-linear models. Non-linear systems are those that do not have static linearity. This study has shown that you can apply the method developed here to study non-stationary models and use the information to obtain the distribution of the estimated regression parameters, the strength of dependency coefficients α_{ij} and β_{ij}.

REFERENCES

Acquah, F. (1998). Prospects for a Chlor-Alkali Industry Brighten in the ECOWAS. Ghana Institute of Industrial Research, Accra.

Alan, W., Randolph, F., Barry, Z., & Posner. (1988). Effective Project Planning and Management Prentice Hall.

Albino, V. Pontrandolfo, P. and Scozzi, B. (2002). "Analysis of information flows to enhance the coordination of production processes," International Journal of Production Economics, vol.75, pp. 7-19.

Baker, B. N., Murphy, D.S., & Fisher, D. (1988). Factors Affecting Project Success, Project Management Handbook, 2nd Edition, end. Pp. 902. New York: John Wiley & Sons.

Barabási, A.-L. and R. Albert (1999). Emergence of scaling in the random networks. Science 268, 509-512

Balázs, C. and Monostori, L. (2008). A Complexity Model for Network of Collaborating Enterprises, 17th IFAC World Congress, Seoul, Korea.

Balderston JB, Whitin TM. Aggregation in the Input-Output Model: - An Economic Activity Analysis, New York: John Wiley & Sons, 1999:79-128.

Bauer, DJ, Thurwachter S, Sheng P. Integration of Environmental Factors in Surface Planning: Part 1- Mass and Energy Modeling. Transactions of NAMRI/SME 1998; XXVI:171-6.

Bernus, P., Nemes, L., & Williams, T. (1996). Architectures for enterprise Integration. Journals of Systems and Software.

Binyam, R., & Anttti, T. (1997). “The Industrial Organization of Corruption: What is the difference in Corruption between Asia and Africa?” The World Bank, Washington DC.

Bird et al., (1960). Transport Phenomena, Wiley, New York, N. Y. 1960

Britt, Stephen, (2000). “Scenario Generation for Financial Simulation — A Primer,” Tillinghast – Towers Perrin Technical Reference, October 2000.

Bernus, P., Nemes, L., & Williams, T. (1996). Architecures for enterprise Integration. Journals of Systems and Software.

Brester, G. B. (2006). Research and Publishing: Relevance and Irreverence. Journal of Agricultural and Resource Economics, 3 1 (3):455-470.

Breuil JM. Input-Output Analysis and Pollutant Emissions in France. The Energy Journal 1992;13(3).

Britt, Stephen, “Scenario Generation for Financial Simulation — A Primer,” Tillinghast – Towers Perrin Technical Reference, October 2000

Caber B., Contreras D., Miravete E. J. Aggregation in Input-Output Tables: How to Select the Best Cluster Linkage. Economic System Research 1991:99-109.

Chandorkar, M. C. Divan, D.M., and Adapa, R. (1993). “Control of parallel connected inverters in standalone ac supply systems,” IEEE Trans. on Industry Applications, 29(1):136–143, Jan 1993.

Choi ACK, Kaebernick H., Lai W. H. Manufacturing Processes Modeling for Environmental Impact Assessment. Journal of Materials Processing Technology 1997; 70:231-38.

Claudio, C. P. (1988). Risk analysis in Developing countries. Society for Risk Analysis.

Cleveland, D. I., King, W. (1983). System Analysis and Project Management. Singapore: McGraw-Hill.

Cooke-Davies, T. (2000). Project Management and the Management of Change. Association for Project Management. London

Cummings A. M. (1970). Mineral facts and problems. U. S. Bureau of Mines

D’Arcy, S. P. (2001). Enterprise Risk Management, Forthcoming in the Journal of Risk Management of Korea, Vol. 12, Number 1.

Davenport, T. H. (1998). Putting the enterprise into the enterprise system. Harvard Business Review 76(4), 121 – 131.

De Witt, A. (1988). Measurement of Project Success. International Journal of Project Management, Vol.6.

Duncan, W. R. (1996). A guide to the Project Management Body of Knowledge. Project Management Institute.

Dudenhoeffer, D. D. Permann, M. R. and Manic, M. (2006) “CIMS: A Framework for Infrastructure Interdependency Modeling and Analysis.” Submitted to Proceedings of the 2006 Winter Simulation Conference.

Douglas, J. M., (1972). Process Dynamics and Control, Vol. 1 Prentice Hall, Inc., Englewood Cliffs, New Jersey

Dvir, D., Lechler, T. (2003). Plans are nothing, changing plans is everything: The impact of changes on project success. Elsevier.

Faylor, H., Taylor, J. (1949). Project Management. International Journal of Project Management.

Forrester, Jay W., (1961). Industrial Dynamics. Portland, OR: Productivity Press. 464 pp.

Friedly, J. C. (1972). Dynamic behavior of processes. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

Fuchs H. U. (2002a). Modeling of Uniform Dynamical Systems. With Computer Based Training Unit. Orell Füssli, Zurich.

Garbowski et al., (2000). Risk modeling in distributed, large scale systems. IEEE Transactions on Systems, Man, and Cybernetics-Part a Systems and Humans, 30(6):651–660, November 2000.

Garvey, P. R., & Pinto, A. C. (2009). Introduction to Functional Dependency Network Analysis. Second International Symposium on Engineering Systems. Cambridge, Massachusetts: Massachusetts Institute of Technology.

Garvey A. P. and Pinto A. C. (2009). An index to measure risk co-relationships in engineering enterprise systems. Int. J. System of Systems Engineering, Vol. 1, No. 3, 2009

Ghana Ministry of Trade and Industry, statistical data, 1997-2005

Gioia, D. A., & Pitre, E. (1990). Multi-paradigm perspectives on theory building. Academy of Management Review.

Grey, S. (1995). Practical Risk Assessment for Project Management. John Wiley & Company.

Hanley, J.P. (1990). How to Keep Control Loops in Service, Intech, pgs. 30-33 October 1990.

Hatanaka M. Note on Consolidation within a Leontief System. Econometrica 1952;20(2):301-03. 18

Hawdon D, Pearson P. Input-Output Simulations of Energy, Environment, and Economy Interactions in the UK Energy Economics 1995;17(1):73-86.

Jokobson, L. (1997). Million Truths – a Decade in China. Finish Journal of Management.

Keating, C. and D. Jacobs. Assumptions Necessary for Project Based Initiatives. Appearing in 1998 Proceedings of the American Society for Engineering Management National Conference, Virginia Beach, Virginia, October 1-3, 1998, pp. 223-229.

Keating, C., Sousa-Poza, A., Mun, J., (2004). System of Systems Engineering Methodology. Engineering Management & Systems Engineering, 20(4), 24-31.

Krygiel, A. J., (1999). Behind the Wizard's Curtain: An introduction Environment for a System of Systems, CCRP.

Kloppenborg, T. J., Opfer, W. (2000). Forty years of project management Research: Trends, Interpretations and predictions. Proceedings of PMI research. Paris: Project Management Institute Inc.

Kerzner, H. (2006). Project Management. Hoboken, New Jersey: John Wiley & Sons.

Lechler, T. (1988). When it comes to Project Management, It's the People that Matters: An Empirical Analysis of Project Management in Germany. Calgary: University of Calgary.

Lave LB, E. Cobas-Flores, Hendrickson CT, McMichael FC. Using Input-Output Analysis to Estimate Economy-wide Discharges. Environmental Science & Technology 1995; 29(9):420A-26A

Leontief W. (1952). Input-Output Economics. New York: Oxford University Press, 1986.

Maier, (1998). Architecting Principles for System of Systems, System Engineering, Vol. 1 No. 4.

Mbiti, L. (2005) "The Spirit of African Leadership". Randburg Knowres.

McAvoy, T. J. (1979). Steady State Decoupling of Distillation Column. ACS Journal.

McCormick, D. (1999). "African enterprise Clusters and Industrialization: Theory and Reality," World Development, 27:9, 1531-1551.

Meyer, M. A., & Booker, J. M. (1990). Eliciting and Analyzing Expert Judgment.US Nuclear Regulatory Commission.

Milacic D, Gowaikar H, Olson WW, Sutherland JW. A Proposed LCA Model of Environmental Effects with Markovian Decision Making. Proceedings of the 1997 Total Life Cycle Conference -Life Cycle Management and Assessment (Part1), 1997:111-8.

Miller RE, Blair PD. (1985). Input-Output Analysis: Foundations and Extensions, Prentice-Hall, Englewood Cliffs, N.J.

Moder, J., Philips, C. (1964). Project Management with CPM and PERT. New York: Litton.

Morimoto Y. On Aggregation Problems in Input-Output Analysis. Review of Economic Studies 1970; 37(109):119-26.

Morris, P. G. (1994). The Management of Projects. Manchester University Press.

Moss, T. (2007). African Development: -Making Sense of the Issues and Actors. Lynne Rienner Publishers.

Munoz, AA, Sheng P. An Analytical Approach for Determining the Environmental Impact of Machining Processes. Journal of Materials Processing Technology 1995; 53:736-58.

Murman, e. a. (2002). Strategic and Tactical levels of Organizational Success. Second International Symposium of Engineering Systems. Cambridge: Massachusetts Institute of Technology.

Nair, A.; Ahlstrom D. and Filer L. (2007). Localized Advantage in a global Economy: The Case of Bangalore. Thunderbird International Business Review. DOI: 10.1002/tic

Newman, M. E. J. (2003). The structure and function of enterprise networks. SIAM Review 45 (2), 167-256

Nightingale, D. (2009). Principles of enterprise Systems, Second International Symposium on Engineering Systems, MIT Cambridge, Massachusetts.

Nocco, B. W. and Stulz, R. M. (2006). enterprise Risk Management: Theory and Practice, Journal of Applied Corporate Finance, Vol. 18 No. 4

Norman, D. O., & al, e. (2004). Engineering an Enterprise System. Mitre Technical Paper.

O'Hagan et al., (2006). Uncertain Judgment: Eliciting Experts' Probability, Chester, John Wiley and Sons.

Orlikowski, W. J. (1991). Studying Information Technology in Organizations: Research Approaches and Assumptions. Information Systems Research, 2(1), 1-28.

Perrone, L. F. Wieland, F. P. Liu, J. Lawson, B. G. Nicol, D. M. and Fujimoto R. M. (2006). CIMS: A Framework for Infrastructure Interdependency Modeling and Analysis. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 2006.

Phongpaicht, P. a. (1994). Corruption and Democracy in Thailand. Faculty of Economics Political Economy Center, Chulalongkorn University.

Pinto, J. K. Slevin, D. (1988). Critical Success Factors. Project Management Journal, Vol. 19, No. 3.

Porter, M. E. (1990). Cluster and the new economics of competition. Harvard Business Review.

Rinaldi, S. M., Peerenboom, J. P., & Kelly, T. K., (2001) Identifying, understanding, and analyzing critical infrastructure interdependencies, IEEE Control Systems, vol. 21, pp. 11-25, 2001.

Roberts N., Shaffer W., Garet M., Deal R., Andersen D. (1994). Introduction to Computer Simulation: A System Dynamics Modeling Approach. Productivity Press, University Park IL.

Sage, A. P. and Rouse, W. B. (1999). Handbook of Systems Engineering and Engineering Management, John Wiley & Sons.

Sage, A. P. and Cuppan, C. (2001). On the System Engineering and Engineering. Management of Systems of Systems and Federations of Systems, Information, Knowledge, Systems Management Journal, Vol. 2, 2001

Sedivy, V. M. (2009). Environmental Balance of Salt Production…, Global NEST Journal, Vol. 11 No 1, pp. 41 – 48

Sekaran, U. (2003). Research methods for business, Fourth edition, Southern, Illinois University at Carbondale, John Wiley &Sons, Inc., USA.

Shang, S. and Seddon, P. B. (2002). Assessing and Managing the Benefits of Enterprise Systems: The Business Manager’s Perspective, Information Systems Journal, and Vol. 12.

Shreve, R. N. (1955). Chemical Process Industries, p.224, McGraw-Hill, New York

Theil H. (1957) Linear Aggregation in Input-output Analysis. Econometrica; 25(1):111-22

Suda, L. V. (2006). The Meaning and Importance of Culture for Project Success. Project Perspectives.

Soja, P. (2008). Difficulties in Enterprise System Implementation in Emerging Economies: Insights from an Exploratory Study in Poland. Wiley Periodicals, Inc.

Stallworthy, E. A. Kharbanda, O. (1983). Total Project Management. International Journal of Project Management.

Tsui, A. S., Schoonhoven, C., Meyer, M., Chung-Ming, L., & Milkovich, G. (2004). Organization and Management during Societal Transformation: The People's Republic of China. Organization Science, 15 (2), 133-144.

Turner J. R. (1993). Handbook of project-based management. London: Mcgraw-Hill.

Turton et al (1998). Analysis, Synthesis and Design of Chemical Processes. Prentice Hall

Van de Ven, A. Delbecq, A. L. and Koenig, R. (1976). "Determinants of coordination modes within organizations," American Sociological Review, vol. 41, pp. 32-338. McGraw-Hill, Inc.

Wrege, C. D., Greenwood, R. (1991). Frederick T. Taylor: The Father of Scientific Management. Business One Irvin.

Wren, D. A. (1994). The Evolution of Management Thought. New York: John Wiley & Sons.

Wiggers, M. Bekooij, M. Jansen, P. and Smit G., (2006). Efficient computation of buffer capacities for multi-rate, real-time systems, with back pressure. International Conference on Hardware/Software Co-design and System Synthesis.

Wolstenholme, E. F. (2003). Towards the definition and use of a core set of archetypal structures in system dynamics, System Dynamics Review vol. 19, No. 1 (Spring 2003), 7-26.

Valle-Riestra, F. J. (1983). Project Evaluation in The Chemical Process Industries. (Acquah, 1998)C (Norman & al, 2004) (Norman & al, 2004) (Albino, P, & B, 2002) (Bake, Murphy, & Fisher, 1988)

APPENDICES

APPENDIX A: MODELING OF INTERDEPENDENCY NETWORK SYSTEMS

THE ENTERPRISE SYSTEM

THE INITIATING EVENTS

For the salt enterprise systems shown in Figure A: -3.3 below

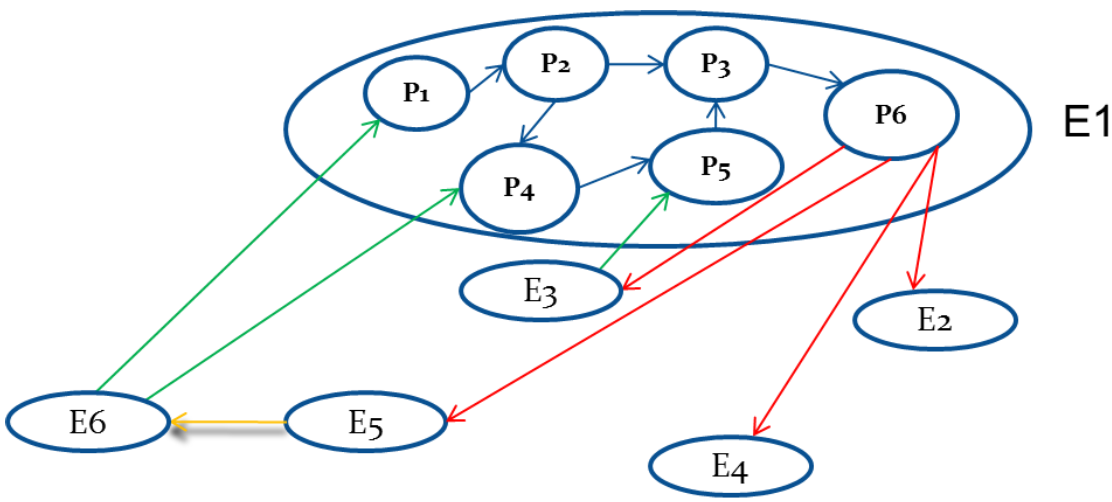

Figure A: - 3.3 formal model of FDNA (Industry Cluster) between E1 and E2

Given a set of initiating events $\{E_{1(P_1)}E_{2(P_7)}\}$ what is the cascading impact on a subset of components of enterprise systems, E_1 and E_2 given as $\{P_1, P_2. P_3, \ldots\ldots, P_8, and\ P_9\}$? All the program nodes or components $\{P_1, P_2. P_3, \ldots\ldots, P_6\}$ are the components of the enterprise system E1 and the components $(P_7, P_8, and\ P_9)$ are the program nodes in E_2. For example, in the case of the chemical precipitation of the Magnesium ion in the program node (n1), what is the effect in all the proceeding nodes if all the Magnesium ions are not removed?

Given a set of program nodes $\{P_1,\ P_7\}$ that would cause this effect? enterprise $E_2(p_7)$ knowing that $E_1(P_1)$ was unable to meet the quality requirement may refuse to accept shipment supplied by E_1 in order to avoid risk of using E_1's output.

Given a set of events $\{E_1(P_1), E_2(P_7)\}$ and a set of observed outcomes of on nodes $\{P_3, P_5, P_7,\}$, is it possible to determine the derived interdependencies $\{INT\ (P_1, P_7), INT(P_1, P_8), INT(P_1, P_9)\}$?

Given a set of enterprise networks and a critical function, what is the subset of critical nodes $\{P_3, P_5, P_6, P_7, \ldots\ P_9\}$ across all networks that will adversely impact specific mission functionality due to direct or derived interdependencies?

Given a set of enterprise networks and a critical function, what is the subset of critical nodes $\{P_3, P_5\ \ldots \ldots, P_9\}$ across all networks that will adversely impact specific mission functionality due to direct or derived dependency?

THE GHANA SALT ENTERPRISE SYSTEMS

Grabowski et al. (2000) outlined the importance of risk framework in risk modeling to organize definitions, a domain-meaningful context, and a structure around which data is collected. Grabowski et al. (2000) emphasized that the purposes for such framework are: -

Understanding risk occurrence in interdependent systems

Organizing the relationship among some of the risk-related concepts given in the literature. The literature review has shown that there are two common dimensions that characterize risks. The two common dimensions of risks are the probability/likelihood of occurrence and the expected outcome/impact/consequences (Buckle et al., 2000). Risk analysis involves identifying the source of the risk, as well as its negative and positive consequences. Risk of interdependency is an inherent context-specific concept between multiple interdependent systems, depicted by Grabowski et al (2000) as the occurrence of risk as an event error chain of causes and consequences. Modeling risks in enterprise systems, there is a need to link sources (drivers) of risks to their consequences. There are three risk drivers, namely the threats of risk, risk triggering chains, and vulnerabilities. Bjørn and Marvin (1999) defined risk as a stable, latent, adverse factor that manifests itself in an accident event. They defined a triggering chain as an enterprise chain of events, interacting together to exploit a latent threat to a hazard. Haimes (2006) defined vulnerability as the manifestation of the inherent system characteristics that can be exploited to adversely affect the system. A hazard is the occurrence of threat in a vulnerable system when the triggering events occur into an event which may cause a potential harm.

In the Ghana salt manufacturing, Potassium Chloride (KCl), Magnesium Chloride (MgCl2), Magnesium Sulfate (MgSO4), and Calcium Sulfate (CaSO4) are impurities that can be a serious threat to the quality of salt required for human Consumer as well as for industrial application. The enterprise chain of events is shown below: -

$$KCl + MgCl_2 + 6H_2O \rightleftharpoons KClM_gCl_26H_2O$$
$$KCl + MgSO_4 + 3H_2O \rightleftharpoons KClM_gSO_43H_2O$$

APPENDIX B: SOLAR EVAPORATION OF SEA WATER

Evap.	ρ	ion Cl-	ion Br-	SO42-	Mg2+	Ca2+	K+	Na+	Strength
0.950	1.024	20.30	0.0697	2.790	1.250	0.391	0.414	11.30	0.72
0.980	1.025	20.50	0.0724	2.880	1.300	0.39	0.427	11.30	0.73
1.100	1.025	20.80	0.0735	2.890	1.450	0.428	0.463	11.50	0.75
1.170	1.028	22.70	0.078	3.210	1.540	0.466	0.51	13.20	0.83
1.290	1.030	26.10	0.091	3.767	1.793	0.562	0.569	15.10	0.957
1.540	1.040	29.50	0.104	4.324	2.553	0.658	0.628	17.00	1.084
1.750	1.041	32.90	0.117	4.880	2.300	0.754	0.688	18.90	1.210
2.260	1.05	41.70	0.138	5.760	2.950	0.823	0.837	22.60	1.500
2.680	1.060	49.70	0.174	7.280	3.480	0.962	1.010	27.20	1.790
2.920	1.070	55.45	0.197	8.065	3.780	1.091	1.160	31.35	2.010
3.16	1.076	61.20	0.219	8.850	4.080	1.220	1.310	35.50	2.230
3.345	1.080	65.10	0.227	8.850	4.305	1.380	1.390	36.65	2.355
3.530	1.084	69.00	0.234	10.100	4.530	1.540	1.470	37.80	2.480
3.806	1.090	73.93	0.251	10.466	4.866	1.440	1.560	40.90	4.150
4.083	1.100	78.86	0.268	10.833	5.203	1.330	1.650	44.00	4.317
4.360	1.101	83.80	0.285	11.20	5.540	1.240	1.740	47.10	2.980
4.390	1.120	91.00	0.323	11.6	6.223	1.041	1.918	52.40	3.303
5.500	1.130	98.20	0.361	11.10	6.907	0.842	2.096	57.70	3.626
6.070	1.136	105.40	0.400	12.40	7.590	,688	2.275	63.00	3.95
6.350	1.140	112,2	0.411	12.90	7.920	0.673	2.390	65.86	4.103
6.630	1.150	119.40	0.422	13.50	8.250	0.658	2.505	68.73	4.256
6.910	1.151	127.00	0.432	13.90	8.580	0.642	2.620	71.60	4.410
7.295	1.160	134.75	0.457	14.45	9.010	0.594	2.770	75.50	4.650
7.680	1.170	142.50	0.482	15.00	9.440	0.546	2.920	79.40	4.895
8.245	1.180	150.25	0.507	15.50	9.870	0.498	3.070	83.30	5.130
8.450	1.185	154.50	0.533	16.10	10.30	0.45	3.220	87.20	5.370
8.620	1.185	158.75	0.525	15.30	10.50	0.442	3.120	88.00	5.390
9.030	1.187	163.00	0.550	16.60	11.00	0.389	3.250	88.20	6.250
9.667	1.190	167.25	0.570	16.85	11.40	0.347	3.418	88.57	6.272
10.035	1.200	171.50	0.594	17.10	11.76	0.304	3.585	88.94	6.295
10.275	1.210	175.75	0.619	17.35	12.20	0.262	3.752	89.31	6.317
10.517	1.214	180.00	0.643	17.60	12.60	0.219	3.920	103.0	6.340

Table B1: - Concentration ponds evaporation of water (density in gm./cc, concentration in gm./liter)

Evap.	ρ	Cl-1	Br-1	SO4-2	Mg2+	Ca2+	K+	Na+	Ionic Strength
12.6	1.218	187.00	0.768	21.80	15.00	0.155	4.02	103.00	6.49
12.9	1.220	185.00	0.859	22.10	15.30	0.142	4.64	101.00	6.55
13.2	1.223	182.00	0.849	23.50	15.80	0.126	5.29	99.20	6.68
15.1	1.229	191.00	0.905	24.60	18.00		5.49	97.20	6.88
16.4	1.226	184.00	0.985	26.90	19.60		6.29	95.80	6.94
17.6	1.222	189.00	1.040	28.10	21.00		6.63	93.90	6.96
18.8	1.230	190.00	1.130	30.20	22.50		6.92	91.90	7.12
20.1	1.231	191.00	1.190	32.60	24.40		7.24	89.90	7.27
20.4	1.233	192.00	1.240	34.20	27.90		7.39	86.60	7.34
23.4	1.243	189.00	1.340	38.20	28.20		8.68	84.20	7.75
23.6	1.235	192.00	1.440	35.70	30.30		8.42	81.90	7.61
24.6	1.240	193.00	1.480	37.90	31.90		8.68	79.50	7.75
25.4	1.242	185.00	1.490	40.90	32.00		8.80	78.00	7.87
26.8	1.235	187.00	1.640	38.50	37.40		9.68	74.30	7.84
31.4	1.248	188.00	1.880	51.30	39.10		11.50	72.00	8.42
32.1	1.250	186.00	1.940	54.00	39.60		11.65	69.60	8.54
32.8	1.254	184.00	2.040	58.00	40.50		11.80	65.80	8.65
34	1.249	186.00	2.010	57.10	43.90		11.90	65.40	8.64
36.8	1.257	187.00	2.130	59.30	46.90		13.20	62.60	9.01
39.4	1.264	185.00	2.350	66.30	48.20		14.00	57.90	9.33

Table B2: - Water Evaporation in Crystallization ponds (density in gm/cc and concentration in gm /liter). Data prepared for my exclusive use from Morton Bahamas solar salt deck.

Sample	Density (ρ)	Cl-1	SO4-2	Mg2+	Ca2+	K+	Na+	Ionic Strength
1	1.024	20,300	2,790	1,250	391	414	11,300	0.72
2	1.025	20,500	2,880	1,300	390	427	11,300	0.73
3	1.026	20,800	2,890	1,450	428	463	11,500	0.75
4	1.028	22,700	3,210	1,540	466	510	13,200	0.83
5	1.041	32,900	4,880	2,300	754	688	18,900	1.21
6	1.050	41,700	5,760	2,950	823	837	22,600	1.50
7	1.060	49,700	7,280	3,480	962	1,010	27,200	1.79
8	1.076	61,200	8,850	4,080	1,220	1,310	35,500	2.23
9	1.084	69,900	10,100	4,530	1,540	1,470	37,800	2.48
10	1.101	83,800	11,200	5,540	1,240	1,740	47,100	2.98
11	1.136	116,000	12,400	7,590	642	2,275	63,000	3.95
12	1.151	127,000	13,900	8,580	688	2,620	71,600	4.41
13	1.185	158,000	16,100	10,300	450	3,220	87,200	5.37
14	1.186	158,800	15,300	10,500	442	3,120	88,000	5.39
15	1.187	158,000	16,600	11,000	398	3,250	88,200	5.46
16	1.214	180,000	17,600	12,600	219	3,920	103,000	6.25
17	1.216	186,000	19,900	13,100	208	3,820	99,200	6.34
18	1.218	187,000	21,800	15,000	155	4,020	96,500	6.49
19	1.223	182,000	23,500	15,800	126	5,290	103,000	6.68
20	1.226	191,000	24,600	18,000		5,490	97,200	6.88
21	1.229	184,000	26,900	19,600		6,290	95,800	6.94
22	1.228	181,000	28,100	21,000		6,630	91,900	6.96
23	1.231	189,000	32,600	24,000		7,240	84,900	7.27
24	1.233	190,000	34,200	24,000		7,390	84,600	7.34
25	1.235	192,000	38,200	27,900		8,680	84,200	7.75
26	1.241	189,000	25,700	28,200		8,420	81,200	7.61
27	1.242	192,000	40,900	30,300		8,800	78,000	7.87
28	1.245	185,000	38,500	32,000		9,680	76,300	7,84
29	1.248	187,000	51,300	37,400		11,500	68,000	8.42
30	1.249	188,000	58,000	39,100		11,800	64,800	8.65
31	1.254	184,000	54,100	40,500		11,900	65,400	8.64
32	1.258	186,000	59,300	43,900		13,200	62,600	9.01
33	1.263	187,000	66,300	46.900		14,000	57,900	9.33

Table B3: - Composition of a typical seawater as a function of density (concentration in mg/liter solution, ρ in g/cc)

APPENDIX C: SODIUM ION PRECIPITATION

$Time, t$	$L_{1(t)}$	$L_{2(t)}$	$L_{3(t)}$
3	5.80	3.324	2.476
4	7.20	4.126	3.074
5	9.10	5.215	3.885
6	9.10	5.789	4.311
7	10.10	7.508	5.592
8	13.10	9.399	7.001
9	16.40	10.776	8.024
10	21.20	12.093	9.007
11	23.50	13.468	10.032
12	25.00	14.328	10.672
13	28.70	16.465	12.235
14	31.00	17.767	13.233
15	33.40	21.549	14.258
16	37.20	21.320	15.880
17	37.60	21.549	16.051
18	40.40	23.154	17.246
19	45.10	25.848	19.252

Table C1: Sodium ion requirement (gm/liter)

Solar salt production in the crystallization ponds can grow to a height before harvesting. The amount of salt produced for commercial use and for human Consumer takes several months initially. Afterword, several ponds are set to produce large quantities which allows for harvesting daily. The samples obtained from Morton Salt Company are used to simulate a growth function daily. The split in ratio between the chemical use of salt in industry and for human Consumer is approximately 60% to 40% ratio. That split is used for $E_1 - E_2$ and $E_1 - E_3$ in Table C1.

Time, t	W1(t)	W2(t)	W3(t)
1	5.082	2.912	2.170
2	9.656	5.534	4.121
3	14.738	8.446	6.292
4	18.295	10.484	7.811
5	23.123	13.251	9.872
6	25.664	14.710	10.954
7	33.287	19.078	14.209
8	41.671	23.883	17.790
9	47.771	27.382	20.389
	63.615	30.728	22.887
11	59.713	34.222	25.491
12	63.525	36.407	27.118
13	72.927	41.838	31.089
14	78.771	45.146	33.625
15	84.869	48.640	36.230
16	94.525	54.174	40.351
17	95.542	54.756	40.786
18	102.656	58.834	43.822
19	114.599	65.680	48.921

Table C2: Sodium Salt Production (kg/day)

In the formation of Sodium Chloride, 1 mole of Sodium ion reacts with 1 mole of chlorine ion to produce 1 mole of solar salt as follows:

$$Na^{+} + Cl^{-} \rightarrow NaCl \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (C)$$

One mole of Sodium ion weighs 23 grams per mol. and one mol. of Chlorine ion weighs 35.45 grams per mole. This allows us to calculate the total weight of solar salt produced in grams, since one mole of pure solar salt weighs 58.45 grams per mole. Solar salt ratios are shown in Table C2.

APPENDIX C: DERIVATION OF LEAST SQUARES

The purpose of constructing a statistical relationship is to predict or explain the effects of one variable resulting from the changes in one or more explanatory variables. In this case we are looking at the Ghana salt ENTERPRISE system. It consists of the salt winning enterprise E_1, the chlor-alkali enterprise E_2, and the stable salt production enterprise system E_3.

figure c1 shows scatter points of the outputs P_1, P_2, and P_3 of the Ghana salt enterprise systems and their linear equations given by $P_2 = \alpha_{12}P_1 + \gamma_{12}$, and $P_3 = \alpha_{13}P_1 + \gamma_{13}$. To determine the strength of dependency of P_2 and P_3 on P_1, we choose to minimize the sum of the square deviation from the fitted lines of P_2 and P_3.

The formation of Sodium Chloride salt from the two elements occurs in their molar ratios. That is 23 grams of Sodium is equivalent to 1-gram mole of Sodium and 35.45 grams of chlorine is also equivalent to 1-gram mole of chlorine. The two elements react to form 1-gram mole of Sodium Chloride with total gram weight of 58.45 grams. The amount of salt precipitated at any time should be multiplied by the ratio of 58.45 or 2.541 grams is the actual amount at the initial crystallization ponds. However, since all values are increase by this amount, it will not change anything in our calculation.

Time, t	$W_{1(t)}$	$W_{2(t)}$	$W_{3(t)}$
1	5.082	2.912	2.170
2	9.656	5.534	4.121
3	14.738	8.446	6.191
4	18.295	10.484	7.811
5	23.123	13.251	9.872
6	25.664	14.710	10.954
7	33.287	19.078	14.209
8	41.671	23.883	17.790
9	47.771	27.382	20.389
10	53.869	30.728	22.887
11	59.714	34.222	25.491
12	63.525	36.407	27.118
13	72.927	41.838	31.089
14	78.771	45.146	33.625
15	84.869	48.640	36.230
16	94.825	54.174	40.351
17	95.542	54.756	40.786
18	102.656	58.834	43.822
19	114.599	65.680	48.921

Table C3: - Outputs of enterprise E_1, E_2 and E_3

Also, in this study, only half of the amount of salt present was removed over the short duration and further salt could be precipitated. As a result, the following are the values of the outputs of the enterprise systems E_1, E_2, and E_3, known as the design capacities of the systems. If we managed to remove all the Sodium Chloride from the concentration pond, we can get $w_{(0)} = 120$

where $P_{i(t)} = \frac{w_{i(t)}}{w_{(0)}}$

Then,

$$P_1(t) = \frac{w_{1(t)}}{w_{1(0)}} \qquad \text{(C1)}$$

$$P_2(t) = \frac{w_{2(t)}}{w_{2(0)}} \qquad \text{(C2)}$$

$$P_3(t) = \frac{W_{3(t)}}{W_{3(0)}} \qquad \text{(C3)}$$

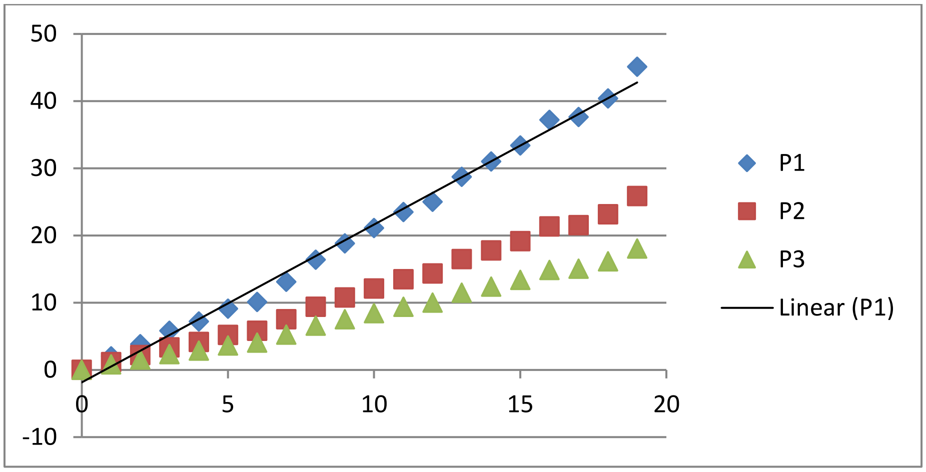

Figure C1: Time Variation of P1, P2, and P3

Also

$$\bar{P}_1 = \frac{1}{N}\sum_{t=1}^{N} P_{1(t)} \qquad \text{…………...……….} \qquad \text{(C4)}$$

$$\bar{P}_2 = \frac{1}{N}\sum_{t=1}^{N} P_{2(t)} \qquad \text{………..…………….} \qquad \text{(C5)}$$

$$\bar{P}_3 = \frac{1}{N}\sum_{t=1}^{N} P_{3(t)} \qquad \text{………..…………..} \qquad \text{(C6)}$$

We construct a statistical relationship between the outputs of enterprises E_1 and $E_{2,}$ then use the least-squares method to predict the effects of the output $P_{2,}$ of enterprises E_1 and E_2 resulting from the changes in outputs P_1 of enterprise $E_{2,}$. From the N observations of the Ghana salt enterprise system, we represent the Garvey relationship between P_2 and P_1 with a scatter points given as $P_2 = \alpha_{12}P_1 + \gamma_{12}$, where P_2 is the receiver enterprise, $E_2{}'s$ outputs and P_1 is the feeder enterprise $E_1{}'s$ outputs. We represent the linear equation between P_2 and P_1 as $\hat{P}_2 = \alpha_{12}P_1 + \gamma_{12}$. To determine the strength of dependency α_{12} between P_2 and P_1 and γ_{12}, we will need to first minimize the sum of squares of deviations between the P_2's and $\hat{P}_2's$, given as:

$$Minimize\ \sum_{t=1}^{N}(P_{2(t)} - \hat{P}_{2(t)})^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (C7)$$

The approach is to choose the values α_{12} and γ_{12} which minimize the expression given in equation C7.

The least squares solution for α_{12} and γ_{12} are

$$\alpha_{12} = \frac{N\sum P_1P_2 - \sum P_1 \sum P_2}{N\sum P^2{}_1 - (\sum P_1)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (C8)$$

$$\gamma_{12} = \frac{\sum P_2}{N} - \alpha_{12}\frac{\sum P_1}{N} = \bar{P}_2 - \alpha_{12}\bar{P}_1 \qquad \ldots\ldots\ldots \qquad (C9)$$

By dividing numerator and the enumerator the right side of equation C3 by N2 we get

$$\alpha_{12} = \frac{\sum\frac{P_1P_2}{N} - (\sum P_1/N)(\sum P_2/N)}{\sum\frac{P^2{}_1}{N} - (\sum P_1/N)^2} \qquad \ldots\ldots\ldots\ldots\ldots \qquad (C10)$$

Then substituting for $\bar{P}_2$ and $\bar{P}_1$ into equation C5, gives

$$\alpha_{12} = \frac{\sum\frac{P_1P_2}{N} - \bar{P}_1\bar{P}_2}{\sum\frac{P^2{}_1}{N} - \bar{P}_1{}^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (C11)$$

We turn our attention to show how the values of α_{12} and γ_{12} are determined. From Table B2, the values for P_2, P_3, and P_1 of the Salt-Chlor-alkali E_1-E_2 and the Salt-Stable salt systems E_1-E_3 are determined as shown in Table B4 below.

Figure 5.3 indicates the Ghana Salt enterprise system consists of the Salt Winning E_1, the chlor-alkali enterprise system E_2, and the staple salt production unit E_3. We now use the regression analysis to determine the values of α_{12} and γ_{12}.

The sample mean of the regression for the Ghana salt enterprise is first calculated as shown in equations C4 through C6. Then α_{12} and γ_{12} are calculated using equations C8 and C9 or equation C10 and C11.

APPENDIX D: REGRESSION ANALYSIS OF DATA

Time, t	$P_1(t)$	$P_2(t)$	$P_3(t)$	$P_1(t) - \bar{P}_1$	$P_2(t) - \bar{P}_2$	$P_3(t) - \bar{P}_3$
1	0.04235	0.02427	0.01808	--0.41819	-0.23718	-0.17662
2	0.08047	0.04612	0.03434	-0.38007	-0.21533	-0.16036
3	0.12282	0.07038	0.05243	-0.33772	-0.19107	-0.14227
4	0.15246	0.08737	0.06509	-0.30808	-0.17408	-0.12961
5	0.19269	0.11043	0.08227	-0.26785	-0.15103	-0.11244
6	0.21387	0.12258	0.09128	-0.24667	-0.13887	-0.10342
7	0.27739	0.15898	0.11841	-0.18315	-0.10247	-0.07630
8	0.34726	0.19903	0.14825	-0.11328	-0.06243	-0.04646
9	0.39809	0.22818	0.16991	-0.06245	-0.03327	-0.02480
10	0.53013	0.25607	0.19073	0.06959	-0.00538	-0.00398
11	0.49761	0.28518	0.21243	0.03707	0.02373	0.01772
12	0.52938	0.30339	0.22598	0.06884	0.04194	0.03128
13	0.60773	0.34865	0.25908	0.14719	0.08720	0.06437
14	0.65643	0.37622	0.28021	0.19589	0.11477	0.08550
15	0.70724	0.40533	0.30192	0.24670	0.14388	0.10721
16	0.78771	0.45145	0.33626	0.32717	0.19000	0.14155
17	0.79618	0.45631	0.33988	0.33564	0.19485	0.14518
18	0.85547	0.49028	0.36518	0.39493	0.22883	0.17048
19	0.95499	0.54733	0.40768	0.49445	0.28588	0.21297

Table D1: -Data analysis for the determination of α_{12}

$\bar{P}_1 = \frac{1}{N}\sum_{t=1}^{N} P_{1(t)}$ = 0.460539, $\bar{P}_2 = \frac{1}{N}\sum_{t=1}^{N} P_{2(t)}$ = 0.26145, $\bar{P}_3 = \frac{1}{N}\sum_{t=1}^{N} P_{3(t)}$ = 0.194705

Time (t)	$(P_1 - \bar{P}_1) * (P_1 - \bar{P}_1)$	$(P_1 - \bar{P}_1) * (P_2 - \bar{P}_2)$
1	0.17488	0.09919
2	0.14445	0.08184
3	0.11406	0.06453
4	0.09491	0.05363
5	0.07174	0.04045
6	0.06085	0.03426
7	0.03354	0.01877
8	0.01283	0.00707
9	0.00390	0.00208
10	0.00484	-0.00037
11	0.00137	0.00088
12	0.00474	0.00289
13	0.02166	0.01284
14	0.03837	0.02248
15	0.06086	0.03550
16	0.10704	0.06216
17	0.11266	0.0654
18	0.15597	0.09037
19	0.24448	0.14136

Table D2: -The Salt Winning E_1 – Chlor-alkali E_2 Systems

Time (t)	$(P_1 - \bar{P}_1) * (P_1 - \bar{P}_1)$	$(P_1 - \bar{P}_1) * (P_3 - \bar{P}_3)$
1	0.17488	0.07386
2	0.14445	0.06095
3	0.11406	0.04805
4	0.09491	0.03993
5	0.07174	0.03012
6	0.06085	0.02551
7	0.03354	0.01397
8	0.01283	0.00526
9	0.00390	0.00155
10	0.00484	-0.00028
11	0.00137	0.00066
12	0.00474	0.00215
13	0.02166	0.00947
14	0.03837	0.01675
15	0.06086	0.02645
16	0.10704	0.04631
17	0.11266	0.04873
18	0.15597	0.06733
19	0.24448	0.10530

Figure D3: - The Salt Winning E_1 and Staple Salt E_3 ENTERPRISE Systems

The estimated ratios for the Salt winning-Chlor-alkali systems as shown in Figure D4, α_{12} can be estimated by first obtaining the sums of the products of the following

$\sum\{(\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}) * (\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}\}$ = 1.463172 ………… (C4)

$\sum\{(\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}) * (\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}\}$ = 0.835406 ………… (C5)

The α_{12} for the Salt winning and chlor-alkali ENTERPRISE system is obtained as follows

$$\alpha_{12} = \frac{\sum\{(\boldsymbol{P_1}-\boldsymbol{\bar{P}_1})*(\boldsymbol{P_2}-\boldsymbol{\bar{P}_2}\}}{\sum\{(\boldsymbol{P_1}-\boldsymbol{\bar{P}_1})*(\boldsymbol{P_1}-\boldsymbol{\bar{P}_1}\}} = \frac{0.835406}{1.463172} = 0.570887$$

Also, α_{13} for the Salt winning and Table salt systems $E_3 - E_1$ can be determine as follows

$\sum\{(\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}) * (\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}\}$ = 1.463172 ………….. (C6)

$\sum\{(\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}) * (\boldsymbol{P_3} - \boldsymbol{\bar{P}_3}\}$ = 0.622079 ………… (C7)

Therefore α_{13} can be determined as the ratio of equation C6 and C7 that is

$\alpha_{13} = \frac{\sum\{(\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}) * (\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}\}}{\sum\{(\boldsymbol{P_1} - \boldsymbol{\bar{P}_1}) * (\boldsymbol{P_3} - \boldsymbol{\bar{P}_3}\}} = \frac{1.463172}{0.622079}$ = 0.4252

APPENDIX E: DEVELOPING FDNA CALCULUS OF THE GHANA SALT

E1. Functional Dependency Network Analysis (FDNA)

Garvey et al (2009) underscores the importance of understanding the entity relationship through the study of the ripple effects of failure of one entity on other dependent entities across enterprise systems. This study is done through the application of system engineering and engineering management principles through identification, representation, and measuring of interdependencies between entities involved in enterprise systems. According to Garvey et al (2009), enterprise systems can be represented as a directional graph whose entities are nodes that depict the direction, strength and criticality of supply-provider relationships (Garvey et al., 2009), through which the effect of operability of the enterprise capability may be degraded due to the realization of risk in one or more contributing program and can cause system failure.

Garvey et al (2009) has designed Functional Dependency Network Analysis, (FDNA) as an analytic philosophy to analyze entity dependencies in enterprise systems space on a whole system perspective. FDNA's perspective is to create capability portfolios of technology programs and initiatives that when assembled together can function to deliver uniform and consistent capabilities that advance the course of enterprise goals and mission outcomes. There are three main steps in FDNA applications for analyzing dependencies among the elements of a system. The first step is the visual representation of enterprise interrelationships between entities in a system (Garvey et al., 2009). The second step is representing dependencies among elements in a system as nodes with directional arrows from one node to other nodes to indicate the direction of flow of information. In this case, the ripple effects of risks due to system failure are identified and recorded. After this is done, then the next thing to do is to establish the characteristic variables of the dependencies among the elements of the systems to develop its calculus that allows the system parameters, the Minimum Effective Operability Level (MEOP), the Baseline Operability Level (BOL), and the strength and critically of dependencies to be determined (Garvey et al., 2009).

Enterprise systems are engineered by bringing together many separate unique systems which provide an overall capability otherwise not possible. Today's enterprise systems continue to grow in complexity and do not have well-defined boundaries and many of them do not have firm specifications and requirements. According to Garvey and Pinto (2009) planning such enterprise engineering systems involves defining the capabilities its systems will provide by creating portfolios of technology programs and initiatives that are made to function together to provide well-staged processes that meet customer requirements. This way of staging enterprise engineering systems is called capability portfolio approach (Garvey et al., 2009) within which risks are managed by identifying those events that threaten the successful integration of such enterprise networks and the delivery of network capabilities developed within each portfolio.

Looking at each portfolio to understand its programs and capabilities, its functions, and dependencies to other portfolios presents a unique way of identifying the ripple effect of risks in enterprise network systems. Garvey has described a portfolio as a collection of technology assembled together to produce goals and outcomes. In some enterprise systems, such as the salt enterprise system, outputs become input to other enterprise systems. As shown in Figure 2 below, the salt enterprise system, to consisting of several capability portfolios with each portfolio having dependency relationships between entities, can be represented with nodes and arrows.

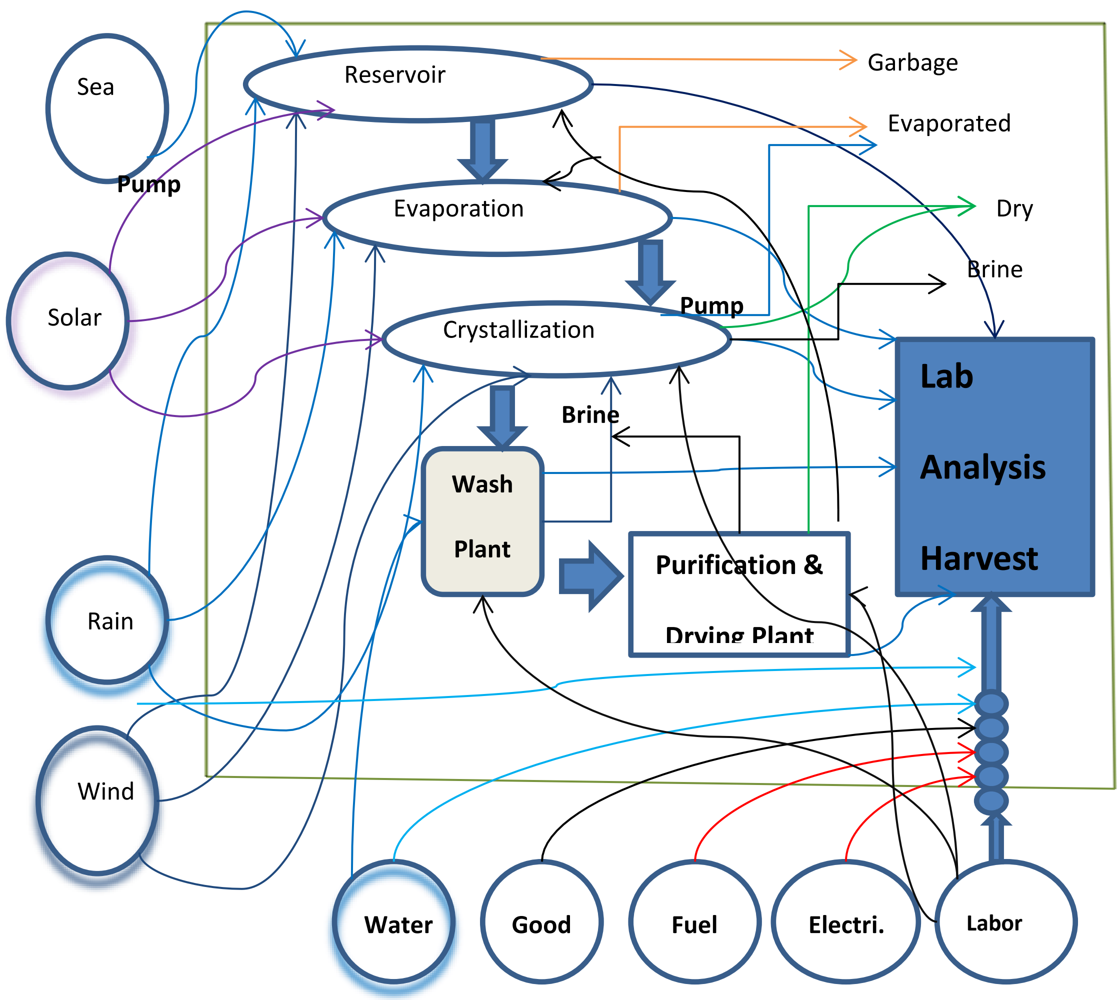

Figure E3: - Flow Diagram of Solar Salt enterprise System

The salt enterprise system produces outcomes, considered as intermediate products, which are used to produce other goals and outcomes as final products or can be used to produce other products. This leads to the formation of industry clusters with related technologies.

The Salt Industry

Salt as Sodium Chloride, which was originally used in the human diet, was found to have significant properties for food preservation. At present, salt has become one of the most important commodities in the modern world. Salt can only be compared to that of petroleum for its significance as a commodity which is greatly used in industrial applications to produce other commodities needed to achieve economic development. Large quantities of salt are needed in all sectors of Ghana's economy: for water treatment, industrial applications for industrial mineral ores refining, for the petroleum refining and crude oilfields applications, medical applications, as well as in the production of consumer products.

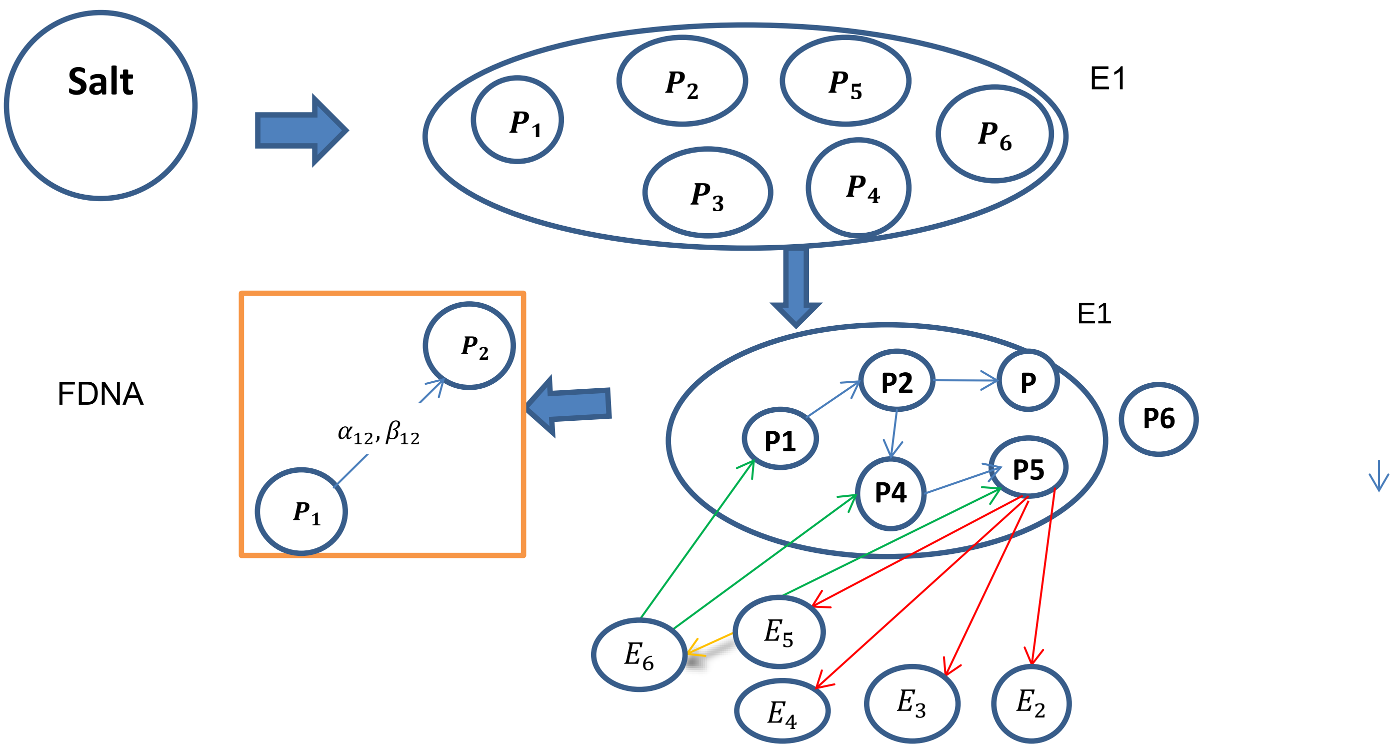

Figure E4: - Developing FDNA Network System

Salt exists in rock caves, lakes, and most abundantly in seawater. In Ghana, salt from the sea enters the lagoons where the salt concentration grows higher due to the evaporation of water in the Lagoons. The seawater and the lagoons salts contain additional components such as Magnesium Sulfate, Calcium Carbonates, Potassium Chloride, as well as the require Sodium Chloride. These components of Sodium Chloride can be used for other applications but for the uses of Sodium Chloride as commercial applications, dietary products, or for medical applications these components are unwanted products that must be removed. In the Chlor-alkali plant, Magnesium Sulfate is a by-product that when found in large concentration will create a very explosive mixture that can lead to the loss of lives and properties. Calcium Carbonate compounds form scales in processing equipment that reduce its efficiencies.

APPENDIX F: PHYSCICAL DATE OF SEA WATER

Chemical ion contributing to seawater salinity	Concentration in average seawater (0/00, part per thousand)	Production of total salinity (no matter what the salinity
Chloride	19.345	55.03
Sodium	10.752	30.59
Sulfate	2.701	7.68
Magnesium	1.295	3.68
Calcium	0.416	1.18
Potassium	0.39	1.11
		99.27

Table F1: Analysis of Seawater Components

			Solution Density	Solution Density	
Concentration Pond		Sea Water concentration	3.5 °Be		
↓	$CaCO3$	Calcium Carbonate	4.6 °Be	1.10 - 1.21	Gypsum
	$CaSO4$	Calcium Sulfate	13.2 °Be	1.2185 - 1.225	
Crystallization					
Pond	$NaCl$	Sodium Chloride	25.7 °Be	1.225 - 1.235	90% of water must be evaporated
↓					
Pure $NaCl$			28 °Be - 29 °Be		
↓					
	$MgSO4$	Magnesium Sulfate	30.0 °Be	above 1.3	

Table F2: Precipitation of seawater components at various densities

APPENDIX G: GHANA SALT DATA

In the Salt industry, systems outputs are what bring about linkage between the interrelated networks of systems to form the whole system. Data obtained as a result of transformation through the equipment used by various processes from their input variables will be evaluated for their impact in the overall result of their outputs. The salt deck has components that must be removed to lower levels to ensure acceptability as input to the receiving processes.

Precise description of the processes used, the types of data obtained and how they are collaborated with the perspective receivers' output material as their feed stocks will be examined to better understand each process' normal performance to its off target values or deviation whenever they occur, the risk factors that prevent systems from meeting their set points and could lead to a total system failure, and when they occur and their impacts after their occurrence. The data corrected will be from the opinions of expert elicited through this research, Ghana salt production.

The aggregate values of the impurities and their impacts on systems capability are important to the overall ability for the clusters of industry to form together.

SOLAR SALT CONCENTRATION PONDS						
Salt Ponds	Specific Gravity at 26°C	Mg, %w/w	Ca, %w/w	SO4, %w/w	Cl, %w/w	Brine height (cm)
D	1.11	1.48	0.09	1.90	8.90	3.1
B	1.08	1.05	0.13	1.40	6.50	3.5
F	1.09	1.36	0.15	1.30	8.10	2.4
D2	1.10	1.02	0.15	1.60	6.80	3.1
B2	1.05	0.61	0.13	0.83	3.60	3.5
A2	1.10	0.96	0.15	1.50	8.30	3.1
H	1.08	0.81	0.15	1.00	6.00	3.7
C	1.09	1.00	0.18	1.40	7.10	3.5
Mean	1.09	1.04	0.14	1.37	6.91	
S.D.	0.02	0.28	0.03	0.34	1.66	

Table G3: Actual Concentration Ponds Salt Samples from Ghanaian Solar Salt Company

		SOLAR SALT CRYSTALIZING PONDS			
Salt Ponds	Specific Gravity at 26°C	Mg, %w/w	Ca, %w/w	SO4, %w/w	Cl, %w/w
D	1.21	2.39	0.030	2.90	16.1
F	1.23	2.07	0.100	4.50	15.1
D2	1.25	3.09	0.030	4.20	14.7
C	1.22	2.30	0.100	3.20	14.9
Mean	1.23	2.46	0.070	3.70	15.2
S.D.	0.02	0.44	0.040	0.77	0.62

Table G4: Actual Crystallizations Pond Salt Samples from Ghanaian Solar Salt Company

		CHARACTERISTICS OF SALT SAMPLES IN GHANA			
Salt Ponds	Mg, %w/w	Ca, %w/w	SO4, %w/w	Cl, %w/w	Cl, cal as NaCl
D	1.00	0.14	1.50	52.41	86.34
B	0.93	0.06	1.20	54.33	89.50
F	1.02	0.12	1.10	54.45	89.71
D2	0.91	0.01	1.50	55.07	90.73
B2	1.08	0.12	1.60	54.33	89.51
A2	0.87	0.06	1.20	53.64	88.37
H	1.03	0.01	1.60	52.65	86.74
C	0.99	0.15	1.10	58.15	95.80
Mean	0.98	0.08	1.36	54.38	89.59
St Dev.	0.07	0.06	0.22	1.78	2.93
GSB*	0.1max	0.2max	0.95max		97.00

Table G5: Actual Crystallizations Pond Salt Samples from Ghanaian Solar Salt Company

APPENDIX H: STUDY OF THE DIAMOND MODEL

THE DIAMOND MODEL

The measure of global business success is the presence of substantial and sustained export to a wide array of other nations and /or significant outbound foreign investment based on skills and asset created in the home country (Porter, 1990). Porter found that an industry's competitiveness was geographically concentrated typically in a single town or region such as the sparkling wines from champagne, France and the fax machine manufactures in eastern Japan are two noted examples that forms a geographical concentration of firms within an industry comprises a cluster. Porter's model identified the factors that, individually, and as a system, contributed to each cluster's success. Porter indicated the four main components that contribute to industry cluster's success in his model were factor conditions, demand conditions, related and supporting industries and firm's strategy, structure and rivalry. He also indicated the importance of government role and chance in cluster industry's success. While the Diamond Model is used mostly in strategic and international business, the factors in the model have significant impact in business growth in developing countries. According to Nair et al (2007) the above studies point out several issues that call for further specification within the porter model in relations to developing countries. First, the role of local demand conditions in industry success, as it is likely that the domestic market in such countries may not be able to offer the market size and sophistication that the model articulates. Second, the role of factor conditions and supporting industries need to be examined within the context of developing countries due to lack of advanced factors and comprehensive infrastructure for industry support. They also argue that the role of governments in developing countries in seeding and encouraging industry success is especially intriguing and ambiguous, while the role of firm strategy, structure and rivalry in industry success requires more specification. Finally, Nair et al (2007) argues that the dynamics of diamond model as systems needs clarification as the model's systems postulate is unclear.

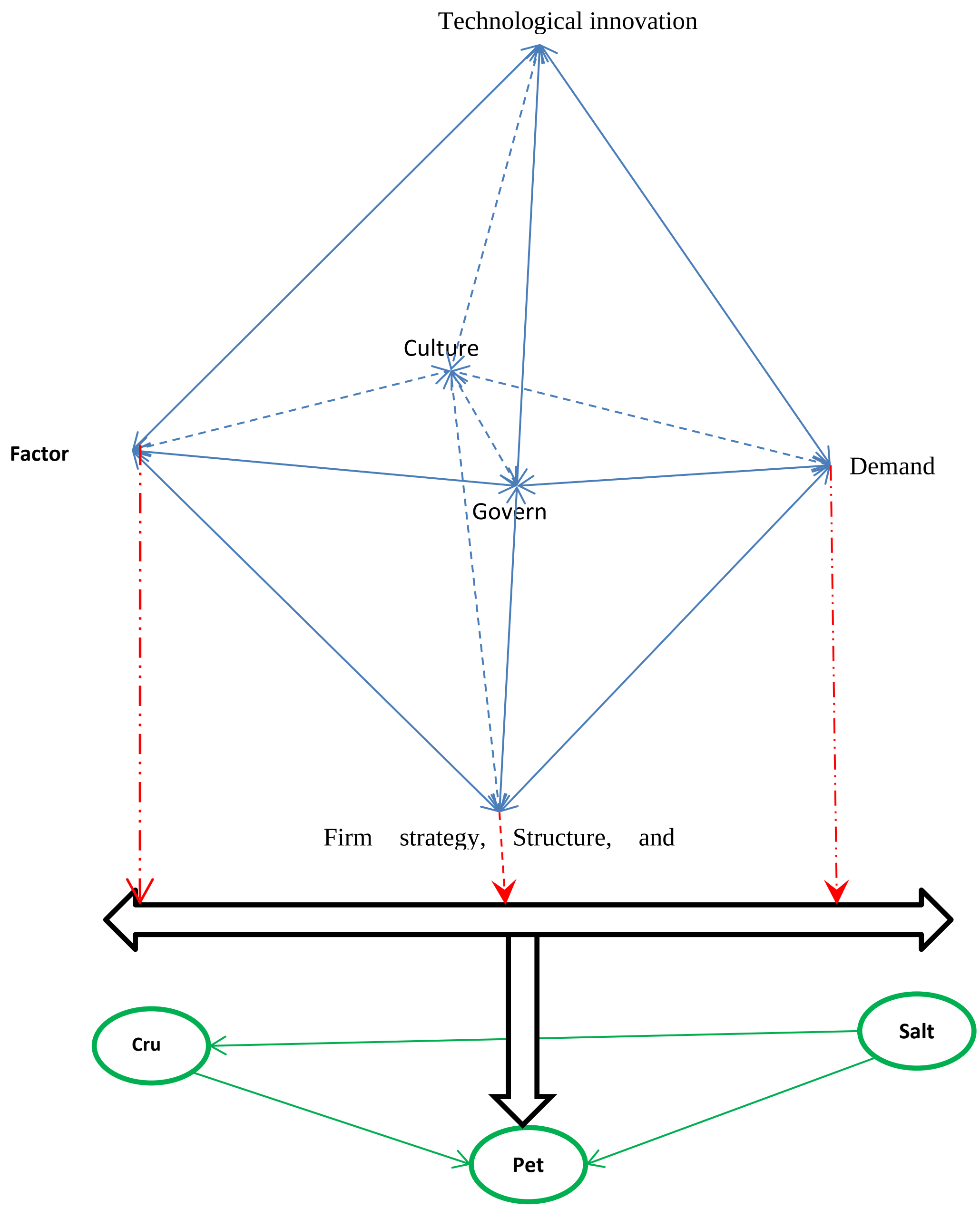

Figure H1: - Study of the Diamond Model

Factor conditions include the nation's position in inputs into production, such as human resources, physical resources, knowledge resource, and capital resources (Nair et al., 2007), of which Porter considered human, physical and natural resources as basic factors and knowledge, sophisticated skills and research capabilities as advances factors, which tends to provide an advantage to industries which processes them to those without them and they are developed specific to a type of industries they serve. It is helpful for a country to have the basic factors and necessary requirement if some of those advanced factors can be produced locally. Ghana has a fully-fledged Scientific and Engineering Institutions to graduate engineers and scientists needed to run enterprise systems. Ghana will also need to draw from experienced Diaspora Ghanaian population living and working outside the country.

In the Diamond Model, demand conditions involve the types of industry product and services the consumer wants, its size, sophistication and growth rate drives industry success. Product quality delivered upon consumer taste at a price the consumer can afford spell success.

Related and supporting Industries: Porter has indicated that the success of an industry tends to be associated with the presences of suppliers as well as customers. In the salt industry, suppliers of related equipment are known as well as customers for the final products made. It is well known that demand outstrip supply and the gap is growing as the population grows. The methods use presently in Ghana are not enough to produce a grain of salt that will meet the quality require for use in several applications and use of salt needed to develop the kinds of technologies required.

Firms Strategy, Structure and Rivalry: This covers the conditions in the nation governing how companies are created, organized and managed, the goals of individuals, and the nature of domestic rivalry (Nair et al., 2007). Understand the customers need and why they are using your product for because if you do not provide what the customers need, you do not have business. Providing a consistent quality product at all the time that meet customer’s expectation is the key to successful business. According to Nair et al (2007), quality, reliability and product scalability are critical to business clients.

Role of Government: The salt enterprise system will create cluster of industries which can have a greater impact on economic growth. Liberalizing industrial, investment and economic policies will improve business investment in developing countries. Also creating venture capital where business can borrow money for projects on liberal terms will help business growth.

APPENDIX I: THE ENERGY BALANCES

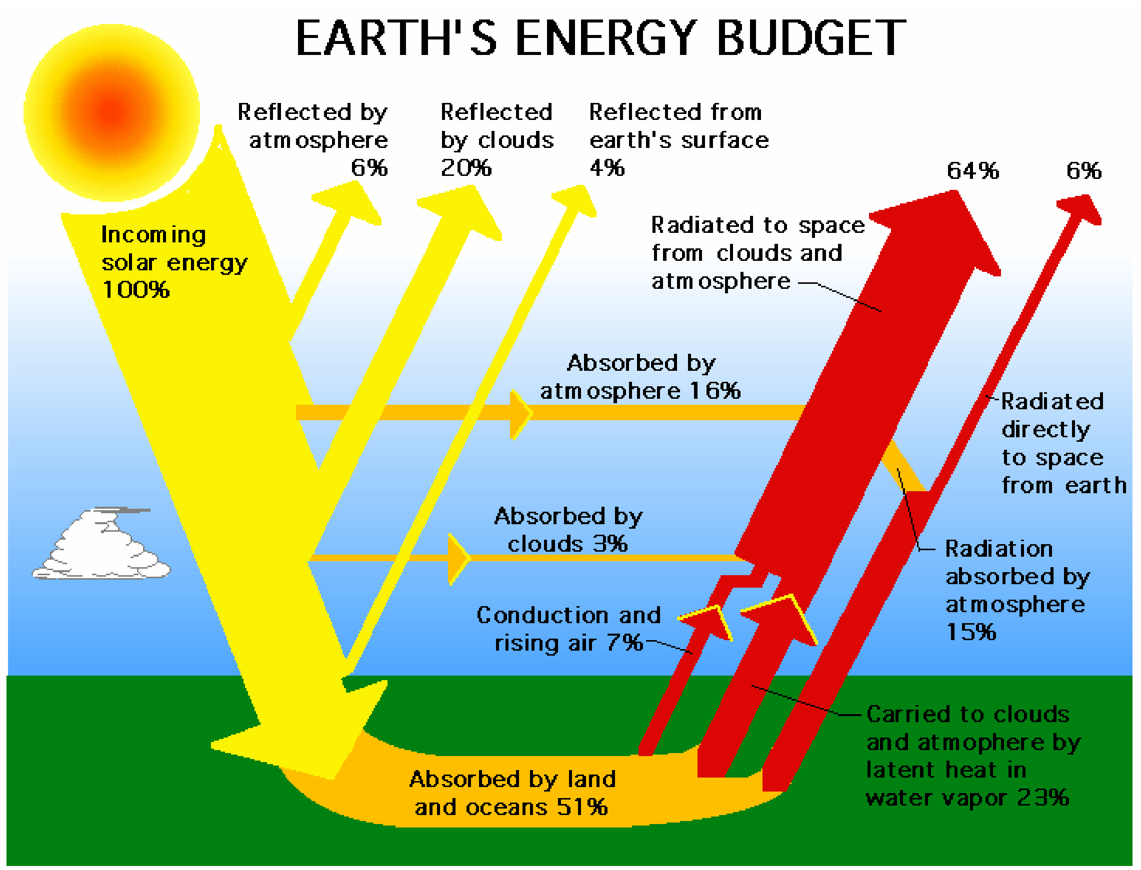

Figure I1: The Sun's Energy usage for Solar Evaporation (Mottershead, 2006)

APPENDIX J: THE MOLECULAR MASS OF SEA WATER COMPONENTS

Chemical Name	Symbol	Atomic Mass Units
Calcium	Ca	40.078
Chlorine	Cl	35.4527
Potassium	P	39.0983
Magnesium	Mg	24.305
Sodium	Na	22.9898
Oxygen	O	15.9994
Sulfur	S	32.066

Table J1: - Atomic Mass Units of Seawater Components

VITA

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Ph.D. Candidate in System Engineering and Engineering Management, Old Dominion University at Norfolk, Virginia, May 2009. Research interest is in the studies of identifying opportunities in Project Risk Management that add value to the bottom-line. This to include studies to develop planned activities in enterprise systems modeling that reduce performance uncertainties in project risks, as well as costs and schedule risks.

M.A. Degree in Business and Economics Forecast, from Old Dominium University at Norfolk, Virginia, December 2006. Course studies included modeling of business activities, using applied econometrics and regression analysis to model linear and non-linear systems.

M.Sc. Degree in Chemical Engineering from University of Kentucky, Lexington, Kentucky in December 1984. Advanced studies consisted of chemical Reaction kinetics, fluid flow, and Chemical Products Separations, Systems Optimization and Distillation Modeling. Thesis: "An Analysis of Dynamic Interaction in Multi-variable Process Control."

B. Sc. Degree in Chemical Engineering from University of Kentucky, Lexington, Kentucky in December1975. Studies consisted of General Engineering and Chemical Engineering fundamentals, Fluid Mechanics and Thermodynamics

PROFESSIONAL EXPERIENCE
I have 20 years' experience in Equipment Design, System Development and Operations in the Chemical and Petroleum Industries. I have years of experience in product separation and product synthesis in the Chemical Process Industries. Strong in providing a customer-driven scientific and technical support for system design and operation, from conceptual design, through system development, implementation and monitoring stages of manufacturing processes. I am a very dynamic and self-reliance engineer, who is accustomed to working as individual or in a collaborative environment with different stakeholders.