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The NASA Mission Operations and Control Architecture Program

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Abstract

The conflict between increases in space mission complexity and rapidly declining space mission budgets has created strong pressures to radically reduce the costs of designing and operating spacecraft. A key approach to achieving such reductions is through reducing the development and operations costs of the supporting mission operations systems.

One of the efforts which the Communications and Data Systems Division at NASA Headquarters is using to meet this challenge is the Mission Operations Control Architecture (MOCA) project. Technical direction of this effort has been delegated to the Mission Operations Division (MOD) of the Goddard Space Flight Center (GSFC).

MOCA is to develop a mission control and data acquisition architecture, and supporting standards, to guide the development of future spacecraft and mission control facilities at GSFC. The architecture will reduce the need for around-the-clock operations staffing, obtain a high level of reuse of flight and ground software elements from mission to mission, and increase overall system flexibility by enabling the migration of appropriate functions from the ground to the spacecraft.

The end results are to be an established way of designing the spacecraft-ground system interface for GSFC's in-house developed spacecraft, and a specification of the end to end spacecraft control process, including data structures, interfaces, and protocols, suitable for inclusion in solicitation documents for future flight spacecraft. A flight software kernel may be developed and maintained in a condition that it can be offered as Government Furnished Equipment in solicitations.

This paper describes the MOCA project, its current status, and the results to date.

Introduction

Most current spacecraft are extensively supervised from the ground, and spacecraft command and control systems have been re-invented by almost every new flight mission. This seriously affects ground systems reusability, and therefore costs for systems development, training, software maintenance, and sharing of operators among projects. This traditional approach is in serious conflict with the realities of declining space mission budgets.

The Communications and Data Systems Division at NASA Headquarters, through the Mission Operations Division (MOD) of the Goddard Space Flight Center (GSFC), is addressing this problem by sponsoring the Mission Operations Control Architecture (MOCA) project. The objective of this program is to develop a spacecraft control and data acquisition architecture which will guide the development of future spacecraft and mission control facilities. The architecture is intended to reduce the need for around-the-clock staffing of operations control centers (partly by increasing spacecraft autonomy), enable a high level of reuse of both flight and ground software from mission to mission, and allow the allocation and migration of functions between ground and spacecraft missions as is appropriate for a given mission requirements set.

MOCA is using a three pronged approach: deep involvement of the ultimate implementing and operating community at GSFC; analysis of current mission operations systems, leading to a redefinition and standardization of architecture; and a survey and assessment of available technologies, subsystems, and commercially available products, with analysis of how to make it all fit together.

Organization and Process

In order to provide a broad base of knowledge and to enhance the ease of acceptance of results, the MOCA project is being conducted by the MOD as a cooperative effort among itself, the GSFC Flight Projects Directorate, and the GSFC Engineering Directorate. The latter is the GSFC's flight systems engineering organization. The organizational tools used to implement this cooperative structure are an ad hoc MOCA Steering Group, with members from management from NASA Headquarters and from each of the three directorates, and a MOCA Users Forum, which is constituted primarily of selected, experienced, engineering level persons from each organization.

MOCA is divided into two phases, the Exploratory Phase (which began in February, 1994) and the System Design Phase. Each phase will last from one year to eighteen months, as required. The Exploratory Phase is a rapid but in-depth survey of the complexity and scope of the problem and an examination of potential solutions. The System Design phase will both develop and deploy the new capabilities required for the system.

When agreement on the architecture is achieved, one or more spacecraft will be selected to use as a prototype to finalize and prove the data structures, protocols, and interfaces between modules defined by the architecture. Ultimately, flight software elements and corresponding ground control modules will be developed, maintained, and configuration-controlled by an inter-directorate team. Therefore, the MOCA is an architecture, a set of interface definitions, supporting protocols and application layer languages, that enable the standardized commanding and supervision of remote space vehicles.

As this work progresses, it will be presented to the American Institute of Aeronautics and Astronautics (AIAA) Spacecraft Control Working Group. It is hoped that a NASA or U. S. Government agreement on an architecture for spacecraft control and a suite of supporting standards will result through this channel. However, the MOCA project focuses on the needs of GSFC specifically.

Approach

The aim of MOCA is to substantially reduce the end-to-end life cycle cost of future flight programs by radically reducing ground operations costs, including development costs.

MOCA disputes the contention that "cheap programs mean dumb spacecraft". Instead, MOCA asserts that when the end-to-end life cycle costs of a program are considered, "cheap programs need smart spacecraft". MOCA further contends that the technology is currently available to have smart spacecraft at very little increase in development cost, and that in fact most of the basic enabling technologies (for example, increased computational power, increased memory, large solid state data storage) are already in flight use. And that therefore what is required to achieve the mission operations cost reduction objectives are the development and implementation of the necessary operations concepts, architecture, and standards.

Preliminary Functional Architecture

The following is very preliminary, and will undoubtedly undergo major changes as the MOCA project matures.

The context of MOCA is "Mission Operations Functions", as shown in Figure 1. Therefore the figure shows the external interfaces to MOCA. There are two fundamental points made by the figure. First, it is important to note that mission operations functions are the domain, regardless of whether the functions are performed on the spacecraft or on the ground. Second, and equally important, flight subsystems and ground supporting subsystems are not in the MOCA domain, but the interfaces with them (and therefore the relevant functions performed by them) are.

The primary driver of mission operations is the science planning entity which provides both strategic planning information (the science plan) and part of the detailed or tactical planning inputs (instrument commands). These inputs are provided in cycles of various time intervals.

The MOCA functions and processes use these inputs to plan and schedule resources, coordinate the execution of the plan across the resources, monitor and assess the status of the resources, and feedback lessons learned into the process for the next cycle. Since the MOCA functions operate in this cyclic manner, the architecture described in this paper decomposes the MOCA functional architecture based on this planning-execution- assessment nature of mission operations. Figure 2 depicts the three functions which make up the first level of

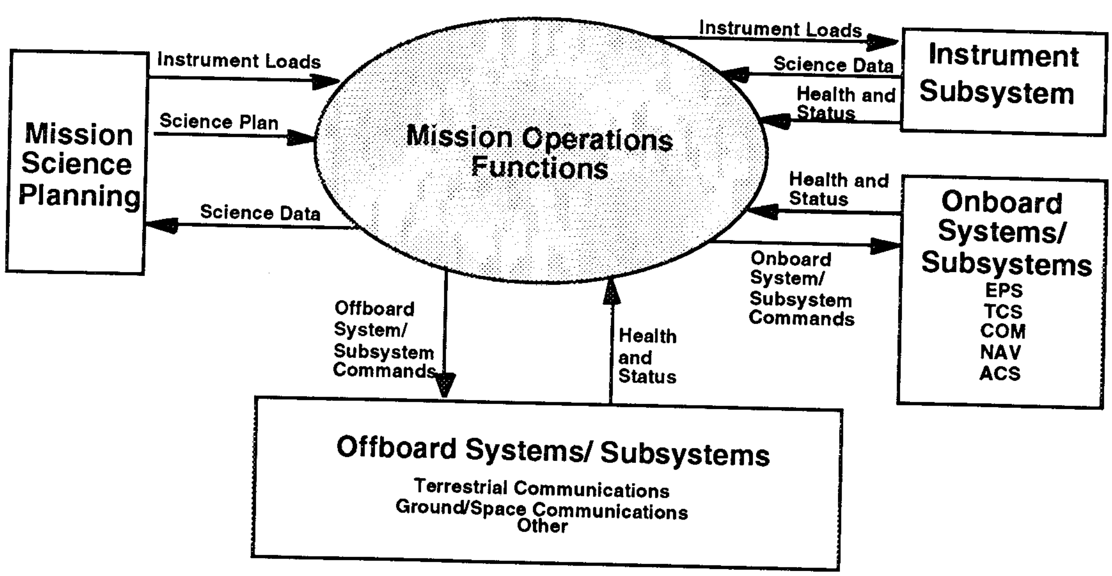

Figure 1: MOCA External Interfaces

the MOCA functional architecture. Also shown in Figure 2 are two entities utilized by all three functions: the Mission Model and the Mission Database.

The Mission Model constitutes an accurate representation of all the resources the MOCA functions have visibility into and interaction with. The Mission Database is a repository of actual data points either used or generated by the mission model and MOCA functions. All three of the primary MOCA functions use these resources but in unique and different ways. For instance, the Planning and Scheduling function uses the Mission Model to predict the events and actions of resources for the next cycle. The Mission Command and Control function uses the Mission Model to compare the real time events and actions of resources against the predicted events and actions to ensure operations are proceeding as planned and within tolerances. The System/Subsystem Analysis function uses the mission model to determine why events and actions did not perform as predicted and to provide feedback into the model as resources degrade or change over the life of the mission.

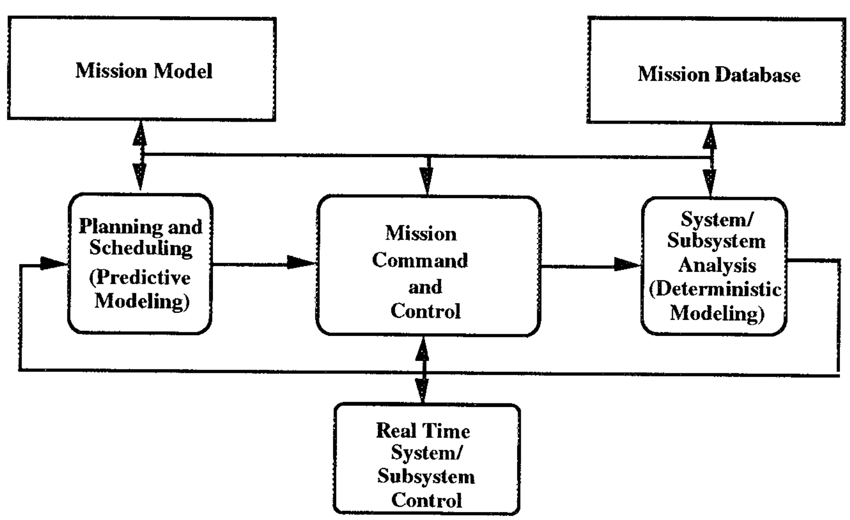

Figure 2: First Level MOCA Functions

Figures 3 through 5 show the next level of decomposition for the three primary MOCA functions. This paper will not go into detail on these lower level representations except to note that the Scheduling and Planning and the System/Subsystem Analysis functions have been further decomposed based on short term and long term processes.

Preliminary Target Characteristics

A preliminary analysis of current mission operations has lead the MOCA to identify the following as highly desirable characteristics which should be included in the MOCA concept of operations, and enabled by the MOCA architecture. These are very early ideas, and will undoubtedly be subject to significant modifications, expansions, and deletions as the project progresses.

It appears highly desirable to minimize the number of contacts between a spacecraft and the ground, as is feasible within the constraints of mission safety and mission performance. The planning, scheduling, initiation, conduct, and termination of a space/ground contact is expensive in itself, and the cost is much more sensitive to the number of contacts than to duration or data rates. This minimization should be accomplished by making spacecraft more autonomous than at present. The feasibility and acceptability of increased autonomy should be realized by designing the process of achieving autonomy to reduce risk, minimize life cycle costs, and maintain flexible control of the process by project management. The process should include the development of ground based backup capability to onboard functions, and by achieving the autonomy via function migration from ground to space as operational experience is gained.

Spacecraft should be made to look operationally as much alike as possible. Through the use of interface, format, and procedural standards to implement a "virtual spacecraft" concept, spacecraft should be made to appear to the ground systems as operationally identical as is feasible. This will eliminate large parts of development and training costs, allow operations crews to be shared among several spacecraft, and increase the reliability of operations.

Standards should define all operational interfaces. Standards should be selected, adapted, or, as necessary, developed and emplaced at all operational interfaces. An example of such existing standards are the tailored communications standards that can be adopted from other non-MOCA sources (e.g. Consultative Committee for Space Data Systems (CCSDS), Space Communications Protocol Standards group (SCPS)). Other standards, such as for the operations functions (i.e. at the Application Layer) will be selected by or developed within MOCA.

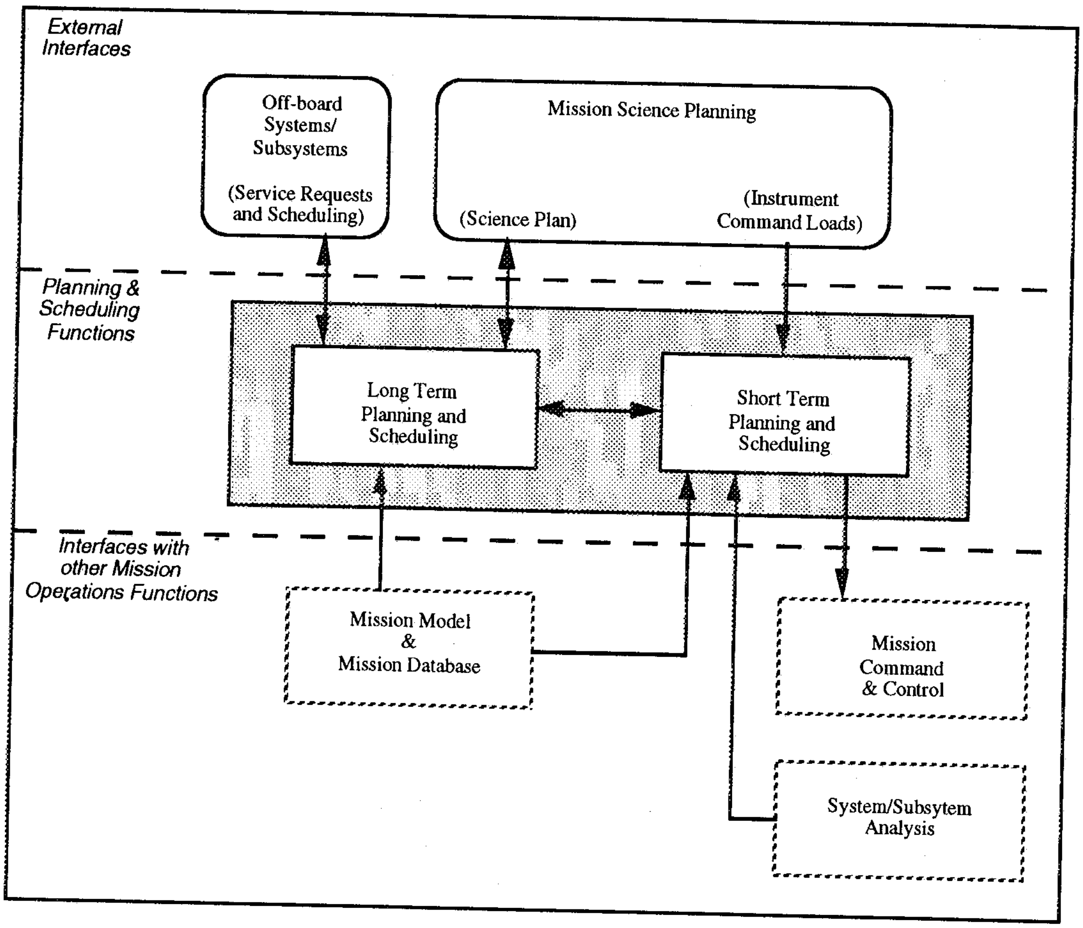

Figure 3: Functional Decomposition of the MOCA Planning and Scheduling Function

The Standards should be used across different projects. To achieve the above targets, the same standards must be used for each flight project. This approach minimizes the non-recurring ground system development and modification costs as well as substantially reducing recurring mission operations costs.

Implementation of the MOCA concepts, architecture, and standards should be accomplished to the maximum extent possible through the use of existing standards, existing technologies, work accomplished by other similar NASA and Department of Defense activities, commercial off-the-shelf products, and through use of existing testbeds and flight opportunities for proof of concept and validation. Major redesign efforts and all new development for control facilities at GSFC should be accomplished in conformance with the MOCA standards.

The Future

Although MOCA is still in an early phase, several key concepts are beginning to emerge which appear to be technically feasible and economically desirable. Among these are: communications between ground systems and spacecraft by an intermediate or high level process control language, rather than by commands and telemetry; on-demand

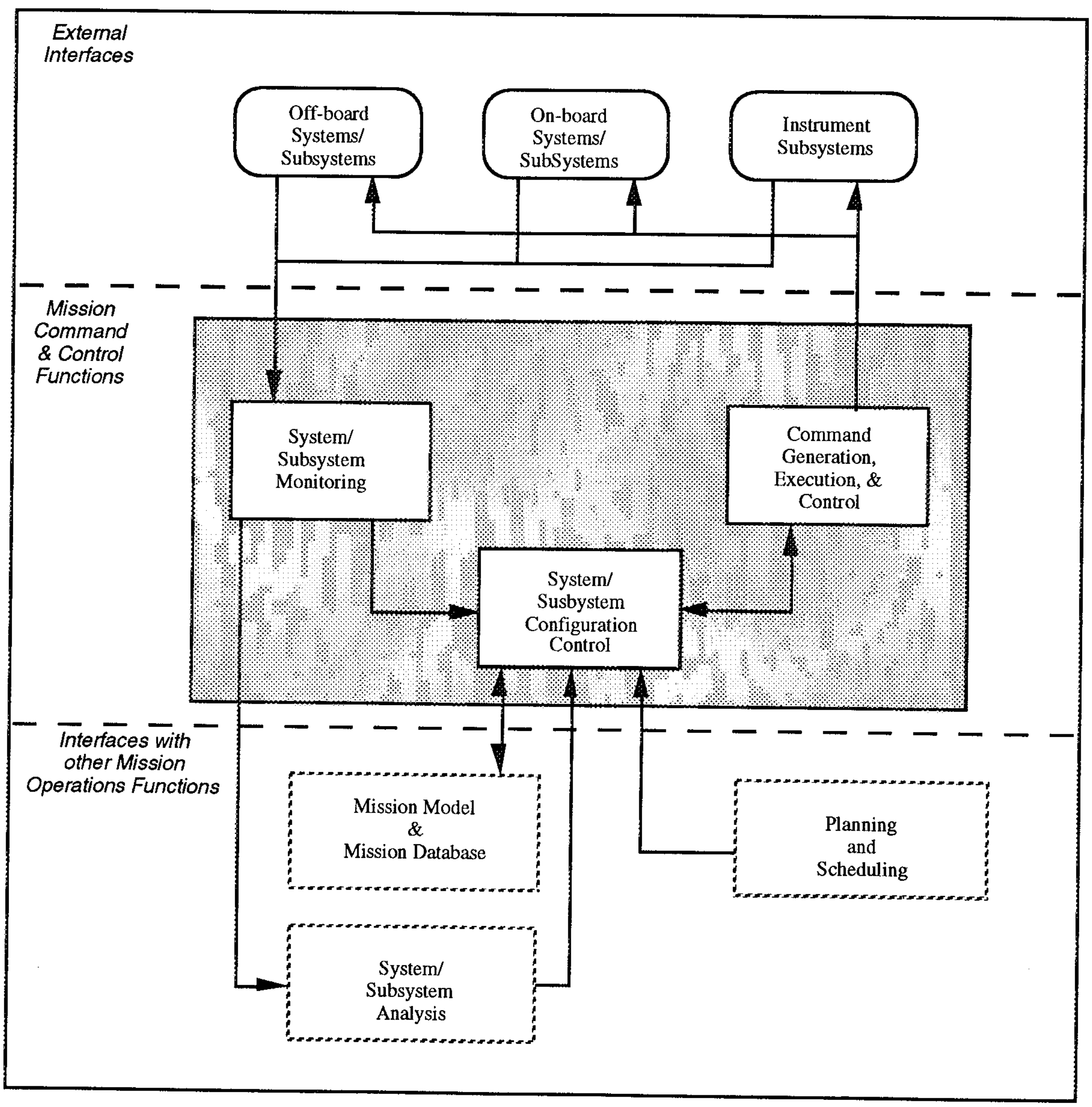

Figure 4: Functional Decomposition of the MOCA Mission Command and Control Function

space/ground communications *by spacecraft demand*; and eventually a reversal of current roles in that a spacecraft may view its supporting ground systems as a collection of on-call resources to help it meet its mission objectives.

It appears at this time that there are no insuperable technical or cost hurdles to achieving greatly decreased end-to-end life-cycle mission operations costs through the techniques of increased spacecraft autonomy, appropriate standards for critical operations interfaces, and standard protocols, all structured by a common mission operations architecture.

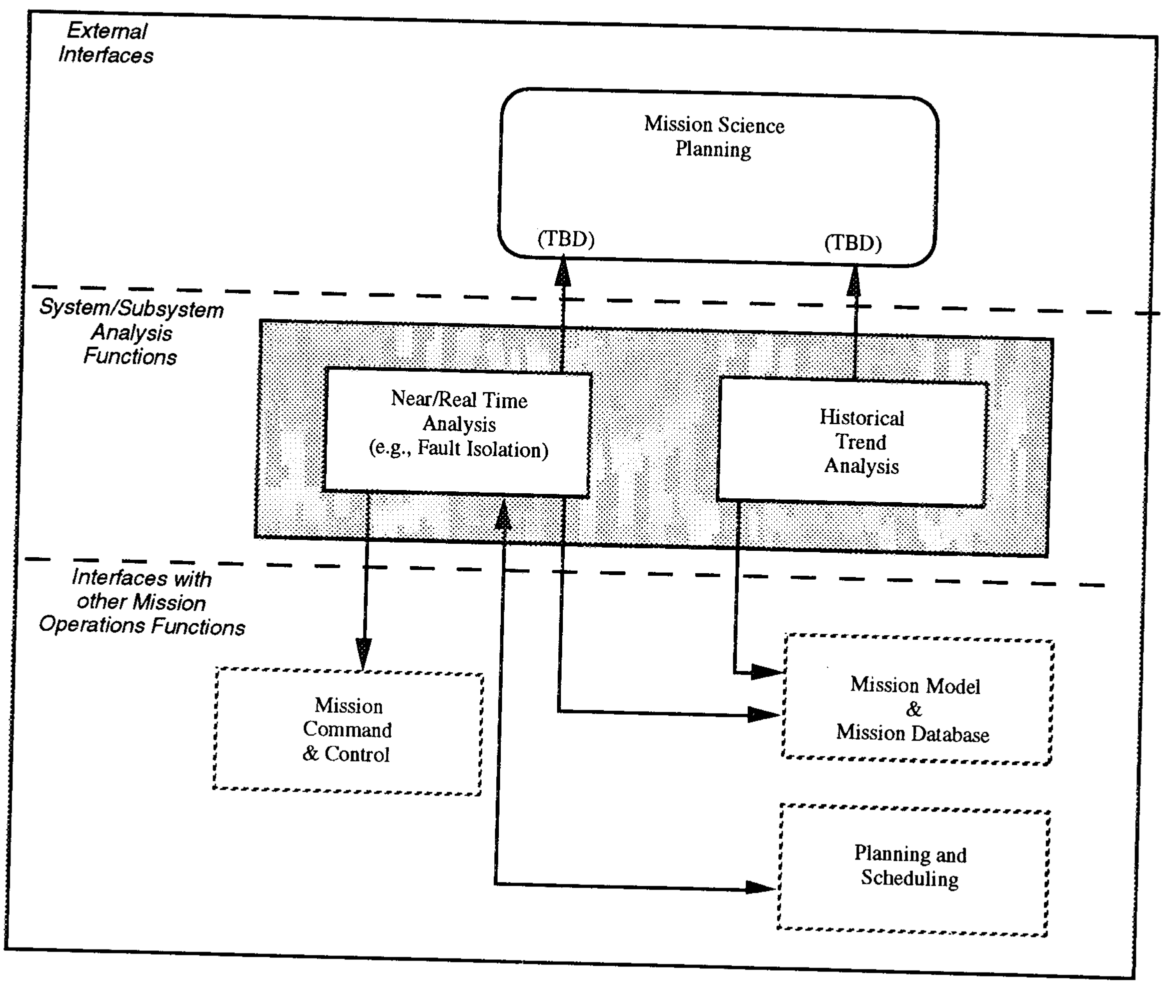

Figure 5: Functional Decomposition of the MOCA System/Subsystem Analysis Function