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Application of System Approach for Design and Operation of Process Control Systems in Oil and Gas Industry

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Process Control Systems are essential parts in oil and gas production plants. The design and operations of these systems are really complex because they must comply with stringent technical requirements, as well as safety and environmental regulations from authorities and third party certifying agents.

In order to simplify and systemize the design and operation, in this study, we have built a logical Flow Chart of System Approach and applied it for study and performing the relevant works for Process Control Systems.

Keywords : System Approach (SA); Flow Chart of System Approach (FCSA); Process Control Systems (PCSs); Design and Operation (D&O).

INTRODUCTION

Oil and gas production plants are always controlled and monitored by dedicated PCSs that are designed in compliance with specific standards and regulations.

As shown in **Fig. 1**, PCSs' life cycle consists of main phases such as Feasible Study (FS); Front - End Engineering Design (FEED); Detail Design (DE); Execution and Construction (E&C); and Commissioning, Operation and Maintenance (CO&M).

The D&O of PCSs are often guided in some standards such as IEC 61892, API RP 554, etc. They also can be performed following companies' practices such as ICM100 (Chevron 1999) or DEP series (Shell 2011). Certifying Agent has also published regulations such as DNVGL-OS-D202 (2015) to standardize PCSs' engineering works.

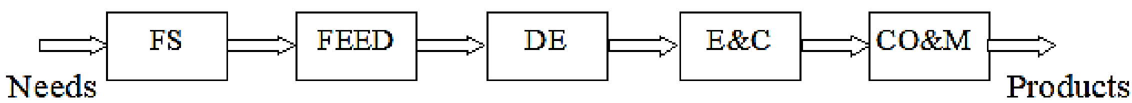

Fig. 1: Life cycle of Process Control Systems

These standards and practices focus and deal with specific control systems, and their applications have some limitations. For instance, API RP 554 focuses on onshore refinery and petrochemical plants; while IEC 61892 focuses on mobile and offshore units. Companies' practices are often developed following internal regulations, and focus on specific control systems and devices provided by their traditional suppliers. While Certifying Agents' regulations often focus and deal with safety issues rather than performances of control systems. As results, it is difficult to apply these as general guidelines for design and operational works of every PCSs.

Furthermore, it often takes about 2-3 years from FS to CO&M. Each phase of PCSs' life cycle can be implemented by different designers and/or operators. Consequently, it is difficult to systematically manage and supervise the objects and objectives of PCSs during their long life cycle. These lead to complications for appraisals, performance evaluations, adjustments, cost optimization for system designs and operations. These disadvantages are cause for study and finding a different way to approach and perform necessary activities on the PCSs. The new way must meet at least two criteria. First, it must be general and can be applied for any PCSs. Second, it must be compliance with specific requirements for each PCS.

SOLUTION AND RESULTS

Since 1970, at universities such as Mendeleev University of Chemical Technology, Ho Chi Minh City University of Technology, Imperial College, etc., Process System Engineering or System Approach (Hai L.X. 2004) have been studied, developed and applied for system problem solving, including system design and operational matters.

From SA point of view, the system D&O are typical processes of SA task performing. In these processes, the PCSs and their functions are the approached objects and subjects respectively; the design and operational requirements are objectives of the approach process; the technical and safety constraints are relations and barriers for the approach; the PCSs and their components interact each other internally and can externally interface with other systems according to their related constraints (Hai L.X. 2004).

Therefore, in the study, based on SA theory and experiences in engineering design (Hai V.V. 2010), we have proposed and applied a logical Flow Chart of System Approach for the design and operation of PCSs as stated in **Fig. 2**.

Whole their life cycle, the PCSs will be approached by a main FCSA completed with appraisal for each phase following the model described in **Fig. 3**.

Hence, in each phase, the PCSs objects will be analyzed and performed necessary

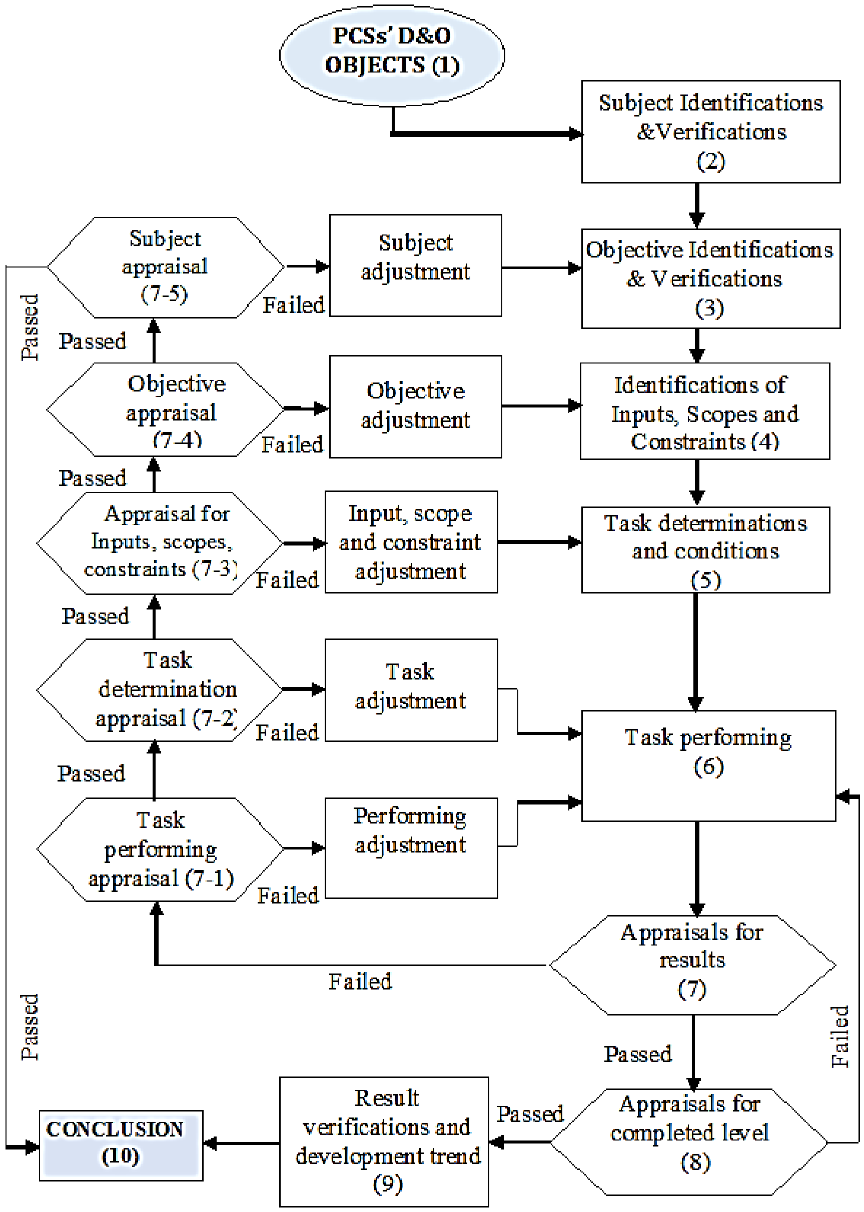

Fig. 2: Flow Chart of System Approach

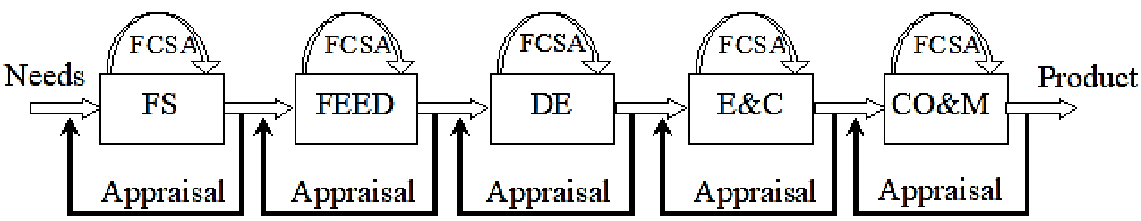

Fig. 3: System Approach Model for PCSs

tasks in compliant with a specific FCSA to accomplish the determined objectives according to technical, economical, management and safety requirements.

Scope of works for each step in the FCSA (Fig. 2) is described as follow:

Table 1. Required performances of PCSs

No.	Required performances and functions	Identified control system (Approached object)
1.	Monitoring, supervision and control for process system	PCS – Process Control System
2.	Monitoring, supervision and shutdown activities for safety matters	SSD - Safety Shutdown System
3.	Monitoring, supervision, early detection for presences of flammable oil and gas ; fire extinguishing	FGS - Fire & Gas System included Fire & Gas Detection (FGDS) and Fire Fighting System (FFS)
4.	Monitoring, supervision and measurement for flowrate of custody process medium complied with given accuracy	Custody Metering Measurement System (CMMS)
5.	Remote monitoring and control systems over communication channels	Supervisory control and data acquisition (SCADA) system and telecommunication system.
6.	Monitoring, supervision and control packaged system units	Unit Control System or Unit Control Panel (UCP)
7.	Etc.	Etc.

Object Identifications and Verifications

Regarding the designs and operations of oil and gas production system, the studied objects are the PCSs. According to detailed specifications of given process systems such as onshore or offshore, gas or oil processing, fixed or mobile system, etc. the specific performances of the PCSs will have to comply with the following criteria:

a) International standards, including Certify Agent's regulations,
b) National regulations,
c) Size of investigation for project
d) Engineering codes and standards applied for project, etc.

Each required performance or function will be performed by at least one of control systems as listed in **Table 1**. Each identified control system is one object of system approach for further studies.

At beginning, these systems will be analyzed through a typical SA task called *system disintegration*. This task complies with a principle: "System is a set of object elements that internally interact each other, and interfaces with other external elements" (Hai L.X. 2004). Each object in the system is one subsystem.

During the PCSs disintegration, based on the determined performances and requirements for system, the objects including sub-systems will be defined; system physical architecture completed with preliminary interfaces **(Fig. 4**) and

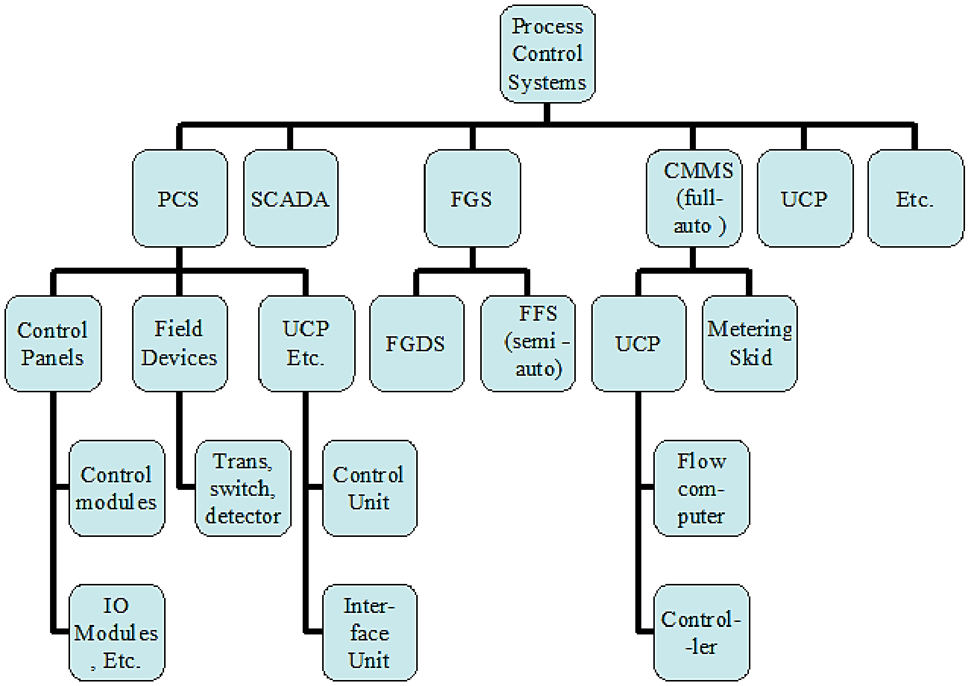

Fig. 4: System physical architecture

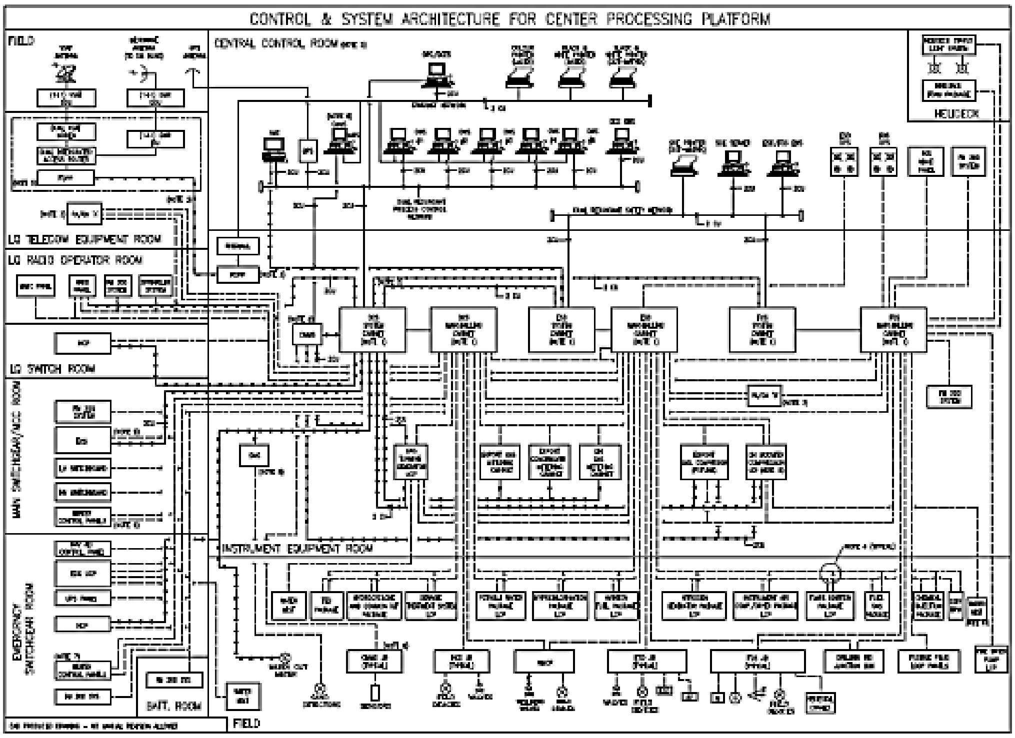

Fig. 5: Real PCSs' control and system architecture (sample)

basic specifications of PCSs' objects will be figured out; Control requirements such as full-automatic, semi-automatic or manual operation will be determined.

The system disintegration will be a team-working process and participated by experienced plant operators, process engineers, safety and control engineers. In the end, control and system architecture (**Fig. 5**), preliminary system equipment list, applied standards, and control philosophies for the PCSs will be defined.

A further system disintegration can be implemented for the defined objects and sub-systems of the PCSs when necessary. The task is limited to objects or sub-systems that can be supplied as a completed device or package by a single manufacturer or system integrator such as PCS or FGS suppliers. In addition, the limitation can be specified by project's End-user also. For example, for equipment packages such as turbine compressor and generator, End-user often orders from a system integrator that will be responsible for whole engineering, fabrication and provision of a completed package, including its system control unit.

Identifications and Verifications of Solving Objects

The solving subjects are set of issues that must be solved according to PCSs' phases as well as requirements of the applied standards. As stated in Table 2, in FS phase, the subjects will be conceptual design basis; in FEED, they will be functional specifications; in project execution, subjects will include hardware and software selections, detailed specifications and construction drawings. When the PCSs are in operational phase, the most important subjects will be business revenue and minimal costs. For each determined control system, subjects to be solved aren't same. For instance, safety-related issues such as Safety Integrated Level will be a subject of SSD system only and will not be subject of PCS.

These solving subjects also depend on number of project phases, project schedule, distribution of capabilities, etc. For instance, a fast-track project can be developed from FS to DE phase without FEED development, hence specifications will be issued in DE. Or DE phase can be implemented in conjunction with execution phase, and Long Lead Purchase Items must be priority subjects to issue for procurement in time.

Identifications and Verifications of Objectives

Based on the list of solving subjects has been verified from step 2, specific objectives will be determined and listed out for each life cycle phase as stated in **Table 2**. These objectives are classified according to their priorities in following succession:

a) Objectives related to national and international regulations for safety and environment,
b) Objectives related to investigation and business revenue,
c) Objectives related to engineering requirements,
d) Objectives related to project schedule,
e) Objectives related to costs of operation and maintenance.

These objectives and their priorities will be utilized as criteria to evaluate success or failure of the SA process. However, these priorities will be able adjusted according to PCSs' specifications. For instance, the safety objectives of safety-related systems such as SSD and the accuracy of custody metering system are more important than costs of investigation.

Table 2. Summary of Solving Subjects, Objectives and Inputs

No.	Phase	Subjects	Objectives	Major Inputs
1.	*Conceptual Design/ Feasible Study (FS)*	Process Control System conceptual design basis	Document the business goals and basis for the project	PFDs, layout, operational plan, Main equipment list, applied standards.
2.	*Front-End Engineering Design (FEED)*	PCSs' functional specifications	Develop functional specifications and scope, functional requirements and overall responsibilities.	P&ID, hazard analysis, equipment lists, PCSs' conceptual design basis.
3.	*Detailed Design (DE)*	Detailed specifications, installation and construction drawings. Hardware and software selection.	Vendor selections. Design hardware, layouts, field devices, wiring, systems interfaces to other systems and hardware.	Design standards and practices. PCSs' functional specification. Documentation requirements.
4	*Execute*			
4.1	Project Execution and Management	Complete design drawings and specifications. Procurement. Implementation and testing.	Execute designs to meet cost, schedule and technical requirements.	Project objectives, cost and schedule, etc.
4.2	Construction and Installation	PCSs are ready for operation.	Install, calibrate, and loop test for instrumentation and control systems.	Design drawings and related specifications and manuals.
5	*Operate*			
5.1	Commissioning	PCSs are in operation. All deficiencies identified and corrected.	Prepare PCSs for operation.	Performance requirements.
5.2	Operation	Business revenue and minimal costs.	Operate the PCSs to best operational effectiveness.	Performance requirements.
5.3	Maintain	Maximum unit performance and availability.	Maintain, Preventative Maintenance and repair the PCSs.	As-built documentation and training.

Identifications of Major Inputs, Scopes of Work and Constraints

For design and engineering works, inputs can be the outputs from previous phase. Designers will study these inputs, compare to the objectives determined from step 3, and identify scopes of works as well as the constraints required by standards and regulations applied for the phase. Upon the scope verifications, battery limit of each sub-system as shown in Fig. 5 will be clearly figured out and interface requirements between PCSs' objects and sub-systems will be defined in compliance with their control philosophies.

For operational phases, major inputs are the designed performances and as-built documents of the certain PCSs.

Inputs can be object-related constraints as well. The objects of PCSs have to comply with safety and environmental requirements, especially mandatory regulations of Certifying Agents. Based on list of applied standards in step 1, designer and operator must list out these constraints and ensure all these requirements will be fully complied in next steps.

According to SA principle, each object will be studied for its internal and external related constraints. Based on experiences and knowledge about mathematical models of PCSs' objects, other inputs that are required for specified objectives will be verified and collected as stated in Table 2. These inputs can be provided by control engineer or other disciplines such as process, safety, management team, etc.

All collected inputs will be evaluated and verified. If input data and applied standards are impossible to be well defined at early stages of the project, uncertainties as well as minor exceptions must be determined as barriers for various cases. The base case and worst case completed with additional assumptions will be specified and supervised so that certain progress can be move toward reaching the objectives within the determined barriers. The approach is appropriate for new object or systems in trail phase (Hai V.V. 2013).

The summary of solving subjects, objectives, major inputs for each phase of PCS's life cycle is described in Table 2.

Task Determinations and Performed Conditions

In order to accomplish the objectives have been determined in step 3, adequate tasks in conjunction with conditions to perform will be listed out by step 4 and 5.

In the design and engineering phase, tasks are documentation deliverables that listed in an engineering master deliverable register (EMDR). The EMDR will specify the milestones, submission schedule and critical path of submission for essential documents. Purposes of each document in EMDR must be specified clearly, including scope, list of applied standards, references… Where required, the document's contents also have to comply with guideline and requirements of Certify Agent in order to standardize the documentation submission, review and approval (DNVGL-D201 2015). Based on the EMDR, engineering manager can arrange and distribute cost, time and resource that are required for the phase.

Similarly, in construction, fabrication and operational phase, tasks shall include activities as specified in manuals of specific PCS to reach specific objectives. Maintenance schedule, preparation of manpower and spare parts, etc. shall be part of these tasks.

In order to ensure that all design and operational tasks are documented and well managed, the management standards such ISO 9001, etc. should be applied for.

Task Performing

According to PCSs' specifications and requirements for documents, detailed tasks will be performed following the determined EMDR, instructions and applied standards. These tasks often include calculations such as control valve, orifice devices, fire and gas mapping study, or equipment selection, wiring and construction development, etc. Handbooks and guidelines often provide full instructions for the task performing.

Other operational tasks will be defined in manuals for specific systems and devices by manufacturers or vendors.

In order to effectively implement these tasks, besides good background, designer or operator must be experienced in related regulations and standards. Furthermore, he shall have to be taught analytical skills and know how to integrate the system, and how to make decision. During the approach, he has to identify and solve the constraints among objects in PCSs and between the PCSs and other systems. On the other hand, the designer or operator has to be trained for SA principles, and well apply it for the D&O works.

Appraisal for Results

The result appraisals will be implemented based on the criteria has been determined in step 3. If any criterion does not meet the requirements, adjustments will be performed step-by-step backwardly as described in FCSA (Fig. 2). All steps such as task performing, objective identification, scope verification, and object definition will be revised and appraised to determine causes and propose adjustments systematically.

For example, a condensate custody metering system was equipped with an auto extraction sampling unit as specified in DE phase. But in testing phase, the sampling unit did not operate correctly at real process conditions. Consequently, the accuracy of the metering system did not reach the determined fiscal objective. The appraisal in step 7-1 verified that all design tasks had been performed correctly for the auto sampling unit. But it found out the working pressure of sampling unit closed to condensate vapor pressure, and an additional pressure drop occurred at sample extraction probe was cause of condensate evaporation, and led to unstable measurement. The possible adjustments were implemented gradually as follow:

a) Task adjustment: Re-calculated and adjusted the sampling unit at step 7-2 so that the pressure drop at sample probe was minimum to prevent the evaporation of condensate. Or,
b) Input adjustment: at step 7-3, adjusted process input data of condensate including its pressure or composition so that evaporated pressure of condensate was out of the unit working pressure range. Or,
c) Objective adjustment: Adjusted and reduced the determined accuracy for the sampling unit at step 7-4. However, the fiscal accuracy was required and fixed by Authority, therefore such objective adjustment wasn't accepted.

d) Subject appraisal: In the worst case, the wrong concept selection for auto extraction sampling unit from step 1 should be recognized at step 7-5, and a selection of new sampling unit equipped with inline mechanism and without pressure drop that suited to the process conditions should be considered.

Appraisals for Completed Level

Completed level is measurement of objective completion from management and development views. Beside criterion-based appraisal has been performed in step 7, a further appraisal for the completed level is also required. The appraisal shall be based on the system operation, operational cost, man-power consumptions, completion of the applied technology, outstanding lists for the D&O, etc. in comparison with expected design and operation.

Where the results are not in expectation, adjustments and optimizations will be performed backwardly step 6. However, some criteria of design and operation have to be accepted as incompletions or insufficiencies in certain systems. The insufficiencies will be basis for the result verification in next step. They will be considered as subjects for modification and upgrading the system in future. For instance, in fire detection design, fire detectors were arranged correctly according to design and fire mapping study. But in certain operation, the designed detection range could not cover fully the determined fire zone by effects of equipment dimensions.

Result Verifications and Development Proposals

According to the results of appraisals in step 7 and 8, a verification will be performed and developing trends will be proposed. Insufficiencies or outstanding issues from step 8 will be listed out completed with procedures to upgrade in future or to minimize their negative and harmful influences. For instance, for the fire detection zone above, if additional installation of fire detectors couldn't increase the detection range, the fire detection should be supplemented by manual detection periodically where auto detection was insufficient.

Final Conclusion for SA Process

The final conclusion for SA process can be the verification for success with results have been verified in step 9. However, in the worst case, the conclusion can be the confirmation from step 7-5 for an unsuccess that caused by a wrong object identification, hence, a new approached trends or solutions will be concluded. For instance, selection of inline sampling unit in step 7 was illustration for an unsuccessful approach process.

DISCUSSIONS

The FCSA has proposed a systematic way to approach PCSs and their components. It has also provided guidelines for studying and task performing on systems to achieve required performances. And it is highlighted that the FCSA's application isn't limited to PCSs. For instance, in project planning, designer and engineering manager can study and apply the FCSA for scheduling tasks for whole project as well as each phase according to model as stated in Fig. 3.

In research and development activities, the FCSA can be utilized as a framework to develop practices and guidelines for design and operation in compliance with specific regulations of company and/or authorities.

Beside technical applications, the FCSA also can be applied for social studies such as human resource management and development (Hai V.V 2013) for complex engineering factories, where their organizational chart, need of manpower and capabilities of human resource always have specific constraints.

Especially, regarding decision-making processes in psychology and operations research, the FCSA also can be used for object analysis, identification and optimization in multiple-criteria decision-making situations.

CONCLUSIONS

As expected, System Approach and FCSA have provided a general methodology as well as specific tasks such as system analysis, integration, result appraisal, etc. in order to solve the PCSs' matters. During the approach, all objects, subjects, objectives and all their constraints have been defined and verified in order to ensure whole design and operational works have been performed and supervised systematically in order to comply with all requirements, standards and regulations.

In conclusion, as a governing methodology, System Approach and FCSA should be studied continuously and applied widely for problem solving of technical and social systems.

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