Were the Ancient Egyptians System Engineers?
How the building of Khufu's Great Pyramid Satisfies Systems Engineering Axioms.

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Abstract:
Systems engineering is a 20th century discipline. To judge whether an organization is on a world class systems engineering level, we evaluate whether the organization's development processes and resulting product satisfy the 8 systems engineering axioms. Could we evaluate ancient organizations? The pyramids on the Giza Plateau are the only remaining wonders of the ancient world. The sheer scale and precision of Khufu's great pyramid obviously required a quality process. But were the ancient Egyptians systems engineers? This paper will outline how the pyramids were built, and whether that process satisfied the systems engineering Axioms.

Author's biography:
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Introduction

Human technology has evolved greatly from the time of the ancient Egyptians to the modern-day. During the 20th century technology advanced at a dizzying pace; medical science, new forms of travel, new forms of entertainment and communications, and the refinement and distribution of computer technology are a small listing of the wonders developed during the 20th century.

Modern Systems Engineers have unprecedented technology at their disposal. However, modern man also has an aggrandized sense of himself when comparing modern engineering feats with ancient engineering feats.

Modern Engineers rely heavily on technology and tools. True innovation is rare. Ancient Egyptian civilizations could only rely on simple tools that were truly innovative and far ahead of their time. In fact, when we compare modern tools with ancient tools, the principles of operation have not changed. What has changed is the sophistication of the tool itself.

When we look at the great pyramid of Khufu (or Cheops), built between 2589 and 2566 BC, we see a majestic symbol of the power of the Pharaoh in ancient Egypt. Because the pyramids were built for gods, no expense or effort was spared. Traditional theory holds that the hundreds of thousands of men that eventually worked on the pyramids were slaves. However, new archeological discoveries suggest that the workers were paid, and even saw service in assuring the afterlife of the Pharaoh as their duty. The universal astonishment at the sheer size of the pyramids and how ancient civilizations could have built them, without the use of modern equipment, is the source of numerous theories. Theories of alien visitors and extinct scientifically advanced civilizations abound. However, by analytically investigating and examining how the pyramids could have been built, a much more rational answer appears.

The precision of the Great Pyramid of Khufu is exact. The great pyramid is as precise as any modern skyscraper. The great pyramid of Khufu consists of 2,300,000 blocks each weighing, on average, 2.5 tons. The latest evidence suggests that it was built in 23 years or less, corresponding to the length of time that Khufu ruled. That translates to 340 blocks a day. With 10 hours of daylight per day, 34 blocks were laid every hour. That includes quarrying, transporting, cutting, finishing and coating. Each base is 230.33 m and the height is 146.59 m. The pyramid's orientation is 3'6" off true North. The base is level within one inch. The greatest distance between the length of the sides is 1.75 inches, truly astonishing. (Lehner, 1997)

To answer the question of whether the Ancient Egyptians were Systems Engineers, we must first examine how the pyramid was built. After this we apply the accepted building methods to the systems engineering axioms. If the methods satisfy the axioms, we can conclude that the ancient Egyptians were indeed systems engineers.

To completely apply systems engineering axioms, more definitive data about how the great pyramid was built is needed. However, this data is not available. Therefore, this paper presents theories as fact and makes assumptions that cannot be proven or disproven through available data and facts. Every effort has been made to research various theories and only accept plausible and likely theories as fact.

How the Pyramids Were Built

There are many mysteries concerning how the great pyramid of Khufu was built. There are also an equal number of theories concerning different aspects of the building project. Through many decades of investigations and research, plausible theories have been proposed and demonstrated. Theories of the building of the pyramid, conveyed as fact in this paper, are divided into specific stages of building the pyramid.

Supply and Transport

To complete the pyramid complex in the King's lifetime, a constant supply of material, labor and food was needed. Among the different stones used were limestone, granite, and gypsum. Other materials included wood, alabaster, and dolerite and quartzite to make tools.

Most of the stone was quarried from the Giza plateau, "downslope from the great Northeast -- Southwest diagonal on which the pyramids are aligned."(Lehner, 1997) Other materials brought to the site included small trees and scrub, harvested from the Egyptian landscape, and food supplies consisting of mainly grain, fish, foul, sheep and cattle. These and other materials, not available near the site, were brought to the site, generally by water transport. The current and winds on the Nile River are in opposite directions, meaning that a boat could ride the current in one direction and use sails in the other direction.

To get the stones and obelisks on and off of the boats, an earth embankment was used. The boats would sail into a small canal and an earth embankment would be built around the boat. Wooden beams would be placed under the stone load, and the cargo would then be lifted off of the boat without fear of capsizing. The embankment was removed freeing the boat. (Lehner, 1997)

Land-based transport presented another challenge. Heavy objects sink in sand. Surviving transport roads, up to 36 feet wide, consist of a fill of limestone chips and mortar with wooden beams inserted to provide solid bedding. A layer of limestone chips and white chips provide a solid surface over the beams. Once the hauling tracks were built, the stones would be placed on wooden sleds and dragged, lubricated by water. Cattle was also used to pull the sleds. (Lehner, 1997)

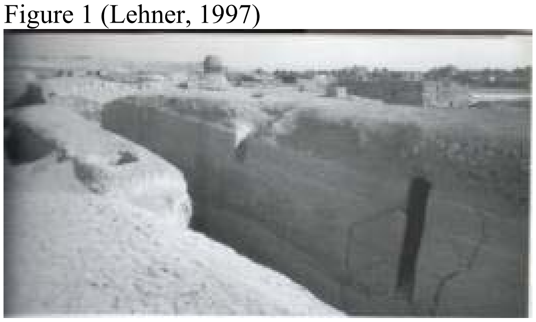
Quarries

Stone quarries were located near the building site. The building stones were excavated by channeling passages in the quarry and using wooden levers to break the stone blocks from the quarry. (Figure 1) Other methods of breaking stone included wedging wood into cracks. The wood was then soaked. As the soaked wood expanded, it would crack the stone. (Lehner, 1997)

The fine limestone for the outer pyramid casing was quarried and transported across the Nile Valley. The ancient quarrymen tunneled in and around poorer quality limestone to extract the good quality limestone.

The granite used for false doors, chamber ceilings, columns, and offering tables was quarried 580 miles south of the build site. Granite was quarried with hand held pounders made of dolerite.

Figure 1 (Lehner, 1997)



Tools

Angles were measured by using ancient versions of modern tools. Wooden set squares were used to measure right angles. Square levels were shaped like an A with a plumb bob suspended from the top. (Figure 2) The two legs of the A would be placed on the surface to measure, if the bob was centered, the surface was level. Vertical levels were similar to the square levels. (Figure 3) Copper saws guided a mixture of water, gypsum, and quartz sand to cut stone and granites. Thin copper chisels were used to smooth stone. Dolerite stones were used on the ends of wooden rods, like hammers, to channel the granite quarry stone. (Lehner, 1997)

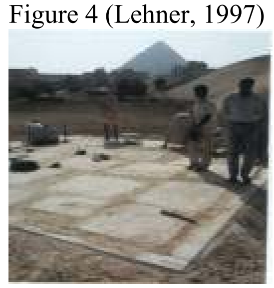
Figure 2 (Lehner, 1997) Figure 3 (Lehner, 1997)

Survey and Alignment

The most plausible theory is that the pyramids were aligned by celestial objects. One method of taking a direction measurement, similar to a compass, was to first build a circular wall, a few feet in diameter, tall enough to exclude all light except for the night sky from the view of the person standing inside. The wall would act as an artificial horizon, and thus had to be absolutely horizontal. (Possibly achieved by using water to level it.) A person standing inside would then face believed north and mark the rising and setting points of a star at the top of the wall. The marks would be extended to the ground inside the wall. The bisection of the angle created between the person and the two lines would be true north. Another method, the sun and shadow method, could also have been used. A poll is set up, using a plumb line to make it vertical. The poll's shadow is measured about three hours before noon. The length of the shadow becomes the radius of a circle. As the sun rises, the shadow shrinks back from the line and then lengthens in the afternoon. When it reaches the circle again it forms an angle with the morning's line. The bisection of the angle is true north. (Lehner, 1997)

Once points were marked and direction established, evidence suggests that double rows of polls were set up and lines were extended between them. As blocks were moved into place, they were leveled according to the rope, ensuring that the sides were straight. (Figure 4)

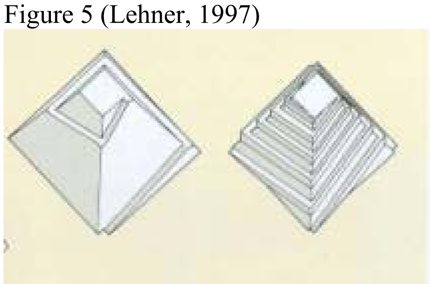
Figure 4 (Lehner, 1997)



Ramps

Due to the sheer size of the pyramids, hauling and placing stones presented a great challenge. To haul stones up onto the pyramid, ramps were used. There are numerous designs for ramps that could have been used. Many ramp designs are immediately dismissed because of the sheer volume of material needed to produce them. A straight ramp for instance would have to be almost as high as the finished pyramid. In addition, as the straight ramp became higher, it would require more support. The most plausible theory is a ramp that clung to the pyramid face. (Figure 5) Further evidence of this design is that the foundation for these ramps could have been casing stones left protruding further out from the pyramid than other stones.

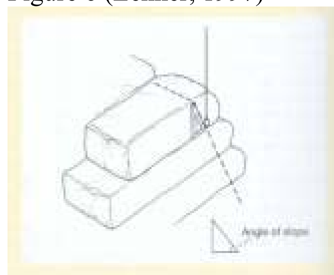
Figure 5 (Lehner, 1997)



Rise and Run

If the sloped diagonal lines that make up sides of the pyramid deviate, the top of the pyramid must be twisted to make them meet. This error has been detected at the tops of other pyramids. Maintaining rise and run was therefore critical to the outcome of a precise pyramid. Rise and run were controlled by marking the face of the pyramid into each casing block as it was laid. (Figure 6) (The surface would be chiseled smooth later.) Stones were brought to the site with only their bottoms chiseled smooth. The sides and tops of the stones were chiseled smooth following the marked lines and stopping once each successive stone had its edge in line with its neighboring stone. Although intuitively, all errors would be magnified, in fact errors were compensating, “a deviation in one block offset by a different deviation in another.” (Lehner, 1997) In addition, instead of relying on previous levels to control rise and run, reference markers on the base of the pyramid, and also in the area around the pyramid, could have been used to control rise and run. Required angles were calculated with tools.

Figure 6 (Lehner, 1997)



Top stones

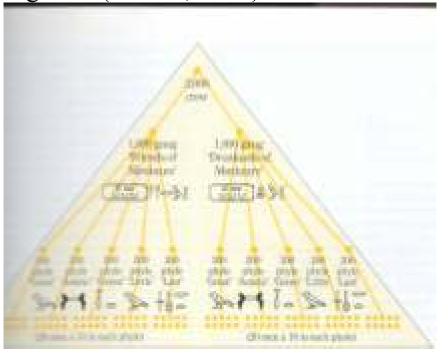
The stones for the top of the pyramid were cut on the ground and hoisted to the top of the pyramid. Evidence of this is that examined top stones have modified concave instead of flat bottoms. The tops of pyramids just shy of the top stone have convex surfaces. To create the convex surface under the top stone, diagonals were cut into the underside of the stone to create the convex surface with four triangular faces. (Lehner, 1997)

Workforce

There were 20,000 to 30,000 workers on site at any one time. (These numbers were calculated by first dividing the work of building the pyramid into its core components; quarrying stones, hauling stones, and setting stones. Each of these activities was then analyzed to determine how many men could work on them, and had to work on them to complete the task in the acquired time.) The mass of the workforce was made up of crews of peasant conscripts numbering 2,000 men. Each crew consisted of two gangs of 1,000, and each gang was divided into five tribes. Each tribe was then divided into 10 divisions of 20 men. (Figure 7) (Lehner, 1997)

It seems impossible that mere men built the pyramids, but scientific analysis and experimentation has yielded interesting results. The French Egyptologist Henry Chevrier found that 3 men could pull a 1-ton block over a tract lubricated with water to eliminate friction. Further studies have shown that 10 to 12 men could easily pull a two ton block mounted on a sledge up an inclined roadway. Hieroglyphs show 172 men pulling approximately 58 tons. In addition, the lower stones in the pyramid are also the heaviest, whereas many stones near the apex of the pyramid are smaller. This further contributes to the idea that the pyramid could have been built using ordinary tools and methods.

Figure 7 (Lehner, 1997)



Workforce Specialties Needed
A project as large as building Khufu's pyramid required a diversely skilled workforce. Some of the specialties needed included:
Stone haulers -- pulled sleds carrying stones
Stone setters -- put stones in proper places and chiseled stone surfaces
Architects -- designed pyramid layouts and stone placement
Masons -- quarried stones
Carpenters -- produce woodwork within pyramid
Sailors -- control rafts carrying stones on Nile
Metal workers -- create and sharpen metal tools including chisels
Potters -- create pots and containers for food and supplies
Bakers -- create dietary rations for workers
Brewers -- create dietary rations for workers

Organization

Control notes have been found on exposed stones. Some of these control notes were for workers and some for scribes. The notes recorded the day of transport, the workmen in charge, the stage of the transport, and the purpose for the stone (approximate placement.) Obviously the notes for workers were construction plans and the notes for scribes were to keep a historical record of the construction.

How the building of the pyramids satisfies the Axioms of Systems Engineering

To determine whether the ancient Egyptians applied the axioms of systems engineering to the building of the pyramids, we must modify the axioms of systems engineering to make them applicable to building a monument. Through this modification, some of the axiom parts will be deleted because they do not apply to this project. Other axiom parts must be changed to reflect both the pyramid project and the time span in which the pyramid was built. To complete the modification, each of the axioms is stated and then the irrelevant parts are labeled N/A. There will also be an accompanying explanation of why the axiom is irrelevant. For the relevant axiom parts, there is a discussion examining whether the builders of the pyramid followed the axioms. (The Systems Engineering Axioms came from Lake,1994.)

Phases of systems engineering:

The best way to understand the systems engineering process is to examine the phases of systems engineering. All of the systems engineering axioms revolve around and support the phases of systems engineering. Although this paper will apply each engineering axiom to the building of the great pyramid, it is equally important to the proof of the theory that systems engineering itself is understood.

Phases of systems engineering:
1. System Definition
Establish System Definition
Complete specifications
Establish baselines
Complete technical reviews
2. Preliminary design
Establish primary subsystem definitions
Complete specifications
Establish baselines
Complete technical reviews
3. Detailed Design
Establish detailed subsystem definitions
Complete specifications
Establish baselines
Complete technical reviews
(Lake, 1994)

Axiom 1
Consider eight lifecycle functions early in development efforts.

- **Development-**
  - Systems engineering management plan
  - Systems engineering master schedules
  - Trade study reports- N/A
  - Logistics support analysis reports.

Development refers to management and organization to complete the product.
The pyramid must have been built during the lifetime of the reigning Pharaoh. Remaining records indicate that Khufu reigned for 23 years. To manage the size of the workforce and the sheer quantity of work, schedules must have been created. Through calculations, we know that 34 blocks were laid every hour, translating to approximately one block every two minutes. Given that each block had an average weight of 2.5 tons, and that time was required to quarry the block, transport it to the pyramid site, site and lay the block, and finish the block surface, in addition to all of the projects in support of the building

effort, such as building the ramp and building the pyramid town, it would have been impossible to complete the task without schedules and management. The control notes included schedule, team, and action information, further proof of management and schedules. Concerning the workforce, we know that it was broken down into teams. The availability of the workforce was also directly related to the floods of the Nile and seasons in Egypt. A part of the workforce was comprised of Egyptian farmers who were available beginning from the period after harvest, through the annual Nile River flood, and a short period after. To manage the groups and provide guidance and information, master architects, stonecutters, and builders were hired. These experts provided management and knowledge to the effort.

- **Manufacturing**
  - Production tools
  - Facilities
  - Layouts
  - Procedures

Manufacturing refers to tools, knowledge, and support to make the product.

Tools were used and created for the tasks at hand. Horizontal and vertical levels, wooden T-squares, and copper chisels have all been uncovered around the area of the great pyramid. Rounded dolerite stones used to quarry granite had been uncovered. Pyramid towns were built to support the workers and the effort. Hired experts laid out controls and procedures for the effort. Found control notes confirm the building procedures.

- **Verification/Test**

Verification/Test refers to comparing the product produced to the initial requirements and testing that product to insure that it meets the requirements and fulfills its purpose.

Each successive stage was tested and compared to the whole effort to insure uniformity. Because rise and run were controlled one level at a time through stone markings, errors in previous levels could be corrected in subsequent levels. In addition, methods to insure proper rise and run had been previously tested on earlier pyramids. Evidence of verification can be seen in other imperfect pyramids whose rise and run were not properly controlled; the tops of these pyramids are twisted to align the size of the pyramid at its top. (To keep this paper straightforward, the inner chambers of the pyramid are not discussed. It should be noted however, that the inside of the pyramid including the great Hall, burial chambers, and the various path and shafts were probably the most difficult to plan and create.)

- **Distribution-** N/A

This function does not apply because the great pyramid was meant to be unique.

- **Operations**

Operations refer to management of the workers to make the product.

The workforce was broken down into teams and controlled by the experts hired. Evidence of workforce teams exists in hieroglyphs. In a sense, operations are similar, for the pyramid project, to development.

- **Support-** N/A

Although there has been evidence that food was left at strategic points outside of the pyramid, that sustenance was outside of the scope of building the great pyramid. In this case, support can include the upkeep of the pyramid.

- **Training –**
  - Simulators
  - Mockups
  - Training material N/A

This function refers to the users of a product. Because the pyramid was not distributed, and was not a product, training does not apply. If we extend the function of training to include workers during construction, certainly workers were trained to do their tasks by the experts hired and the foreman of each team.

- **Disposal- N/A**

The great pyramid was built to be an eternal monument and tomb for the Pharaoh; there were therefore no plans or reason for disposal.

Quality factors must be designed into every function:

- **Producibility** -- Can the product be produced?

Although the great Pyramid was the largest pyramid ever built, prior attempts at building pyramids had verified that it could be done. Incremental learning of how to build pyramids started from the burial mounds, proceeded to step pyramids, evolved to slant pyramids, and concluded with true geometrical pyramids. Lessons and procedures were learned along the way. Slant pyramids and twisted pyramids presented a chronology of pyramid perfection.

- **Testability** -- Can it be tested?

The end result of the effort was an eternal tomb for the Pharaoh. The tomb would serve as a path for the Pharaoh's soul to ascend to heaven. Because the goal of the product was to produce an eternal tomb, the geometric accuracy of the great pyramid, along with the fact that it was used as a tomb means that it could be and was tested both throughout building and after completion. When we look at Khufu's pyramid today, we see broken outer casings and a damaged top. Most of the damage to the pyramid was caused by man. Limestone was removed from the outer surface of the pyramid for use in other projects. Once the limestone was removed, the interior of the pyramid began to decay. The inside of the pyramid was also repeatedly looted.

- **Distributability** -- Can be distributed and installed? N/A
- **Operability** -- Is it operable? - N/A
- **Supportability** -- Is it supportable?- N/A
- **Disposability** -- Is it disposable?- N/A
- **Trainability** -- Can people be trained to operate and support it?- N/A

The last five of the above factors do not apply to the great pyramid simply because the great pyramid was not a distributable product as we define it today. It was a unique monument that is the only survivor of the ancient Seven Wonders of the World.

Axiom 2
Each world-class system is made up of eight simultaneously developed and tightly controlled integrated system elements –

Although axiom 2 refers to a system of elements, the pyramid project can also be broken down into elements. Thus, each of these elements had to interact and blend seamlessly to complete the project.

- **Hardware**- N/A

The term hardware refers to computer-based equipment that is part of the product. Although we could say that the finished pyramid was hardware, the finished pyramid was the product itself. The finished pyramid is not a system per se, but an object, therefore hardware does not apply.

- **Software**- N/A

The term software refers to computer-based instructions necessary for the hardware/system to operate. Again, we could say that the procedures for building a pyramid were software, but the procedures were methods of creating the product, and were not used after the pyramid was completed.

The remaining six elements apply to the project development.

- **Services**

In pyramid building, services refer to worker care. Although the pyramid workers saw their efforts as noble, the quantity of the needed effort was grand. Services included feeding, housing, and clothing the workers, as well as maintaining comradery and a sense of purpose.

- **Facilities**

The main facility used in the project was the pyramid site. This is due mainly to the enormity and logistics of the project. Other facilities included sites for gathering materials; quarries, fields, etc. Pyramid towns were set up next to the building site to house, feed, and entertain the workers.

- **Techniques**

Lessons learned from earlier attempts to build true pyramids produced techniques used during construction. Further, management and worker care techniques were learned from cities, populations, and any prior large-scale efforts.

- **People**
- **Data**

In this project, data included techniques and procedures.

- **Material**

Material was quarried, gathered, cut, and prepared.

The remaining six elements were seamlessly integrated. Workers stayed in pyramid towns. Workers used techniques on material to transform the raw material into the finished product. Experts had data and process knowledge to complete the tasks. The pyramid towns provided services to maintain the workforce.

Axiom 3
A world-class system is developed one level of decomposition at a time.
System->Subsystem->Component.
A physical solution is proposed for each level and that solution is decomposed until a decision can be made as to whether the component defined can be purchased, subcontracted, or fabricated.
(Work breakdown structure.)

The last part of this axiom, deciding whether the component can be purchased, subcontracted, or fabricated does not apply to the pyramid project. All components, in this case materials, procedures, and effort were all fabricated or quarried/gathered. We have evidence that all of the pyramid builders were paid by the state, so the decision to purchase or subcontract does not apply.

The valid part of this axiom is development by decomposition. An effort as large as the building of the pyramid required that the various pyramid components be broken down into subcomponents that could be handled by a 20-man team, as evidenced by the organization of labor. The organization of the workforce demonstrated that a work breakdown structure was developed. In addition, the control notes name teams for each task. Aside from the evidence, logic suggests a sequence for completing each pyramid task. For instance, to lay a stone, a serial order must be followed. First, the type and size of the stone must be requested from a central plan. Next, that stone must be quarried. The stone must then be transported to the building site. Finally, the stone must be set in place and chiseled smooth. Because of this logical sequence of events, the pyramid project itself was naturally decomposed into sub components.

Axiom 4
After each physical solution is developed from Axiom 3, a technical review is held to ascertain:

1. **Maturity of the development effort –**
   - **Review all documents for completeness and for satisfying requirements**

   The pyramid project produced one document, the scribes copy of the control notes. It can be assumed that if the scribes copied all of the control notes, the documentation would be complete.
   - **Scrutinize decision making**

   There was very little decision making involved in the pyramid project. All the procedures used to build the pyramids had been tried and perfected earlier. Validation and verification could have been used to insure that the pyramid was built properly and suitably.
2. **Assessment of risk for the next development effort and the risk management plan**

   This pyramid for the God king could not be abandoned. The development effort did not proceed in stages. Instead, sub components were repeated for each stone laid. Risk mitigation strategies were used to insure project completion. Specifically, marking the outside face of the pyramid into stones as they are laid, but not smoothing the stones until later stages, compensated for small rise and run errors. In addition, the initial project plan and build site assured availability of materials.
3. **Resource requirements needed for the next development level effort. N/A**

   Because the pyramid project was completed by repeating a series of sub components steps, resource requirements did not change through the course of the development effort.
4. **Supplier management requirements and planning N/A**
   - **Identify sources of subcontracted work and materials and review contractual documents**

   There were no true subcontractors or contractual documents. The state directly hired workers. Because of the absolute power of the state, control over workers was also absolute.

The major result of a technical review is to decide whether the investment should be made to continue development.

Because the result of a technical review is to decide whether the effort should continue, the abandonment of flawed pyramids demonstrates that reviews were held. Further, slant pyramids demonstrate that reviews were held to determine structural stability, and structural blueprints were modified based on the outcome of the reviews.

Axiom 5
Effective integration of multidisciplinary efforts requires integrated product teams. Each of the integrated product team would be assigned components. Team must be given product-oriented responsibilities, the authority to make engineering decisions, and budget authority.

Because the budget for the effort was the state's wealth, budget authority does not apply. Integrated product teams were used as evidenced by the worker breakdown. Experts in building and architecture guided the task teams. Depending on how teams are defined, the authority to make engineering decisions would or would not apply. Experts ultimately controlled the building of the pyramid. Most of the task teams provided physical labor. Therefore, if engineering decision authority is given to experts, this axiom is satisfied.

Axiom 6
A world-class development effort requires a disciplined and recursive application of the Systems Engineering Process. (Figure 8)
Figure 8

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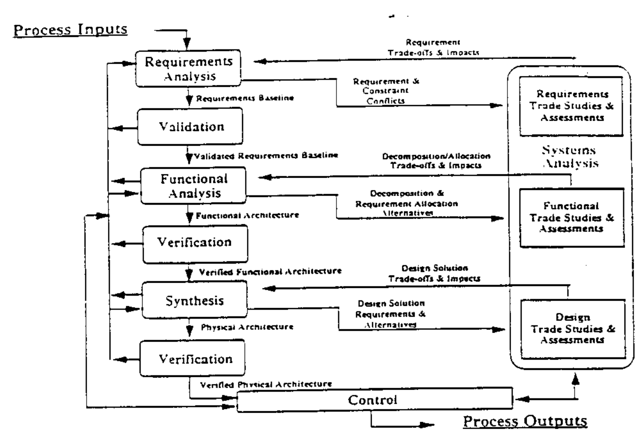

Figure 3 The Systems Engineering Process

(Lake, 1994)

No analysis or design records exist for the building of the great pyramid. Control notes have been discovered, but they are limited and incomplete. The only way to determine whether axiom 6 is satisfied is to apply a sub process to the chart above and test whether the systems engineering process was followed.

The process to be analyzed is transporting stones from the quarry site to the pyramid site. (All phases will be abbreviated.)

<u>Requirements:</u> Transport stone from quarry to building site.

Transport 2.5 ton blocks 985 feet from quarry to pyramid site.

Stone must not be damaged, cracked, or altered during transport.

Transport must take less than ten minutes from point of loading to arriving at southeast boundary of pyramid site.

<u>Requirements Analysis:</u>

No conflicts, requirements feasible, no trade-offs (stones must be transported).

<u>Validation:</u> N/A

<u>Functional Analysis:</u>

Consult experts to gather alternatives and prior knowledge.

Functional architecture systems include involves loading stone, creating sled, creating path, and pulling sled.

<u>Verification:</u> N/A

<u>Synthesis:</u>

Design sleds, and path structure and composition. Consult with experts including carpenters, to build the wooden sleds, architects, to design the path, and experienced project builders to determine required manpower to meet speed requirements.

<u>Verification:</u> N/A

Through the application of the systems engineering process to the transporting stones from quarry to building site task, all relevant components of the systems engineering process are followed, and the axiom is satisfied.

Axiom 7

The systems engineering process is applied as necessary during each development level to produce products needed for that stage of development.

Axiom 7 implies that axiom 6 is repeatedly applied. It can be assumed that by proving the applicability of axiom 6 to the project, axiom 7 is also automatically incorporated for the pyramid project only, because of the lack of specific details about the pyramid's construction.

Axiom 8

System design and design capture must be conducted simultaneously. All data generated by the systems engineering process must be captured and maintained in an integrated database:

- **Tracability of changes**

This is only partially applicable to the pyramid project. The product produced is unique, and is intended to be sealed after construction, therefore an exact record of changes from the original plans is not necessary. However, any structural changes during construction must be recorded and taken into account while completing later phases. The pyramid project was definitely successful and has stood the test of time, therefore we can assume that any structural changes were incorporated into the later stages of the project.

- **Decisions made during each sub process activity**

Again, this is only partially applicable to the pyramid project. Building the pyramid requires the same processes and sub processes repeated millions of times. There was limited decision making within the repetition. In addition, because the product is unique, a detailed record is not necessary.

- **Rationale for selecting a given alternative**

The pyramid project was built following lessons learned from other flawed pyramid projects. Due to the repetitive nature of building the pyramid, there were few if any alternatives.

- **Information which the integrated product team needs to complete sub process activities**

Experts were hired to lead the project effort. They had information to complete the sub process activities. In addition, control notes kept a general record of the effort.

- **All requirements**
- **Customer and management set priorities**

The only priority for the pyramid project was scheduling and eventual durability; the pyramid must have been completed within the Pharaoh's lifetime, and must last for eternity. Although these priorities seem incomplete, it makes intuitive sense that the Pharaoh had very little to do with the pyramid project's design, except to issue an order that the greatest pyramid of all time be built to serve his soul.

- **Data generated by all systems engineering process activities**

The only data generated by any activities were the control notes recorded by scribes.

- **Implementation plans**
- **Systems analysis specifics**

- **Tools and methods used for analysis, design, verification, and conduct of other systems engineering process activities**

Experts were hired to lead the project effort. Only these experts and possibly the team leaders needed access to plans, activities or specifics. Control notes on the stones laid out where each stone was to be put.

The integrated database must be available to all members of the development effort, based on need and role.

Control notes have been found for both workers and scribes. This implies that the effort was meticulously recorded. We can assume that if this project was documented, other projects were also documented. Hieroglyphs also offer limited information about how the pyramid was built. Because of this, hieroglyphs can also be considered an integrated database. In addition, techniques learned from earlier building attempts must have also been recorded.

In essence, the axioms for system engineering require a defined lifecycle approach to product development, using work breakdown structures, assigning tasks from the work breakdown structures to autonomous teams, and maintaining a data repository for all phases of development.

Conclusion:

Even though we attribute the discipline of Systems Engineering to have been started in the 20th century, the axioms of Systems Engineering are evident in the building of Khufu's great pyramid.

When we modify the axioms of systems engineering to be relevant at the time of the building of the great pyramid and to the pyramid project itself, we can conclude that the ancient Egyptian builders of Khufu's great pyramid were indeed Systems Engineers.

This paper has presented pyramid construction theories as facts. Every effort has been made to analyze the pyramid construction theories and only use the most plausible and accepted theories.

The problem with modifying the systems engineering axioms to apply to the building of Khufu's pyramid is that the purpose and product of the effort are at odds with the purpose of the systems engineering axioms. This paper has made every effort to explain the rationale used to modify the axioms. A theory can be proven by simply altering the acceptance criteria. This paper only modified axioms in which the axiom part eliminated could not be made to apply. Explanations of why certain axiom components were removed also included possible methods of incorporating the axioms; but those methods cannot validate inclusion of the axiom components.

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