



KEEL Technology impact on “Sea Power 21”

Compsim Whitepaper

Overview:

The “Sea Power 21”¹ vision sets out the objectives for future naval operations. Most of these objectives demand the use of advanced information / cognitive capabilities, such as those offered by Compsim’s proprietary KEEL[®] (Knowledge Enhanced Electronic Logic) technology. This paper decomposes the Impact, Capabilities, Technologies, and Action Steps for the “Sea Strike”, “Sea Shield” and “Sea Basing” domains. This paper will also respond to the “Sea Trial Impact”, “Sea Warrior Impact” and “Sea Enterprise Impact” statements.

KEEL Introduction:

A “technology” implies a “way to address a problem”. A “tool” facilitates the implementation of a technology. Compsim’s KEEL (Knowledge Enhanced Electronic Logic) “Technology” can be used to put human-like decision-making in products or software applications. It provides a new way to process information, similar to the way that humans exercise judgment or reasoning. KEEL technology can be considered an “expert” system technology that uses the decision-making skills of a human as the basis of judgmental decisions. The KEEL Toolkit provides the “tools” to collect and test those reasoning skills before packaging as a KEEL Engine for deployment in the final device or application.

A KEEL based system will interpret and balance the impact of multiple inter-related problems / alternatives to determine the best overall solution to the problem set.

KEEL Technology includes:

- A development environment (KEEL Toolkit)
- A model for accumulating supporting and objecting arguments in order to make a decision or take an action
- A small footprint engine that processes sensors or other inputs according to the design of a system created in the development environment (KEEL Engine)
- A methodology for implementing the KEEL Engine as an analog circuit (when very high performance is required).

Characteristics of Applications that can benefit from KEEL Technology:

¹ Clark, Admiral Vern Clark, U.S.Navy, “Proceedings”, October 2002, “Sea Power 21”;
<http://www.navy.mil/navydata/cno/proceedings.html>



- Human experts are required to interpret information to make the best decisions or take the most appropriate actions
- Devices must operate autonomously and make judgmental decisions on their own
- Devices can make control decisions when human operators are not present
- Repetitive judgmental decisions are prone to error
- Judgmental decisions by trained operators are potentially “tricked” into overlooking critical attributes
- Human experts take too long to make judgmental decisions
- Applications where the judgmental decisions must be explained
- Complex situations where it is uneconomical to develop and maintain straight line code (IF, THEN, ELSE)
- Situations where the environment is dynamic and the importance of information changes and the system must react to change
- Situations where there is an advantage to be able to create one design and execute it on multiple platforms: device, software simulation, web
- When the small memory footprint of a KEEL engine is an advantage
- Where architectural issues may prohibit other solutions (KEEL technology is architecture independent: localized, distributed, web based, multiprocessor...)
- Applications where “surprise” might be an issue, since with KEEL you define how to interpret information, not how to solve specific issues.

Suggested Guidelines for Selecting a Cognitive Technology:

The following list provides a set of guidelines that might be used to select a cognitive technology to satisfy the needs of Sea Power 21:

- 1. A methodology must be provided that allows the domain expert to define the policy with sufficient granularity so that it can be exactly translated into a form that can be explicitly executed by a device or software application.**
The KEEL dynamic graphical language allows policies to be described as continuous curves that can be interpreted by a device or software application as if they were discrete formulas.
- 2. The methodology for describing the policy must support the efficient development of policies to address complex, non-linear scenarios.**
The KEEL dynamic graphical language provides an easy way to document how information is to be processed without resorting to conventional formulas.
- 3. The execution engine for the device or software application that will execute the policies must be suitable for embedded real-time operation.**
KEEL Engines that represent the domain expert's design are high-performance, small-footprint functions. It is desirable that the same



policies used in simulations can be used in devices. M&S will become the test bed for actual devices.

4. The methodology must be completely understandable so it can be efficiently tested before deployment.

All functionality is displayed graphically. By tracing the wires one can see instantaneously how different and potentially conflicting data items are interpreted.

5. Device or software application performance needs to be audited after deployment.

Services are provided as part of the KEEL Toolkit such that real world data can animate the graphical language so that decisions and actions can be traced to their cause and justification. In this way simulations can reflect reality.

6. The efficiency of the entire policy life cycle must be considered (design, test, deploy, audit, extend).

The design of a KEEL-based system is interactive, while it is being developed. This allows it to be tested during the development process. Conventional code is created automatically, thus avoiding human typing errors. Deployment is handled by providing text files in the source code language of choice for easy integration into any IDE (integrated development environment). Auditing is provided with the ability to easily review the real-world interpretation using black box file reviews. Visually observing the importance of information and relationships allows complex scenarios to be reviewed with relative ease. Data is absolute so there is no human interpretation of the results required. Designs can easily be extended, by inserting new items and linking them into existing policies. There is no need to start over every time.

7. The methodology must be architecture independent so it can be deployed on a variety of platforms and in a variety of situations.

KEEL Engines are architecture neutral. They are simply cognitive engines created in the programming language of choice. The system architect has complete control over the marshaling of information and the scheduling of policy interpretation and execution. The same judgmental model can be deployed in a simulation, in emulation, in the device / software application itself, in a training system, and in a web based demonstration without re-engineering.

Sea Strike:



Sea Strike Impact

- Amplified, effects-based striking power – The ability to package human-like intelligence into weapons systems, C4ISR systems, autonomous vehicles, sensors, information interpretation / data fusion systems that can operate on real-time data and control (or advise human operators that control) will define tactical capabilities of the 21st century. KEEL Technology provides this capability today.
- Increased precision attack and information operations – Computers have long been recognized as an important tool for rapidly processing digital information according to a set of rules (programs). The “interpretation of information” has largely remained a human role. KEEL Technology provides a new way to utilize computers in the subjective roles that have been the domain of humans. Human decision-making and reasoning is also one of the major roadblocks to achieving the objectives of Sea Power 21. Only by automating / accelerating the packaging and deployment of human expertise can many of the objectives be satisfied. KEEL Technology provides a new paradigm for processing information. It is supported with a set of tools to create KEEL (cognitive) Engines that can be deployed into devices, into software applications, or as analog circuits.
- Enhanced warfighting contribution of Marines and Special Forces – Devices and software applications with embedded expertise can accelerate / amplify the capabilities of the Marines and Special Forces. These could be UAVs, intelligent weapons, or advanced sensors.
- "24 / 7" offensive operations – Devices and systems augmented with packaged expertise will always be ready, even when human systems are unavailable. These resources could be strategic or tactical. Automating all echelons will make them available 24 / 7. KEEL Technology enables human reasoning to be packaged and distributed to systems and devices, making those capabilities always available.
- Seamless integration with joint strike packages – KEEL Technology is platform and architecture independent, making it suitable for any type of deployment into existing and future systems.

Sea Strike Capabilities

- Persistent intelligence, surveillance, and reconnaissance – By providing the ability to integrate human-like reasoning (policy interpretation and execution) into devices and systems, persistent / continuous operation will be available.
- Time-sensitive strike – KEEL Technology supports concepts like Time Utility Functions (TUFs) to address time and distance-related reasoning. Deployment into devices can provide this type of service to autonomous devices.
- Electronic warfare / information operations – Electronic warfare and information systems need the ability to interpret information in a dynamic, ever changing environment. KEEL technology supports these kinds of problem domains.
- Ship-to-objective maneuver – Moving ships and moving targets require human-like reasoning to adapt to dynamic situations. Policies can be explicitly defined to



- address these complex, dynamic, non-linear, inter-related, multi-dimensional problem sets.
- Covert strike – The use of autonomous devices with their own reasoning capabilities that can hide, evade, attack, and retreat (using their own embedded judgment) that allows them to work alone or as part of a coordinated effort can enable any kind of strategy to be deployed. Key to this capability will be the ability to exercise human-like reasoning such as that provided with KEEL Technology.

Future Sea Strike Technologies

- Autonomous, organic, long-dwell sensors – Two capabilities are offered with KEEL Technology. Autonomous behavior is provided with the ability to augment rules with human-like judgment and reasoning skills. Deployment in sensors can often benefit from small memory footprints and low power consumption. The small memory footprint of KEEL (cognitive) Engines makes KEEL Technology suitable for many information fusion applications.
- Integrated national, theater, and force sensors – KEEL Technology is platform and architecture independent. Therefore KEEL-based devices can be integrated into any architecture. The networking / inter-networking is independent of KEEL Technology.
- Knowledge-enhancement systems - KEEL Technology provides a new form of information / knowledge processing. It has an advantage over Artificial Neural Nets because it is completely explainable and auditable. It has an advantage over Fuzzy Logic because there is no fuzzification / defuzzification (it equates to a formula). It has an advantage over Bayesian Belief Nets in that it works well with non-linear systems. It has an advantage over hard coded solutions because they are not flexible and are often hard to maintain and understand.
- Unmanned combat vehicles – As unmanned combat systems are expected to become more than remotely controlled vehicles, they will have to take on more subjective roles where they can make decisions and take actions on their own. KEEL Technology provides a new way for these devices to interpret information according to explicit, explainable policies that will allow them to pursue goals on their own.
- Hypersonic missiles – The impact of adding real-time cognitive capabilities implemented as custom KEEL analog circuits is unknown at this time.
- Electro-magnetic rail guns – The impact of adding real-time cognitive capabilities implemented as custom KEEL analog circuits is unknown at this time.
- Hyper-spectral imaging – The impact of adding real-time cognitive capabilities implemented as custom KEEL analog circuits is unknown at this time.

Sea Strike: Action Steps



- Accelerate information dominance via ForceNet – KEEL Technology is available now and can be deployed into almost any existing and new system.
- Develop, acquire, and integrate systems to increase combat reach, stealth, and lethality – Adding intelligence into weapon systems can greatly focus their impact. KEEL Technology can be deployed anywhere there is value in embedding human-like reasoning into devices and support applications. It can also be deployed in control systems where there is a need to address complex, dynamic, non-linear, inter-related, multi-dimensional problems that might otherwise require the development of complex differential equations. In these cases the cost of development should be a contributing factor.
- Distribute offensive striking capability throughout the entire force – The ability to distribute real-time, actionable policies across an entire force can be accomplished by distributing KEEL information processing models electronically. How the KEEL engines get distributed is beyond the scope of KEEL Technology. KEEL is platform and architecture independent.
- Deploy sea-based, long-dwell, manned and unmanned sensors – The small memory footprint of deployed KEEL Technology makes it suitable for long-dwell, manned and unmanned sensor systems. Depending on performance needs it can be deployed in very low power systems.
- Develop information operations as a major warfare area – KEEL Technology is a fundamental new way to process information. Its use allows the packaging of human expertise and policies such that they can be deployed in human support systems and in autonomous devices.
- Synergize with Marine Corps transformation efforts – This is beyond the scope of KEEL Technology as this is a management function.
- Partner with the other services to accelerate Navy transformation – This is beyond the scope of KEEL Technology as this is a management function.

Sea Shield:

Sea Shield Impact

- Projected defense for joint forces and allies ashore – Protection is strongly related to the interpretation of information. Human systems fail for four primary reasons: Lack of Attention, Failure to Perceive, Memory / Complexity of the Situation, and Poor Judgment. Computer based systems address the first three: Attention, because they can always be “ready”; Perception, because they can be taught / programmed to watch for certain situations; Memory, because memory is, for all intensive purposes, unlimited. KEEL Technology can provide them a way to exercise judgment. The interpretation of information requires judgment. With



- KEEL Technology one can package human-like expertise (judgment / reasoning) which is more than just rule processing. It includes the interpretation of information and the balancing of alternatives.
- Sustained access for maritime trade, coalition building, and military operations – The access of information is beyond the scope of KEEL Technology. Once access has been provided, KEEL can interpret the information and react accordingly.
 - Extended homeland defense via forward presence and networked intelligence – Embedding human-like reasoning / judgment into advanced / networked sensors will allow information to be fused at the source and judgment to be distributed to the front lines. Judgmental decisions can react locally or can provide processed information up the echelons of command.
 - Enhanced international stability, security, and engagement – KEEL-based agents are information, platform and architecture neutral. Anyplace there is value in distributing human-like expertise in the protection of joint forces would benefit from the deployment of KEEL-based systems.

Sea Shield Capabilities

- Homeland defense – Homeland defense requires the interpretation of information. KEEL Technology provides a new way to deploy human-like expertise into devices, software applications, and as analog circuits.
- Sea / littoral superiority – The smartest forces / devices will be victorious. This will be a continuing effort. KEEL Technology supports evolutionary developments because designs (cognitive models) can easily be extended without continuously starting over.
- Theater air missile defense – There will be a continuing race between intelligent missiles and intelligent defenses. KEEL technology can embed human-like expertise into both offensive and defensive systems.
- Force entry enabling – The automated exercise of expertise in the interpretation of information and the establishment of an “appropriate” response can be packaged as a KEEL Engine and facilitate Force Entry Operations, whether these services are provided by autonomous devices or manned operations.

Future Sea Shield Technologies

- Interagency intelligence and communications reach-back systems – KEEL Technology provides a new way to package “intelligence” that can be integrated into almost any “system”. KEEL Engines are platform and architecture independent. KEEL Engines are completely “explainable and auditable”; a feature that might be considered mandatory as more intelligent systems are deployed.
- Organic mine countermeasures – KEEL Technology provides a way for devices and systems to adapt on their own.



- Multi-sensor cargo inspection equipment – KEEL Technology provides a new way to process information (information fusion). Human expertise is packaged in KEEL Engines. If a human “expert” can interpret the input from multi-sensor systems, then this reasoning / judgment can be packaged as a KEEL Engine.
- Advanced hull forms and modular mission payloads – KEEL Technology might someday be deployed into adaptive hull structures that can change based on the environment or the requirements of a specific task. If there would be value in adding intelligence into modular payloads such that the payload “package” could adapt to the collective elements, then KEEL should be able to provide this integrated reasoning.
- Directed-energy weapons – If there would be value in integrating information about the weapon and information about the target, into an adaptable solution, then this integration should be possible using KEEL Technology. KEEL Technology addresses complex, dynamic, non-linear, inter-related, multi-dimensional problem sets and allows the solution to be packaged into an analog circuit when very high performance is required.
- Autonomous unmanned vehicles – As autonomous vehicles are assigned more and more complex tasks they will have to be able to interpret information and react on their own. KEEL Technology provides a way to interpret information in a human-like way (valuing information and balancing alternatives and allocating its resources). KEEL Engines are effectively analog solutions that are now being recognized as the most appropriate way to address these complex dynamic problems.
- Common undersea picture – KEEL Technology provides a way to package human-like reasoning in a way that is completely explainable and auditable. KEEL Engines are low level functions that can be integrated into any platform or architecture. The same cognitive models can be deployed into multiple (different) platforms.
- Single integrated air picture – While KEEL is primarily an information processing technology, the KEEL dynamic graphical language “could” provide a view into any device or system so one can “see” the component think.
- Distributed weapons coordination – KEEL Engines are architecture independent. The system designers control how information is exchanged between devices. Systems that include KEEL Engines can be a tightly or loosely coupled as any human system.
- Theater missile defense – Missile defense requires the interpretation of information. KEEL Technology provides a way to package this interpretation of information in an explicit way.

Sea Shield: Action Steps

- Expand combat reach – KEEL Technology is platform independent and can be deployed into distributed sensor systems.



- Deploy theater missile defense as soon as possible – KEEL Technology is ready now (TRL 4-5).
- Create common operational pictures for air, surface, and subsurface forces – KEEL Engines are low level functions that interpret complex, non-linear, dynamic behavior. KEEL Engines would drive the presentation layer.
- Accelerate the development of sea-based unmanned vehicles to operate in every environment – KEEL Technology supports the complex reasoning that is required for sea-based unmanned vehicles to execute to their goals. This technology is available now.
- Invest in self-defense capabilities to ensure sea superiority – Investment is a management function.

Sea Basing:

Sea Basing Impact

- Pre-positioned warfighting capabilities for immediate employment – Human judgment can be augmented with KEEL Engines to facilitate appropriate pre-positioning of warfighting capabilities. Policies documented with the KEEL dynamic graphical language are completely explainable and auditable. They can be deployed in simulations, tested with relative ease, and deployed in tactical systems without the need for redesign (since KEEL Engines can be created for multiple platforms with minimal effort).
- Enhanced joint support from a fully netted, dispersed naval force – The KEEL dynamic graphical language allows complex models to be created. The models can be deployed into multiple languages for different deployments (C, C++, C++ .NET, Java, C#, Visual Basic, VB .NET, Flash, PLC Structured Text). KEEL cognitive Engines are low level devices with a simple API that can be deployed as stand-alone reasoning engines or as components of distributed intelligence.
- Strengthened international coalition building – Since decisions and actions driven by KEEL Technology are completely explainable and auditable, it would be possible to show “exactly” why decisions are made. The human “English” language is subject to interpretation. The KEEL dynamic graphical language is explicit (like a formula) which allows one to “see” exactly how much importance is given to any information item.
- Increased joint force security and operational agility – KEEL Engines are high performance reasoning engines. If super fast reasoning is required they can be deployed as analog circuits. Devices / systems incorporating KEEL Engines can make “very” fast / agile / adaptable decisions and apply resources as appropriate. Allowing these systems to run without human “delay points” will allow very reactive systems to be created.



- Minimized operational reliance on shore infrastructure – KEEL Engines can operate autonomously. They can interpret information completely independently. Designs can also take direction from humans if this is determined appropriate. Compsim has demonstrations suggesting how autonomous devices can still be controlled by higher level systems.

Sea Basing Capabilities

- Enhanced afloat positioning of joint assets – KEEL Technology can be deployed in Strategic as well as Tactical systems. Anyplace there is value in embedding human-like reasoning is an opportunity for KEEL deployment.
- Offensive and defensive power projection – There may be some value in utilizing KEEL Technology when human-like expertise can be embedded into diagnostic and prognostic systems that interpret the environment and automatically react. When power systems are deployed into complex shipboard systems they may need to react to damage in an intelligent way. KEEL Technology can be deployed to interpret the situations and react in real time.
- Command and control – KEEL Technology can be used to package human-like reasoning into command and control systems. This can be used to augment human systems or for deployment into autonomous systems. KEEL Engines deployed into these systems will operate continuously and adapt to change.
- Integrated joint logistics – Logistics systems need the ability to react to a continuously changing environment. Policies described with the KEEL dynamic graphical language can be integrated into logistic systems. Logistic decisions will always be explicitly auditable. If there is a need to change the policies as new situations are encountered, then this can be accomplished with relative ease.
- Accelerated deployment and employment timelines – The automation of human-like judgment according to published policies can greatly accelerate any timelines.

Future Sea Basing Technologies

- Enhanced sea-based joint command and control – The automation of human-like expertise can enhance C2 systems.
- Heavy equipment transfer capabilities – If the logistics associated with this activity can be augmented with human expertise, then this type of reasoning can be packaged as KEEL Engines.
- Intra-theater high-speed sealift – The autonomous operation of this equipment will eventually lead to higher performance of all assets.
- Improved vertical delivery methods – Increased use of embedded intelligence that can be packaged as KEEL Engines and thus create adaptable systems will improve performance.
- Integrated joint logistics – Autonomous operation of logistic systems will increase their capabilities. KEEL Technology can support the autonomous operation.



- Rotational crewing infrastructure – The allocation of resources is a dynamic process. Models created with the KEEL dynamic graphical language can be used to automate the execution of policies.
- International data-sharing networks – KEEL Technology provides a way to package human-like expertise into KEEL (cognitive) Engines. How the reasoning models are deployed and shared, and decisions and actions made by the KEEL Engines are deployed and shared are management decisions beyond the scope of KEEL Technology.

Sea Basing: Action Steps

- Exploit the advantages of sea-based forces wherever possible – KEEL Technology is available now.
- Develop technologies to enhance on-station time and minimize maintenance requirements – KEEL Technology is available now.
- Experiment with innovative employment concepts and platforms – KEEL Technology is available now.
- Challenge every assumption that results in shore basing of Navy capabilities – KEEL Technology is available now. Its deployment is a management decision.

Sea Trial Impact / Sea Warrior Impact / Sea Enterprise Impact:

“Sea Power 21” will achieve its goals by automating and mechanizing many manpower intensive activities that are performed today by humans. Therefore to achieve these goals, one must translate human-expertise into device expertise. KEEL Technology, with its “dynamic graphical language” supports this requirement. One can see the time when the primary responsibilities of humans will be to define, test, audit and extend the automated / autonomous systems reasoning capabilities. Humans will transform from operators and warriors to teachers and trainers of the automated equipment. Humans will write the policies for the equipment to follow. This can be described as a paradigm shift as the equipment transforms from “programmed” equipment to “policy execution” equipment. “Policy execution” equipment will be interpreting information according to policy, not just following scripted rules.



Summary:

The vision of Sea Power 21 demands that devices and applications are more “intelligent”. Only with advanced intelligence will they be able to satisfy the stated objectives. Advanced “intelligence” will require more than just faster processors and new architectures for distributing information. Compsim’s KEEL Technology allows these devices to exercise reason and judgment, while interpreting information and determining courses of action. KEEL Technology also lets humans retain control of the devices and applications since it is an “expert system” technology where humans define the policies. This makes KEEL Technology a powerful approach to address many of the objectives of Sea Power 21.

Compsim LLC is a provider of next generation cognitive technology for application in automotive, industrial automation, medical, military, governmental, enterprise software and electronic gaming markets. The company is headquartered in Brookfield, Wisconsin.

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