An Innovative Requirements Solution: Combining Six Sigma KJ Language Data Analysis with Automated Content Analysis

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Requirements Engineering Challenge:
Applying Measurement & Analysis to Qualitative Problems

Users & customers often have **unrealistic performance expectations.***

To meet this challenge in military acquisition, it is not enough that

- program managers begin to collect unbiased data to analyze project costs & projections.
- programs perform technology maturation activities, competitive prototyping or Preliminary Design Reviews (PDRs).

Most importantly,

- Mutual understanding of capabilities in context & what it takes to enable them need to be established ***before*** a project is initiated among those who
  - determine what capabilities are needed
  - write requirement specifications
  - acquire the systems that meet specifications,

so that appropriate measures of performance & other ***quality attributes*** of the capabilities & their enabling systems can be determined and aligned.

* OPINION : Reforms for the Department of Defense, by Sen. Carl Levin (D-MI), *Niles Star*, Michigan, 03/11/2009 re the Levin-McCain 2009 Weapons Systems Acquisition Reform Bill

A Promising Solution

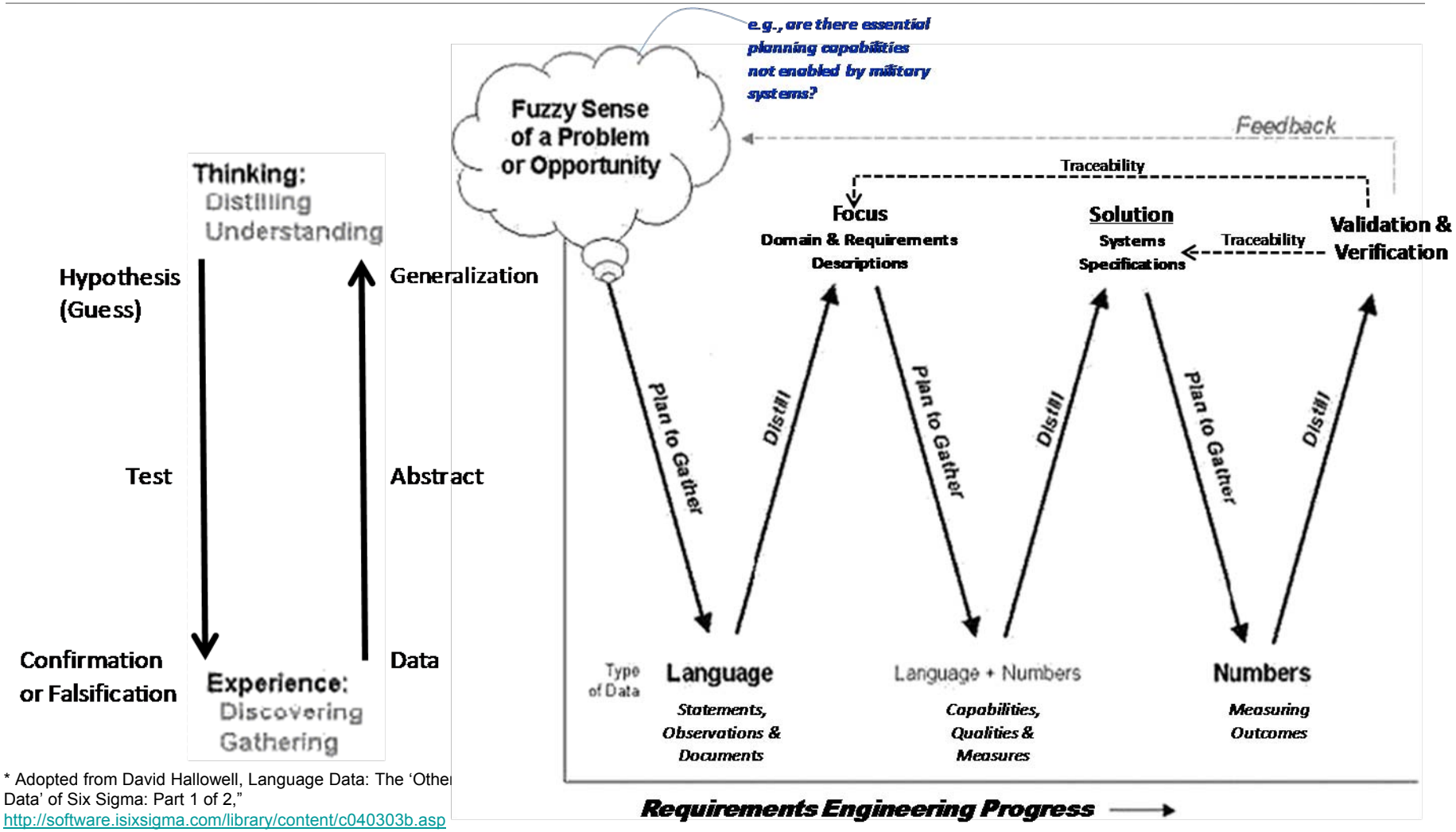
A key to understanding ***quality attributes*** is handling qualitative data, which in large part is language data, & making it quantitative.

Two complementary language data techniques are being used

- KJ Analysis
  - Structured methods for eliciting & clarifying/interpreting semantic meaning of textual information
  - That automated text analysis simply does not have
- Semi-automated content analysis based on automated text analysis
  - Enables more input from more stakeholders and identifies concepts in common that enables consistent applications of KJ across time & sites

Merging the two allows understanding of language data crucial for requirements & their measured validation.

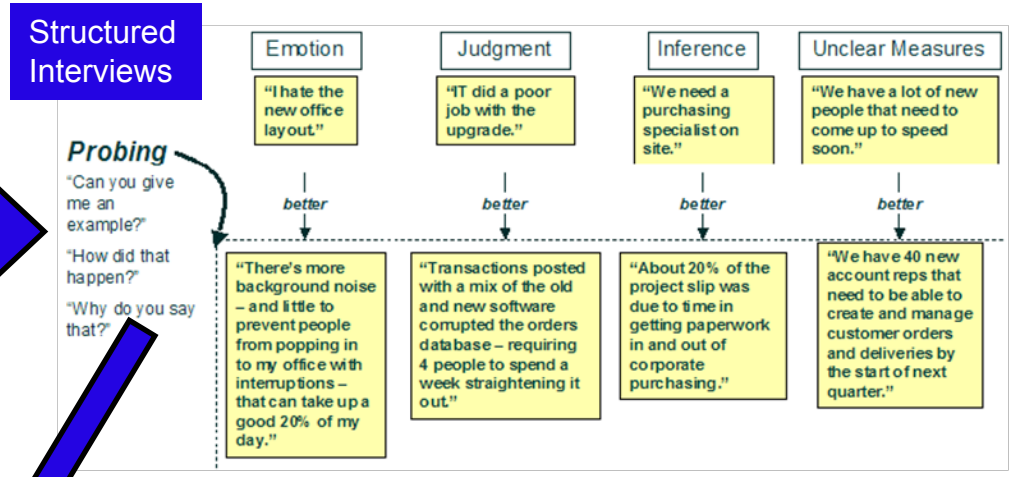
Language Data: "The Other Data of Measurement & Analysis"* for Requirements Engineering



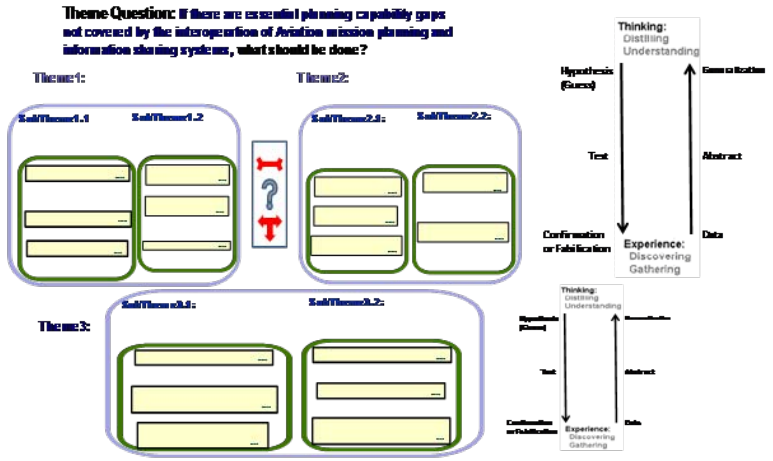
* Adopted from David Hallowell, Language Data: The 'Other Data' of Six Sigma: Part 1 of 2," http://software.isixsigma.com/library/content/c040303b.asp

KJ – a Method for Collaborative Processing of Language Data

KJ (named after Jiro Kawakita) is a method for transmuting *tacit* knowledge into *explicit* and more & more objective statements …



… and refining a collection of these statements into *a 2-D patterned representation (KJ template) that conveys lots of information and related thought processes for those communicating asynchronously.*



Adopted from David Hallowell, Language Data: The 'Other Data' of Six Sigma: Part s 1 & 2,"
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Distilling Meaning in Language Data:
Benefits of Combining KJ with Automated Content Analysis

Content analysis (CA) methods to analyze large bodies of textual documentation have existed for over seventy years, but until recently were predominantly manual.

- They were used during World War II to predict the bombing of London by analyzing Joseph Goebbels' speeches.
- However, humans cannot read & digest all the documents & recognize *all* the patterns that machines are getting increasingly better at doing.
- Yet humans must interpret the meaning, or lack thereof, of what machines can find.

Benefits of Combining CA & KJ

- *Automated text analysis can process a much richer body of information & provide common concepts for KJ participants to establish consistency from group to group.*
- *KJ analysis provides a framework for collaborative interpretation of concept maps produced by CA.*

Upshot: The combination is a hybrid that alters both CA & KJ but that generates insights that neither could produce alone.

Insuring Consistency & Completeness Across KJ Settings is a Problem

To date, KJ analysis has been applied in small, face-to-face one-day workshops where both customer and technologist points of view are represented.

One worry is that results might be quite different if different representatives were assembled on a different day.

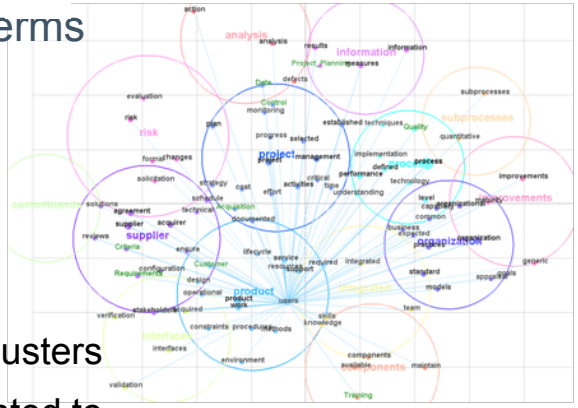
An automated language or content analysis approach is being developed to supplement the KJ method so that

- a significantly larger group of individuals in geographically disparate locations can participate asynchronously.
- additional textual information is captured beyond that in KJ face-to-face sessions:
  - documentation in the form of requirement descriptions & specifications
  - problem and defect report databases
  - open text surveys
- there is more confidence that results are complete and repeatable.

Content Analysis & Concept Maps – a Language Data Computational Processing Method

CA uses automated text analysis tools to identify recurring concepts & clusters of concepts:

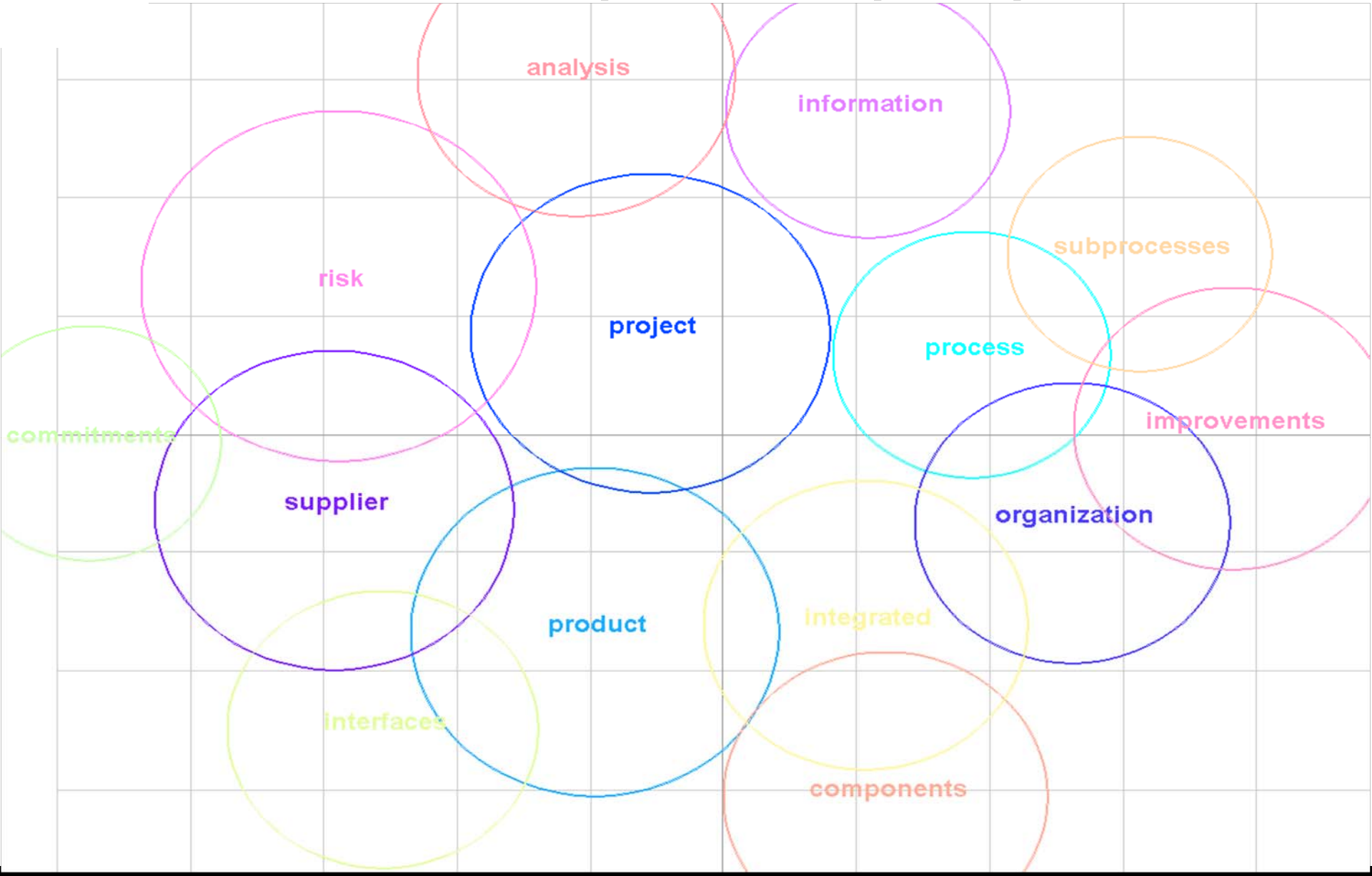
- Concepts are synonyms of strongly related **co-occurring** terms
  - constituted in automatically generated affinity lists
  - named by most representative term in affinity list
- Concept Clusters are collections concepts of similar co-occurrence patterns
  - more strongly related to each other than to concepts in other clusters
  - named by automatic selection of the concept most strongly related to other concepts in the cluster



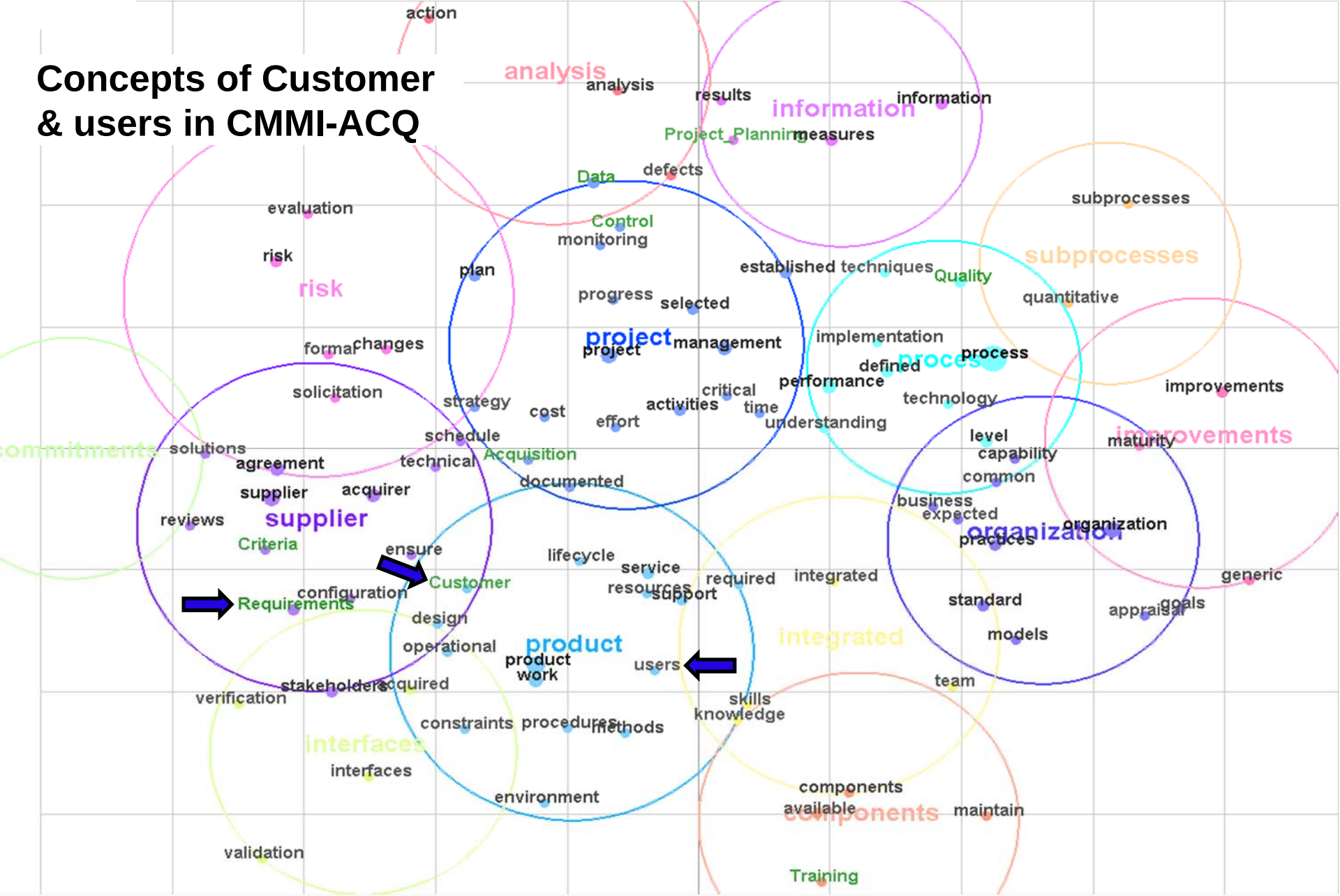
Concept Clusters are represented graphically as Venn diagrams

- Concept names labeling dots are in concept clusters represented as circles
- dots can be linked by lines whose brightness represents frequency of co-occurrence
- dots can appear in the overlap of two (or more) circles
- circle size does not always indicate importance since circles can be sparsely populated

A CMMI-ACQ Example: Concept Map Clusters



Concepts of Customer & users in CMMI-ACQ



Handling Language Data Numerically

Ranked Concept List

Concept	Absolute Count	Relative Count
process	2068	100%
project	845	40.8%
organization	815	39.4%
product	812	39.2%
supplier	671	32.4%
performance	536	25.9%
work	510	24.6%
management	504	24.3%
agreement	493	23.8%
information	474	22.9%
plan	450	21.7%
Requirements	417	20.1%
measures	374	18%
acquirer	361	17.4%
risk	345	16.6%
practices	343	16.5%
standard	308	14.8%
improvements	295	14.2%
activities	291	14%
level	290	14%
Quality	259	12.5%
results	257	12.4%
Data	254	12.2%
organizational	253	12.2%
defined	248	11.9%
stakeholders	240	11.6%
selected	235	11.3%
Criteria	234	11.3%
established	224	10.8%
support	220	10.6%
analysis	214	10.3%
changes	209	10.1%
models	194	9.3%
action	194	9.3%
service	193	9.3%
reviews	189	9.1%

The most frequent CMMI-ACQ concepts are listed at the left.

The absolute count is the number of text blocks where a concept occurs – highest count set at 100%.

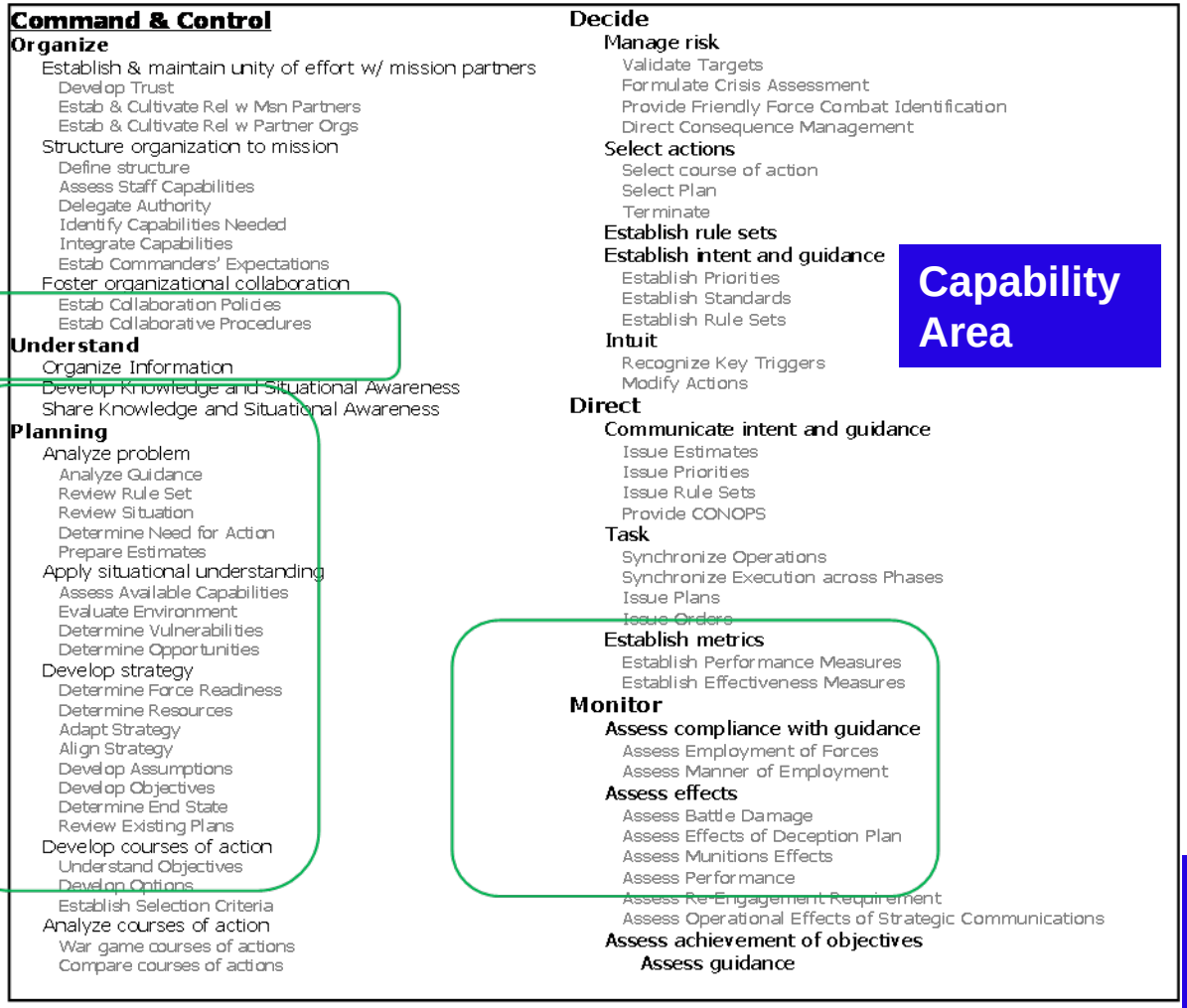
The relative count is the percentage of text blocks concepts occur in.

Not surprisingly for a process model, conceptual traces of **process** are found in the most CMMI-ACQ text blocks.

Project and **organization** are the *next most* significant thematic concepts.

These are followed by **product** and then **supplier all of which are important to the points made previously**

All are in the top 10% of concepts appearing in concept maps that follow.



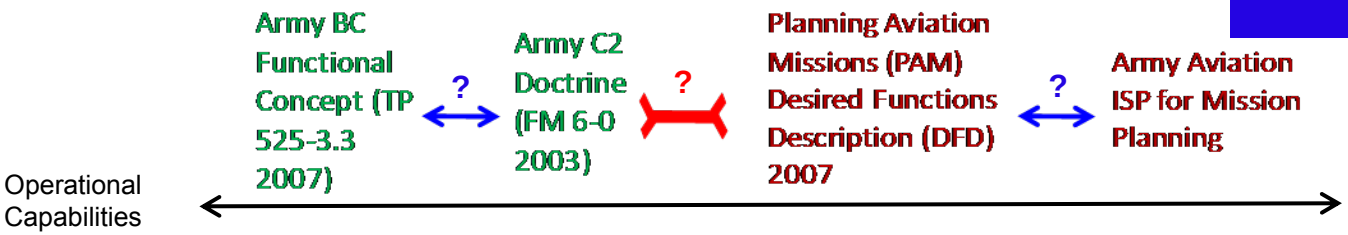
Combining KJ and CA An Example:

Starting with military capability areas & corresponding documentation

and documentation of systems that may enable essential capabilities,

formulate a Theme Question:

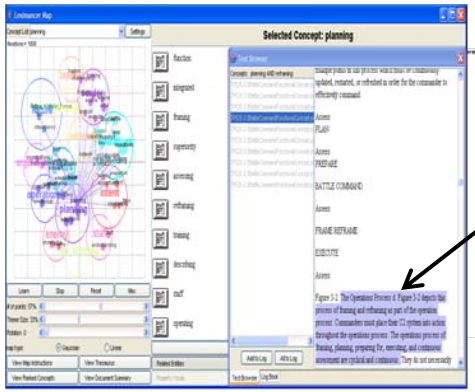
Are there essential planning capabilities not enabled by military systems?



Combining CA with KJ 2

Automated Content Analysis

Are there essential planning capabilities not enabled by military systems?



New Theme Question

Theme Question: Given that there are essential planning capability gaps not covered by the interoperation of Aviation mission planning and information sharing systems, *what should be done?*

Theme3: Establish processes for evolution of Aviation planning capabilities & their quality attributes

SubTheme3.1: If providing a capability like adjusting plans in-flight is an objective, planning & analysis is needed across programs responsible for the multiple systems enabling the capability

- Sensor, planning & information sharing systems are mutually responsible for enabling plan adjustment during flight
- There are technical, tactical & human limitations on the extent to which planning & missions can be reframed both pre & during flight
- Multiple systems have to interoperate throughout their evolution

SubTheme3.2: Establish a process for defining, operationalizing & analyzing quality attributes like agility & interoperability across combat forces and systems

- Agility & interoperability are quality attributes for both combat forces and systems that need to be operationalized & aligned
- There are semantic & pragmatic levels of interoperability that need to be reached in addition to technical & syntactic levels
- Planning & plan reframing provide context for specifying agility & interoperability measures

realignment

Theme Question: *if there are essential planning capability gaps not covered by the interoperation of Aviation mission planning and information sharing systems*, what should be done?

misalignment

Theme1 (ITP525-3.3 & FM 6-0): An essential planning capability is refinanning or adjusting plans during mission execution as a form of agility

Theme2: (DFD & ISP): Agility & flexibility are not specified & interoperability is not sufficiently specified nor operationalized; adjusting plans in-flight not really considered

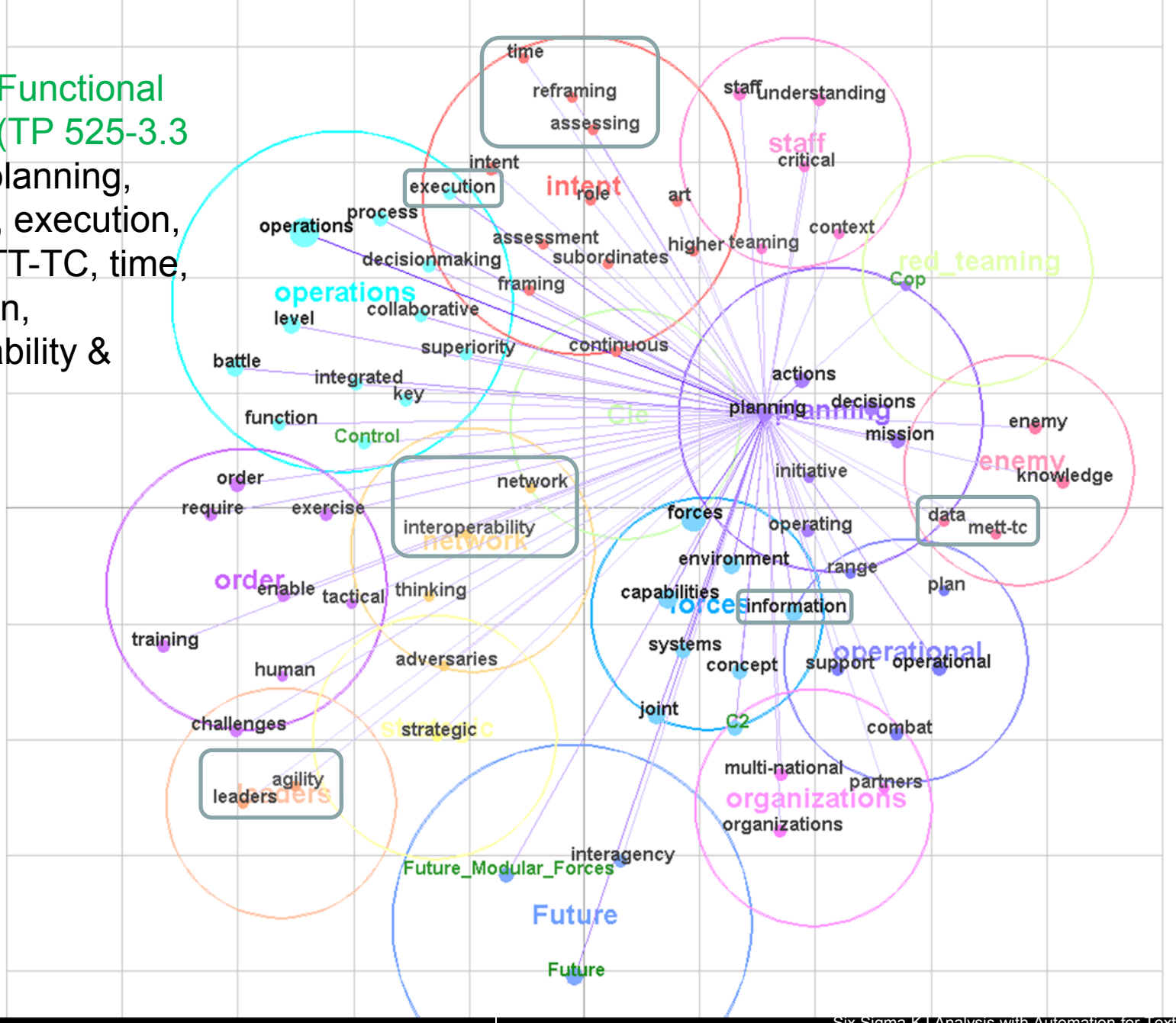
Statements & SubThemes 3.1 & 3.2 were formulated in discussion with representatives from PEO Aviation. They are still preliminary.

More discussions with more Aviation groups is being planned using a mix of KJ and CA methods both synchronously and asynchronously.

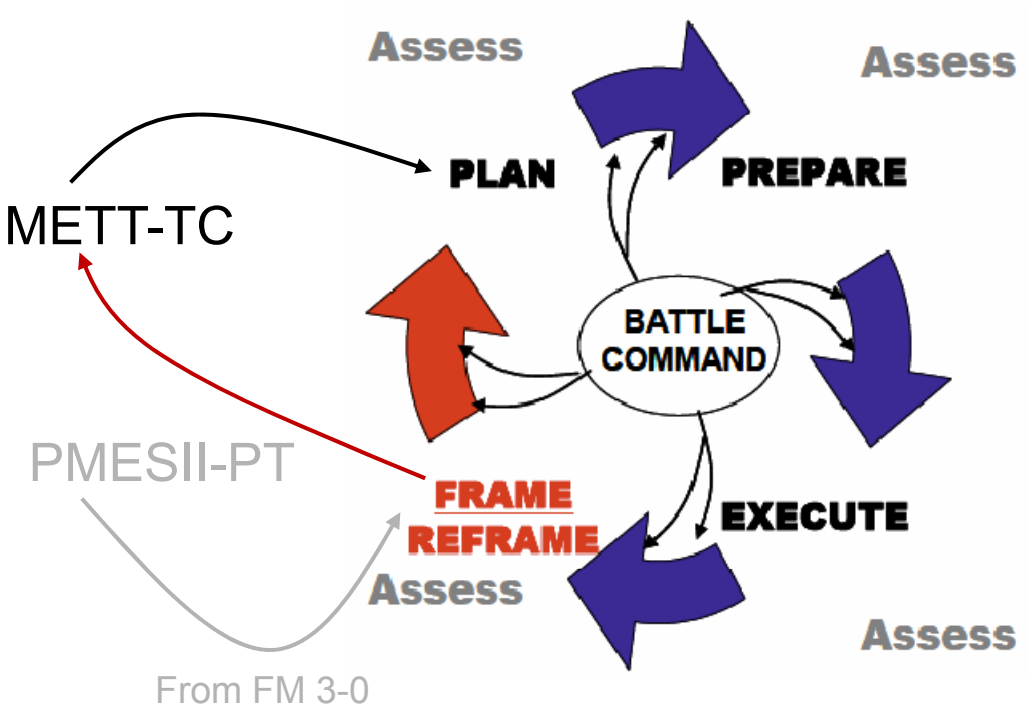
The conditional of the theme question appears to be true, so what should be done?

Iterations = 1000

Army BC Functional Concept (TP 525-3.3 2007) – planning, reframing, execution, data, METT-TC, time, information, interoperability & agility



Army Battle Command – Continuous (Re)Planning
(TP 525-3.3 BC Functional Concept)



From FM 3-0

At the operational and strategic levels, the commander frames the existing conditions by interrelating PMESSII-PT factors (Politics, Military, Economic, Social, Information, Infrastructure, Physical & Time).

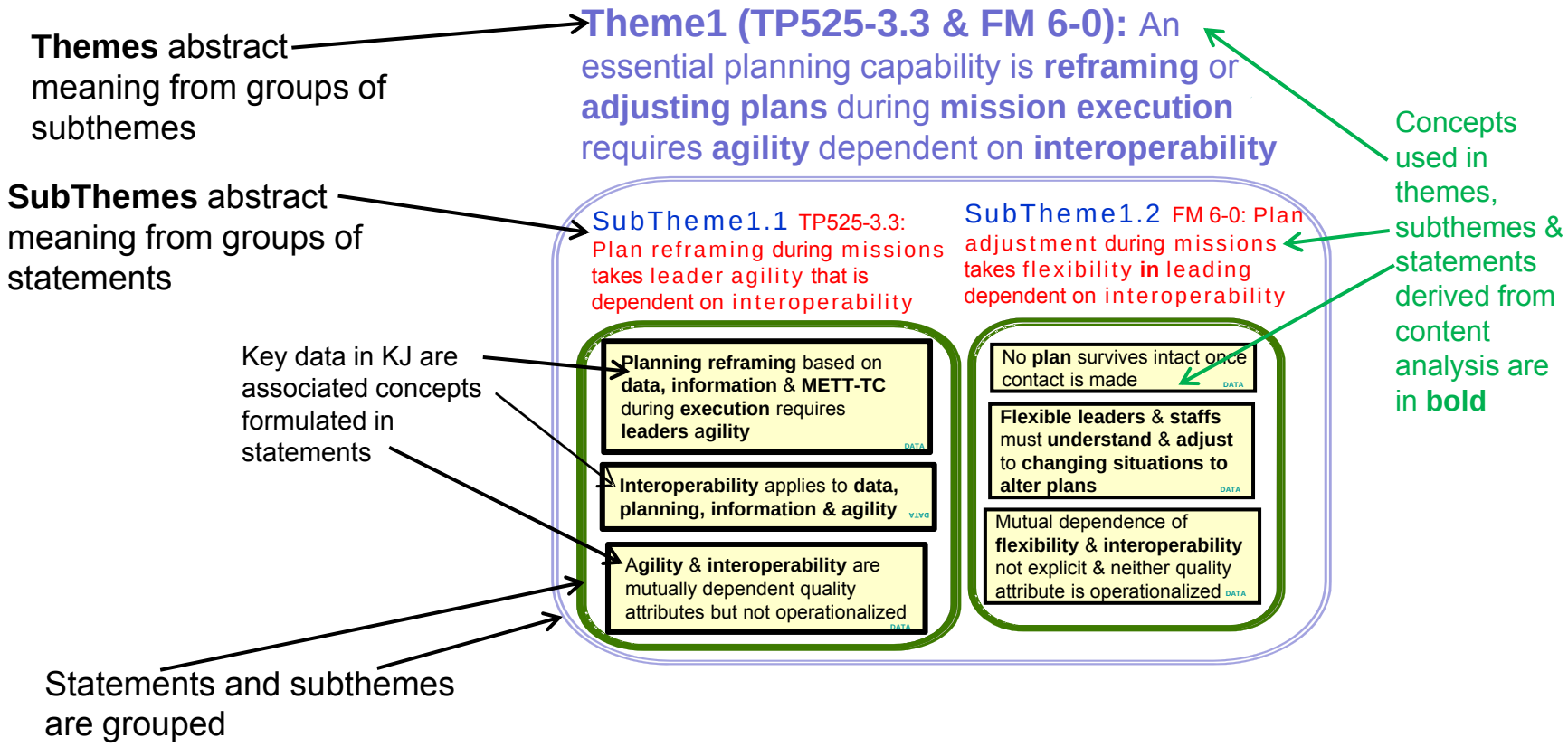
At the tactical level, commanders consider METT-TC factors (Mission, Enemy, Terrain & weather, Troops & support, Time available, Civil considerations) wrt what they are learning from accumulating PMESII-PT information covering both friendly forces & enemy forces.

"No battle plan survives contact with the enemy." **(Moltke in FM 6-0)**

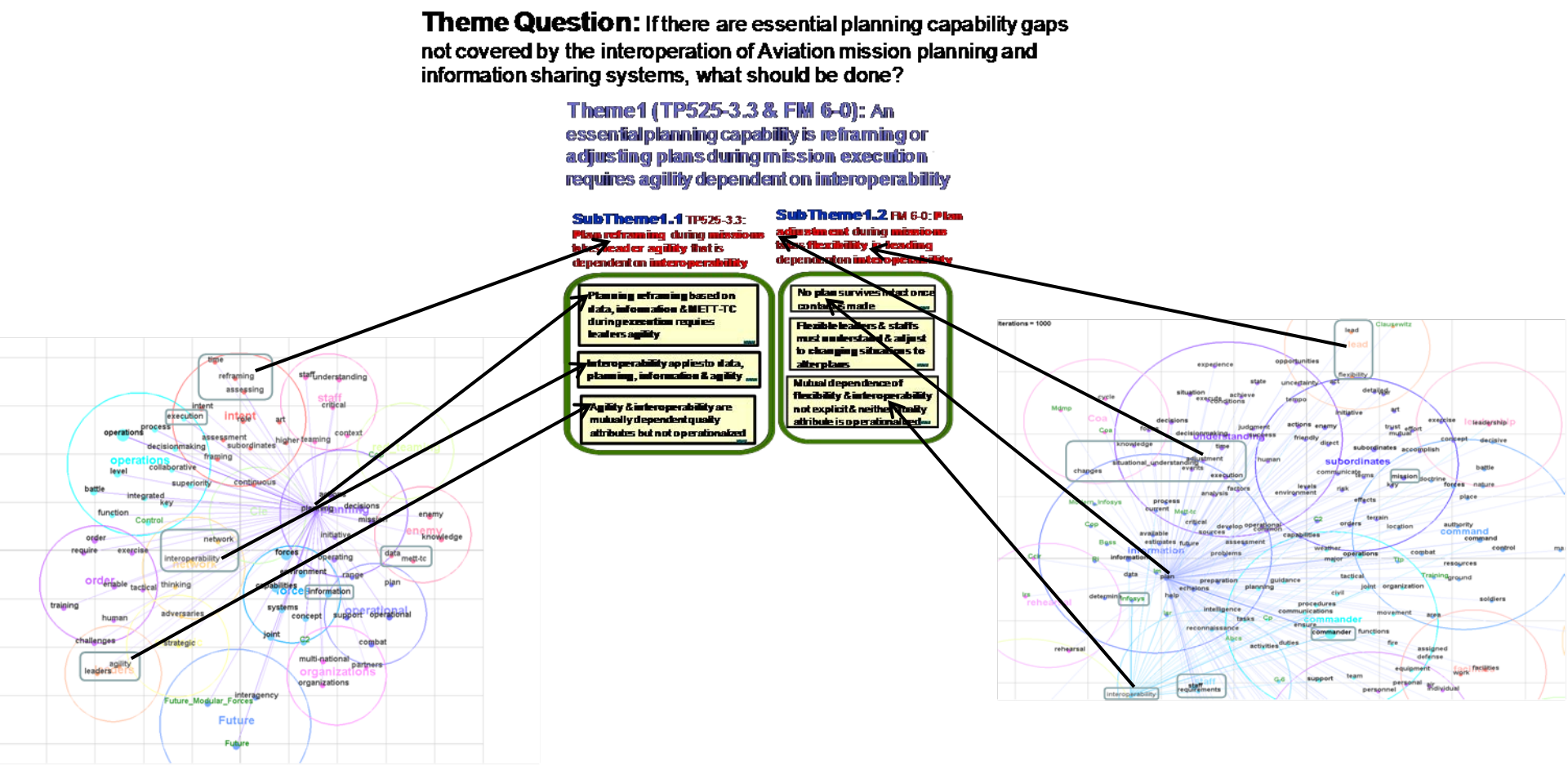
After initial planning, framing is referred to as reframing.

Elements of a KJ Template

Theme Question: If there are essential planning capability gaps not covered by the interoperation of Aviation mission planning and information sharing systems, what should be done?



Concepts Used in KJ Templates Derived from Concept Maps



Misalignment between TP 525-3.3/FM 6-0 & PAM DFD/ISP

Theme Question: ***Given that there are essential planning capability gaps not covered by the interoperation of Aviation mission planning and information sharing systems*, what should be done?**

Theme1 (TP525-3.3 & FM 6-0): An essential planning capability is **reframing** or **adjusting plans** during **mission execution** requires **agility** dependent on **interoperability**

misalignment

Theme2: (DFD & ISP): **Agility & flexibility** are not specified & **interoperability** is not sufficiently specified nor operationalized; **adjusting plans in-flight** not really considered

SubTheme1.1 TP525-3.3: **Plan reframing** during **missions** takes **leader agility** that is dependent on **interoperability**

- **Planning reframing** based on **data, information & METT-TC** during **execution** requires **leaders agility**
- **Interoperability** applies to **data, planning, information & agility**
- **Agility & interoperability** are mutually dependent quality attributes but not operationalized

SubTheme1.2 FM 6-0: **Plan adjustment** during **missions** takes **flexibility in leading** dependent on **interoperability**

- No plan survives intact once contact is made
- **Flexible leaders & staffs** must **understand & adjust** to **changing situations** to **alter plans**
- Mutual dependence of **flexibility & interoperability** not explicit & neither quality attribute is operationalized

SubTheme2.1: The DFD does not explicitly address **plan adjustment** during **execution** nor specify **agility & interoperability**

- The **system** is more geared to **loading Data** before **flight** & using it to **execute a plan**
- **Adjusting plans** takes place before **loading data** into **aircraft systems**
- **Interoperability** is included as an objective but only up to the syntactic level

SubTheme2.2: The ISP requires **interoperability** at a syntactic **level**, but does not define **interoperability** at different **levels**

- **Control of information** is provided by **interoperability** functions that support **transfer of data** in various **formats**
- **Interoperability levels** labeled 0, 1 or 2 are used but not defined, let alone operationalized with measures specified

The conditional of the theme question appears to be true, so what should be done?

Given the Misalignment, What Should be Done?

Theme Question: Given that there are essential planning capability gaps not covered by the interoperation of Aviation mission planning and information sharing systems, *what should be done?*

Theme3: Establish processes for evolution of Aviation planning capabilities & their quality attributes

SubTheme3.1: If providing a capability like adjusting plans in-flight is an objective, planning & analysis is needed across programs responsible for the multiple systems enabling the capability

- Sensor, planning & information sharing systems are mutually responsible for enabling plan adjustment during flight
- There are technical, tactical & human limitations on the extent to which planning & missions can be reframed both pre & during flight
- Multiple systems have to interoperate throughout their evolution

SubTheme3.2: Establish a process for defining, operationalizing & aligning quality attributes like agility & interoperability across combat forces and systems

- Agility & interoperability are quality attributes for both combat forces and systems that need to be operationalized & aligned
- There are semantic & pragmatic levels of interoperability that need to be reached in addition to technical & syntactic levels
- Planning & plan reframing provide context for specifying agility & interoperability measures

A preliminary answer is provided in Statements & SubThemes 3.1 & 3.2 formulated in discussion with a few representatives from PEO Aviation.

Elaboration, confirmation & buy-in has to be achieved with many more stakeholders.

More discussions with more Aviation groups is being planned using a mix of KJ and CA methods both synchronously and asynchronously.

Relationships of all Three Themes

Theme Question: Given that there are essential planning capability gaps not covered by the interoperation of Aviation mission planning and information sharing systems, what should be done?

Theme1 (TP525-3.3 & FM 6-0): An essential planning capability is reframing or adjusting plans during mission execution taking agility dependent on interoperability

misalignment

Theme2: (DFD & ISP): Agility & flexibility are not specified & interoperability is not sufficiently specified nor operationalized; adjusting plans in-flight not really considered

SubTheme1.1 TP525-3.3: **Plan reframing** during **missions** takes **leader agility** that is dependent on **interoperability**

- Planning reframing based on data, information & METT-TC during execution requires leaders agility
- Interoperability applies to data, planning, information & agility
- Agility & interoperability are mutually dependent quality attributes but not operationalized

SubTheme1.2 FM 6-0: **Plan adjustment** during **missions** takes **flexibility** in **leading** dependent on **interoperability**

- No plan survives intact once contact is made
- Flexible leaders & staffs must understand & adjust to changing situations to alter plans
- Mutual dependence of flexibility & interoperability not explicit & neither quality attribute is operationalized

realignment

SubTheme2.1: The DFD does not explicitly address **plan adjustment** during **execution** nor specify **agility & interoperability**

- The system is more geared to loading Data before flight & using it to execute a plan
- Adjusting plans takes place before loading data into aircraft systems
- Interoperability is included as an objective but only up to the syntactic level

SubTheme2.2: The ISP requires **interoperability** at a syntactic **level**, but does not define **interoperability** at different **levels**

- Control of information is provided by interoperability functions that support transfer of data in various formats
- Interoperability levels labeled 0, 1 or 2 are used but not defined, let alone operationalized with measures specified

Theme3: Establish processes for evolution of Aviation planning capabilities & their quality attributes

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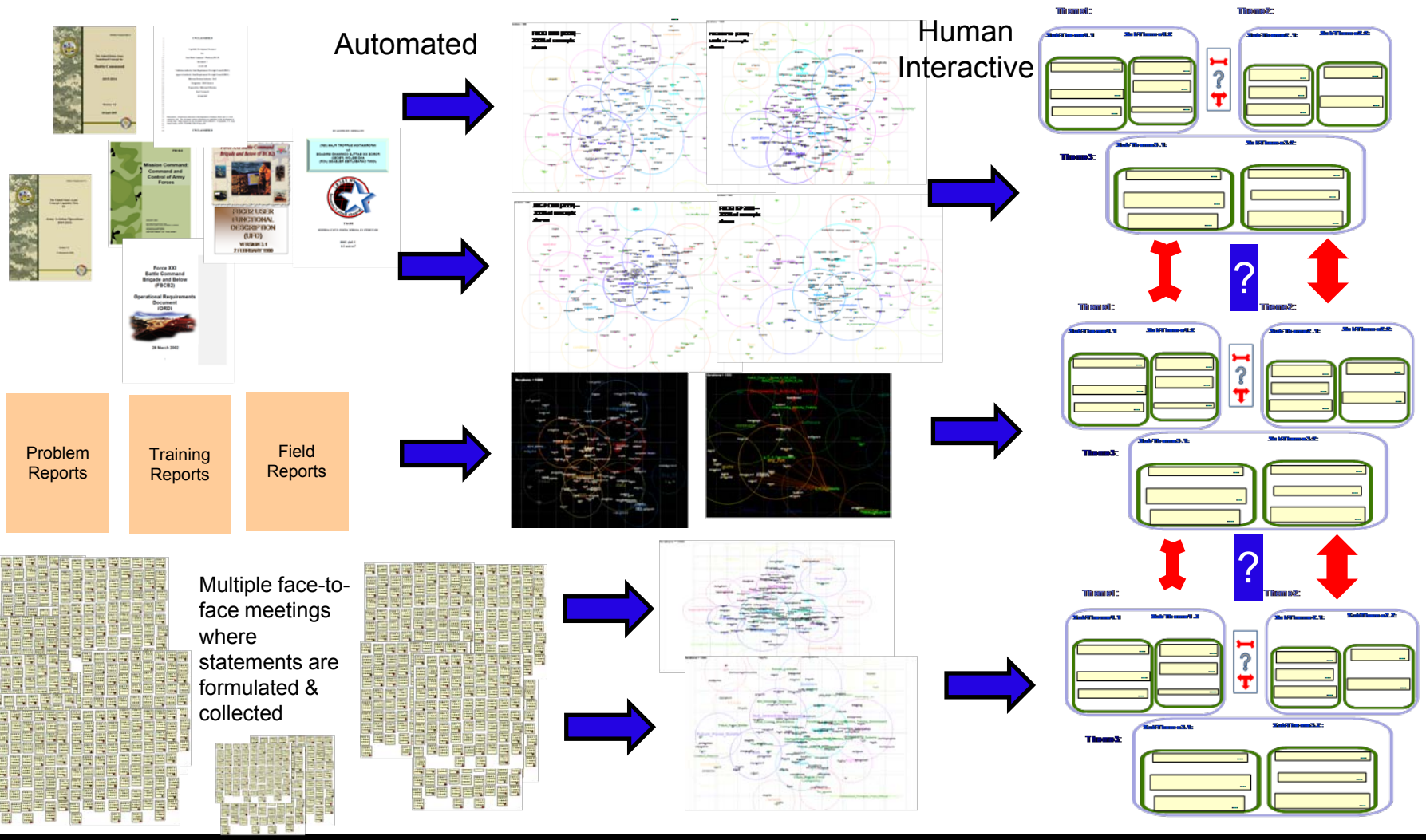
Scaling Up the Process



Concluding Thoughts

What has been shown is the potential for CA to

- uncover misalignments among documents describing capabilities & systems
- identify quality attributes in these documents that need to be better defined & operationalized

These results can be used in KJ analyses in the form of common concepts that can be combined in statements, subthemes & themes in

- multiple face-to-face interview probing
- collaborative interpretation of concept maps derived from different documents leading to determinations of their alignment or misalignment.

So far this combined use of CA & KJ has shown promise when used informally with a few representatives of military organizations.

The next step is to refine the emerging process with greater numbers of people and documents in multiple settings.

Thank you for your attention!

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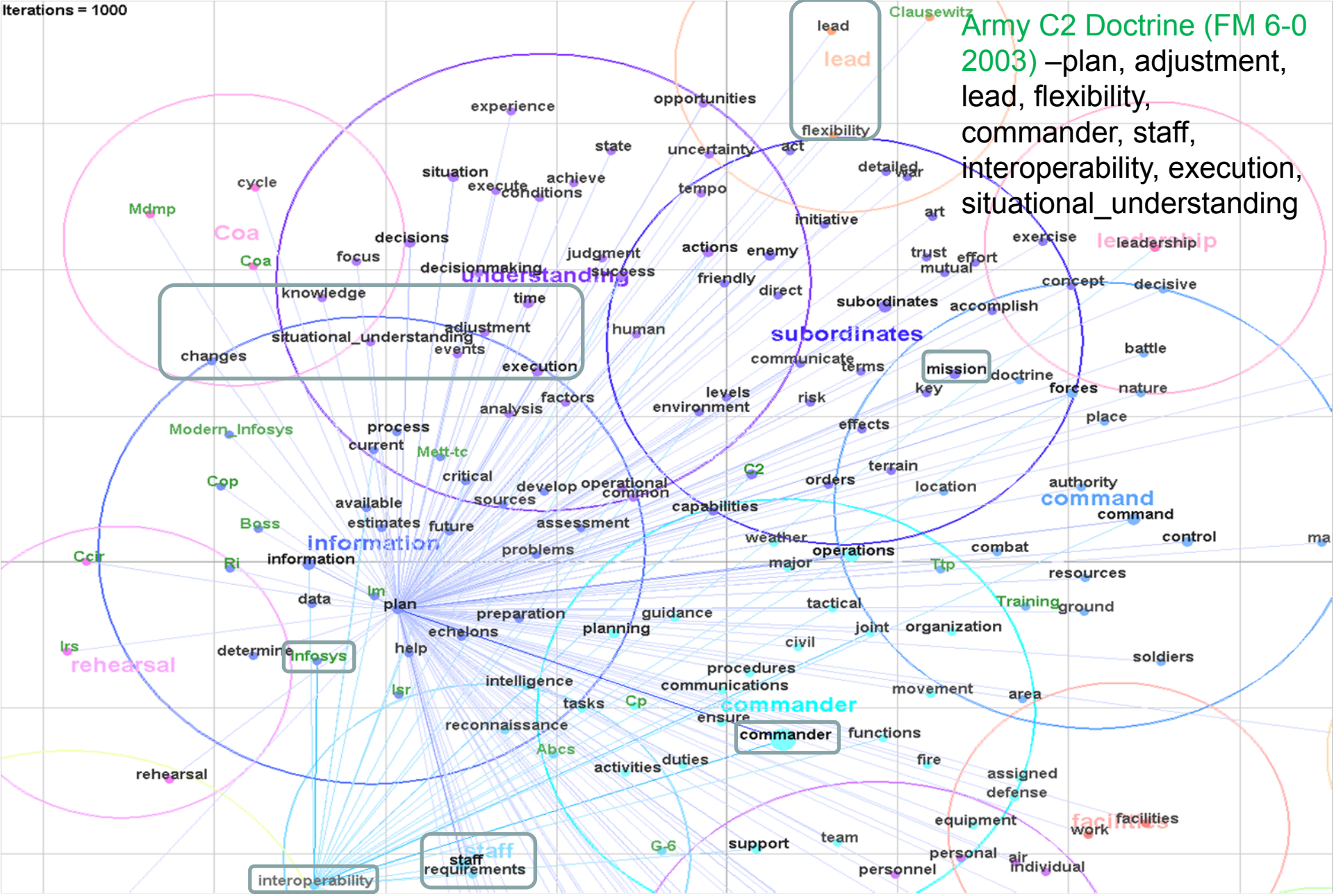
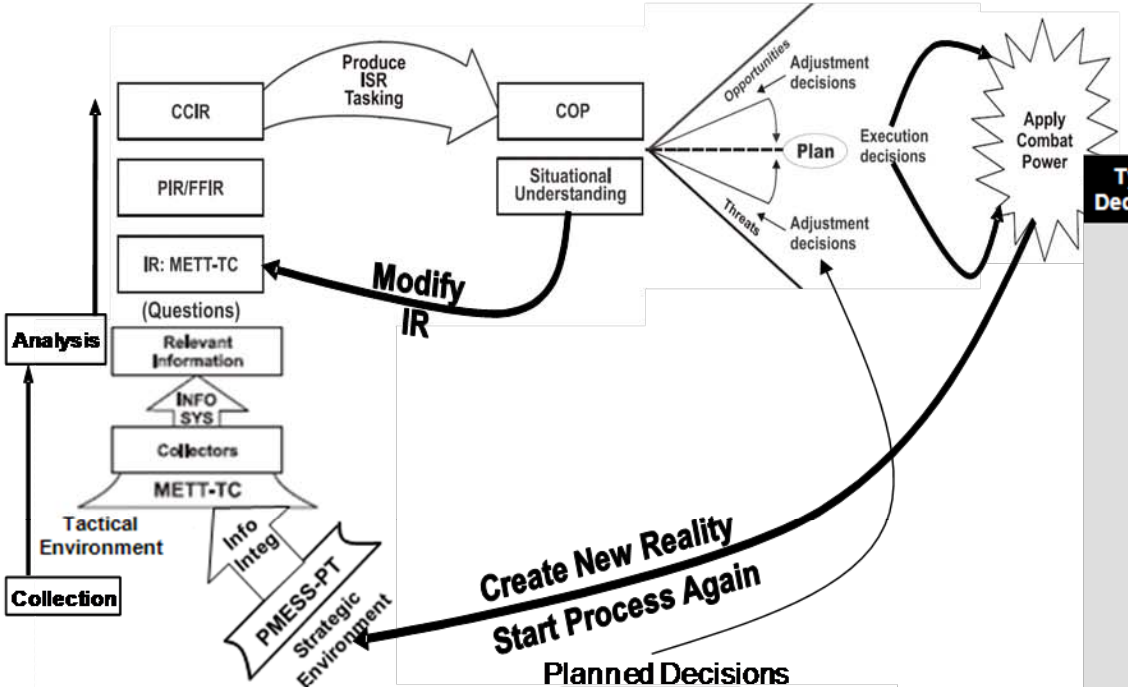
Backup



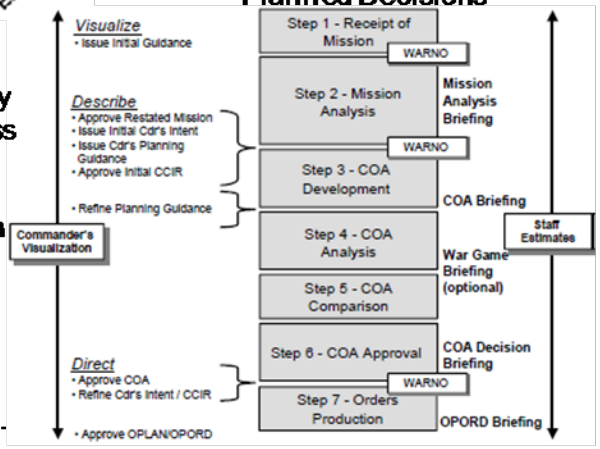
Army Command & Control Doctrine (FM 6-0)



Type Decision	Situation	Action
Execution	**Minor Variances from the Plan** Operation proceding according to plan. Variances are within acceptable limits.	**Execute Planned Actions** • Commander or designee decides which planned actions best meet situation and directs their execution. • Staff completes follow-up actions. • Decision may be permissive. • FRAGO not normally issued.
	Anticipated Situation Operation encountering variances within the limits for one or more sequels.	**Execute a Branch or Sequel** • Commander or staff review branch/sequel plan. • Commander receives assessments and recommendations for modifi-cations to the plan, determines the time available to refine it, and either issues guidance for further actions or directs execution of a branch/sequel. • Staff issues FRAGO. • Staff completes follow-up actions.
Adjustment	**Unanticipated Situation—Friendly Success** Significant unanticipated positive variances result in opportunities to achieve the end state in ways that differ significantly from the plan.	**Make an Adjustment Decision** • Commander recognizes threat/ opportunity and determines time available for decisionmaking. • Commander selects a decisionmaking method. If there is not enough time for a complete MDMP, the commander directs the staff to refine a single COA or directs actions by subordinates to counter the threat/exploit opportunity and exercise initiative within the higher commander's intent. • Commander normally does not attempt to restore the plan. • Commander issues a verbal WARNO or FRAGO to subordinate commanders. • Staff resynchronizes operation, modifies the criteria of success, and begins assessing operations for progress using the new criteria of success.
	Unanticipated Situation—Enemy Threat Significant, unanticipated negative variances impede mission accomplishment.	

Application of the Military Decision Making Process (MDMP) prior to execution projects synchronized application of combat power.

During execution variances due to unanticipated situations disrupts synchronization.



MDMP

Interpreting Analysis of TP 525-3.3 & FM 6-0:
Quality attributes need to be specified & operationalized

Plan reframing during **mission** execution is a form of **leader *agility*** (inference from Battle Command graphic TP 525-3.3 and **leaders** cluster in concept map)

— ***Agility**, as it applies to joint C2, has six key elements: robustness, resilience, adaptability, responsiveness, flexibility, and innovation* (TP 525-3.3)

Plan adjustment during mission execution is a form of **leader flexibility** (inference from and lead cluster)

— *No **plan** survives intact once contact is made. Tactical **flexibility** requires **flexible leaders** capable of adapting to rapidly changing circumstances; and **staffs** able to recognize significant **changes** in the **situation**, and resynchronize the operation by coordinating the **changes** to alter the **plan*** (FM 6-0).

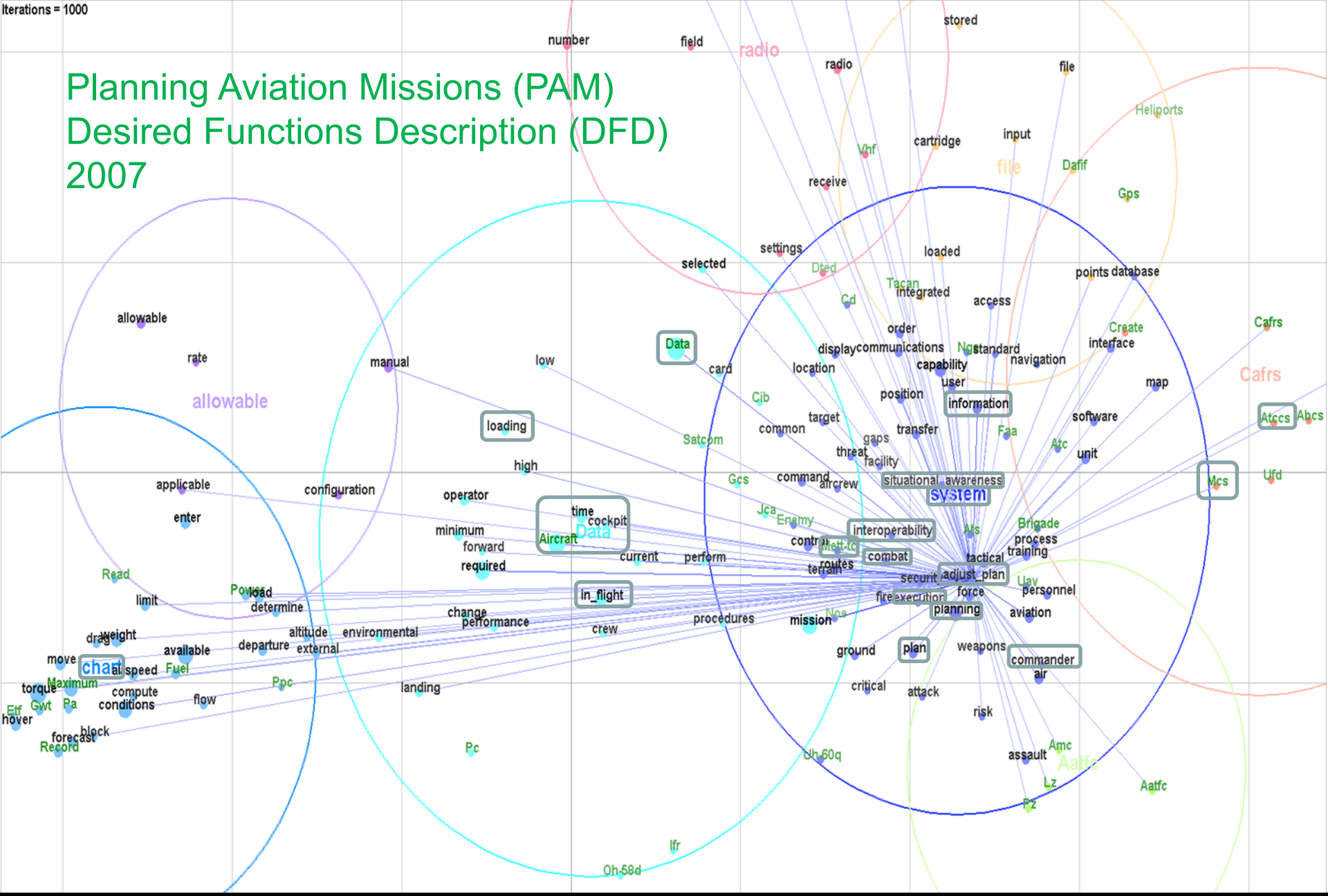
Agility & flexibility depend on (semantic & pragmatic) **interoperability**

— *in order to share needed information when it is needed & in a form it can be understood and acted on with confidence* (TP 525-3.3).

Agility, **flexibility** & **interoperability** are battle command quality attributes

- need to be operationalized with numeric thresholds and objectives specified
- Planning & plan reframing provide context for specifying these measures.

Planning Aviation Missions (PAM) Desired Functions Description (DFD) 2007



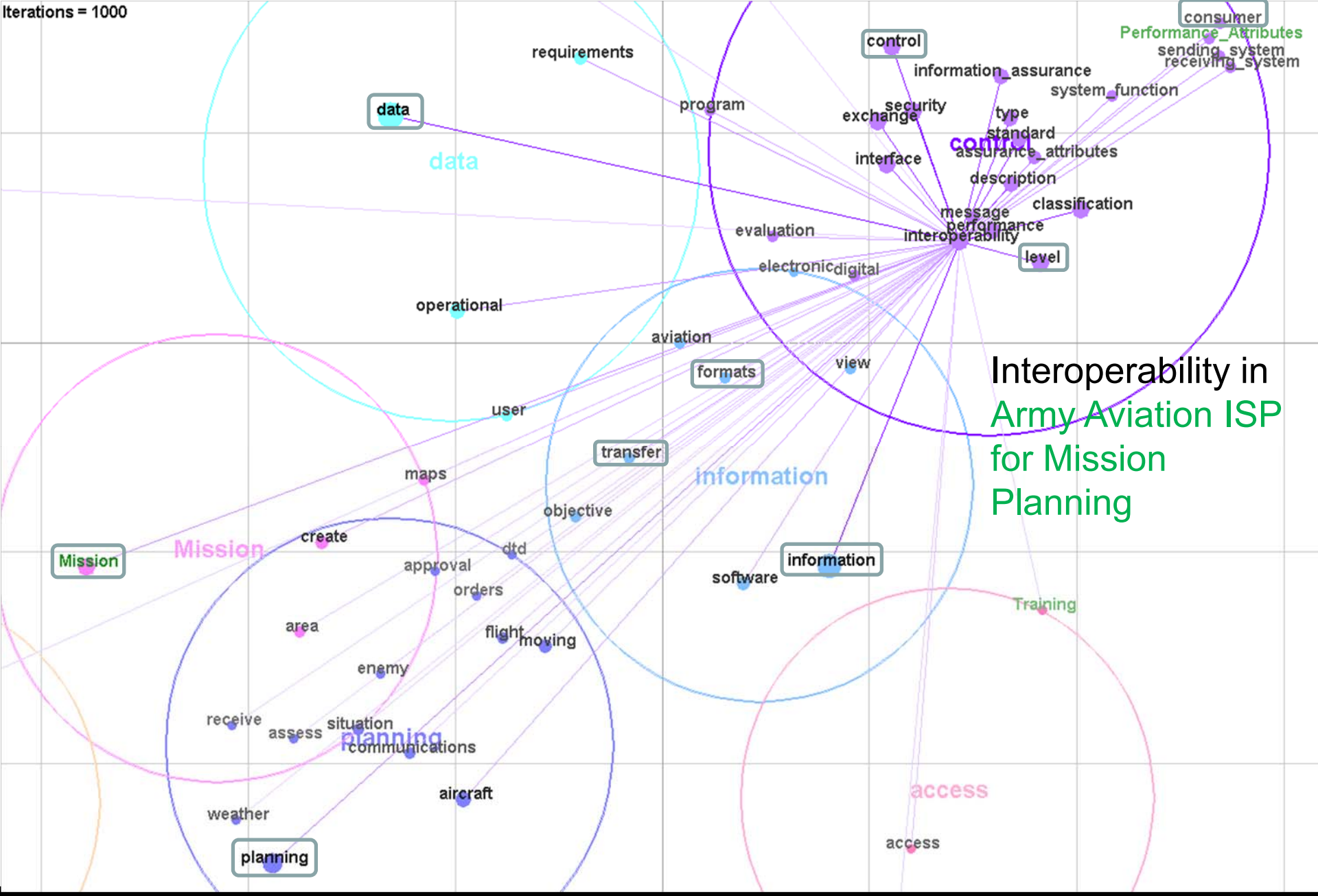
Interpreting the Significance of Adjust_Plan in the PAM DFD

Statements in the document do not explicitly commit to **plan adjustments** in-flight.

While the document says

- *"The … interface to the Maneuver Control System (MCS) … provides the aviation commander with continuous updates of the friendly and enemy situation and allows the commander to rapidly **adjust his plan** to accomplish his assigned mission."*
- it also says, *"The assigned missions, orders and map data are then transferred down to the air crew level where specific air crew mission planning takes place. This mission information is then loaded into the aircraft systems via hardware or digital radio transfer for use during mission execution."*
- In fact, in conversation with aviation mission planning acquisition people, they asserted their system only served pre-flight planning.

High level **interoperability** requirements are stated, but not clearly defined or operationalized with measures specified.



Interoperability in Army Aviation ISP for Mission Planning

Interpreting the Significance of Interoperability in the PAM ISP

According to the ISP, most of the **interoperability** functions support **data transfer** in various **formats** enabling the **planning** system to be

- the collector & consolidator of all pertinent battlefield **information** needed for effective aviation **missions** thereby serving as an information **consumer**
- capable of in-flight re-targeting and re-planning (though this is only stated once as an objective)

However, supporting data transfer in various formats is syntactic **interoperability** – not semantic or pragmatic **interoperability** needed for in-flight re-targeting & re-planning.

Interoperability levels labeled 0, 1 or 2 are used but not defined, let alone operationalized with measures specified.