OODAWN in the MER: from distributed Situation Awareness to Decisions and Actions in operational C2 using weighted network theory

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Abstract

We present a weighted network model for representing the distributed nature of activities across the spectrum of the Boyd OODA loop in the deployed operational environment. The model, denoted the OODA-Weighted-Networks (OODAWN), is a generalisation of the SAWN model presented previously at ICCRTS by some of the authors. Essentially, the approach develops a 'social network' – where some people-people interactions may be mediated by information technology artefacts – with links weighted according to the function played by the information conveyed in the interaction using an eight scale OODA model. After detailing the data collection approach, we apply to the model data from headquarters across the Australian Defence Force Middle-East-Region (MER) of operations. Over and above showing network diagrams, we apply quantitative social network analysis to complement the visual insights the method provides.

Introduction

Command and control (C2) of a joint task force in the modern era is necessarily complex with a balance between appropriate and important command chains, such as national and theatre command, and between joint and service based management, such as for air operations. This is particularly pertinent for the Australian Defence Force (ADF) in the Middle East Region (MER).

The research we report here began as a task to support the Commander of the ADF's task force in the MER in analysing the C2 arrangements in and out of theatre. This led to examination of information exchange within and between the various deployed and Australian based headquarters, and coalition nodes. The study was undertaken soon after the commencement of Australia's contribution to the international effort to address the Daesh terrorist threat in the Middle-East [1]. The research sought to characterise information flow through the C2 structure and to analyse how it supported effective decision-making.

This paper both documents the scientific model and empirical method developed in the study and builds on it by extending the quantitative analysis it enables. We therefore validate the model by demonstrating how well-known properties of the C2 system may be both visually and quantitatively detected in the analysis.

In the paper we first describe the theoretical model and the data collection. We then display results as a set of weighted networks. We elaborate on the insights these offer into the C2 arrangements and compare with doctrine. Whereas many of these aspects have been presented elsewhere [2], the present paper goes further by applying standard Social Network Analysis (SNA) metrics to further quantify these insights. We conclude with comments on the wider integration of this method into ongoing operations.

Theoretical Foundation: C2, SA and OODA

Definitions of C2 are numerous and subtly varied though most doctrinal formulations are similar. NATO for example [3] puts it as "the exercise of authority and direction by a properly designated individual over assigned resources in the accomplishment of a common goal" while ADF doctrine extends this beyond an individual: "C2 is the system empowering designated personnel to exercise lawful authority and direction over assigned forces for the accomplishment of missions and tasks" [4]. This points to a fundamentally distributed nature of C2. Pigeau and McCann, providing a scientific formulation, separately define Command (creative exercise of will) and Control (structures and processes), and then give C2 as "establishment of common intent to achieve coordinated action" [5,6]. Thus intent should be common across all in the system, and *action* is the object of this. This connects then to the other well-known model for C2, that of John Boyd's Observe-Orient-Decide-Act (OODA) loop [7], [8] with extensions to entire organisations [9]. Boyd's C2 model integrates Actions into the *cognitive* processes (namely *orientation and decision*) of the individual.

The unit of analysis may be taken even further, beyond commanders and staffs, to the information aids and artefacts they use and produce. Hutchins' Distributed Cognition extends cognition from what goes on "in the head" of an operator to a "computational ecology" of devices. Hutchins' classic study in which this is explored is in the work of a team in a ship's Combat Information Centre (CIC) undertaking the task of navigation into port [10]. Smith and Hancock [11] relate this to another term applied to military operators: *Situation Awareness (SA)* is "adaptive, externally-directed consciousness" involving individuals engaged in their environment, undertaking "directed action". We also cite another model from cognitive psychology, Neisser's Perception-Action cycle [12] which is reminiscent of Boyd's OODA loop. Most of these models are quite conceptual and qualitative. However, Stanton et al [13] have elevated them to a comprehensive empirical approach in *Distributed SA (DSA)* with emphasis on the system level. DSA involves data collection to deliver three types of network representations: the social network of communications between human individuals; the propositional network of relationships between information objects and functions; and finally the task network of activities that operators undertake within the system. These make SNA quantitative analysis accessible, a property we exploit in this paper.

In our previous work we united Endsley's "three level" (Perception, Comprehension and Projection) model of SA [14] with the Stanton distributed approach to give the Situation Awareness Weighted Network (SAWN) model [15, 16] and associated empirical method. As with DSA, SAWN collects and arranges data related to networks of interactions – though here social and information objects are combined into a single 'socio-technical' network. But using the Endsley model, we weighted (or coloured) the links of the network with refinements of the three SA levels.

In this paper, we now expand SAWN to cover the entire OODA loop. Namely we collect data to populate a network model – of *who talks to whom* – but also provide for *how* (type of nature, type of information or social artefact), how often (frequency), and weight the links of the network with, what we term, the information *function*: Perception, Comprehension, Projection, Decision, and Action. This improved model has been termed the OODA Weighted Network or OODAWN model. In this respect, we also unify the Boyd and Endsley models in that both recognise that the cognitive sub-processes (be they labelled Observe-Orient, or Perceive- Comprehend-Project) are directed to the making of a decision and then action in the external world. A subtlety in this mapping of one model to another is the issue that Grant and Kooter [17] argue that 'Orient' in Boyd's OODA loop does not include planning whereas Endsley's model does. However, we would argue that the projection into future states is simply not as elaborated with Boyd's level of fidelity.

Data Collection

Using Excel and a SharePoint site, data was collected online from deployed ADF units and cells across the Middle East Region to categorise who they communicate with (in both directions), the form of the communication and the information function as defined above. These information flows involve what we have labelled HQ1, the focus of the study, and its interactions with a higher headquarters 'Higher HQ', a subordinate, HQ2, and numerous other single service entities. Preparation of the data collection instrument sought to ensure consistent labelling of senders and recipients, with drop-down lists to minimise effort on part of the respondents. As well as geographical location, senders and recipients were identified by a "Group" (the particular JTF), "Unit" (the HQ, for example) and "Position" (such as a J-number). Due to operational priorities, not all of the deployed units provided data for this survey. However, complete coverage of a core selection of units was achieved: of 351 nodes, we received 141, namely a 40% response rate. It is around this group that we base this analysis. The network of respondents consists of:

i. Core deployed units, where responses were received from each relevant position.

ii. Other deployed units, where coverage is partial.

iii. Coalition units, which were not surveyed, but data about information flow to and from these units from an ADF unit is captured.

iv. Australian Strategic groups, namely groups, HQs and Services in Australia, which were also not surveyed but for which data about information flow to and from these units is represented from a unit in the first two categories.

Each information transmission was characterised (by the respondent) against five categories: information function, information type, frequency, means and network, shown in Tables *1* and *2*.

Because the data was captured over the course of several weeks, many issues were occurring across the many units in theatre. Therefore the information flows captured do not represent processes in train for any specific issue. In that respect, there are many OODA loops in train in the data set, some directly interacting and others more indirectly.

Table 1 Characteristics of Information Exchange

Information Type	This is the nature of the communication. Person to person (written incl email, letter, chat); Meeting (incl VTC, telecon); SIGNAL, SITREP, Incident Report; Standing instructions; Minute; Decision Brief; Noting Brief; CONOPS; Agenda, program or schedule; RFI; RFI response; Data or statistics; Register; Report; Powerpoint slides; Form; Contract or SOW; Business case; Other
Frequency	Hourly; Daily; Three times a week; Twice weekly; Weekly; Fortnightly; Monthly; Quarterly; Less than quarterly; Other
Means	Email; Sharepoint; Network drives; In person; chat; Video link; Audio link; Records management system; Other
Network	17 networks listed, covering different classifications and including coalition networks.

Table 2 Information functions using the OODA Weighted Network Model.

Information function	**Description**	**Examples**
Perception	Report of facts: What is there? When was it there? What is/was it doing? Reporting of individuals, groups, platforms or environmental events of significance.	Contact and detection reporting, log stats, pers stats, incident reports
Comprehension	Provides analysis of detected individuals, groups, platform or environmental events, describing their current or recent activity. Comprehension is associated with understanding why these events and assets are where they are, and how they affect the surrounding region. Analysis of context, history of behaviours.	Providing analysis e.g. Situation Report (SITREP) Adding context to an incident report

Projection	Analysis of activities of individuals, groups, platform or environmental events comparing their current or recent activity with a history or pattern in order to anticipate future developments or providing a schedule of future activities of Blue Force elements. This is the highest level of SA and draws together perception and comprehension, by making predictions on the future of the aforementioned events and assets. Deductions about future behaviours or statement of known future activities based on a schedule or program.	Prediction, threat assessment, activity schedule, Course of Action analysis briefs, etc.
Decision	Brief providing recommended Courses of Action and/or seeking endorsement of an articulated decision from an approving authority, or issuing an endorsed decision	Decision briefs
Action	Orders requiring actions or tasks to be undertaken by assigned force elements. Drafting or issuing instructions to be undertaken by assigned units	Task Orders (TASKORDs), Fragmentary Order (FRAGO)

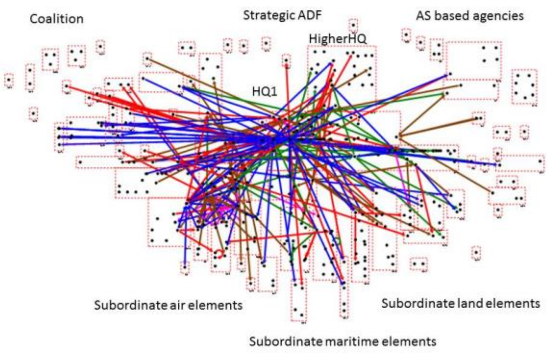
Characteristics of the data

Collected together, the entire dataset represents a network of 351 nodes and 1237 links, which would generate an impenetrable diagram if shown as a whole. For this reason we provide quite focused lenses on the network. By frequency, these break down into two primary groups: 323 occur daily or faster and 586 occur within the weekly timeframe (once, twice or three times per week) so that 70% of the data is in the weekly or faster frequency. This already matches with what one might anticipate for C2 in the deployed environment: fast time-frames where information directly sensed from the environment plays a strong role and where decision-making needs to be a step ahead of the adversary so that anticipation is paramount.

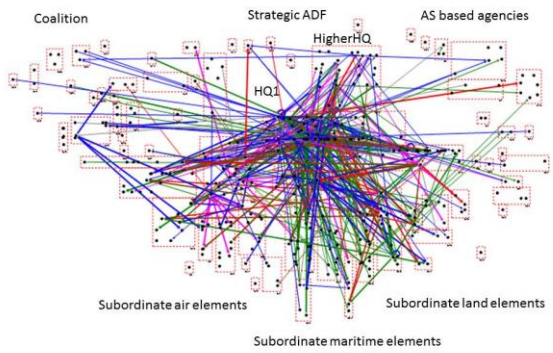
A further descriptive characterisation of the data involves separating the nature of information flow into ‘formal’ and ‘informal’. Given the ‘means’ field in the data we may group Audio, Chat, In Person, and Verbal into ‘informal’ and take the rest as ‘formal’ (documents registered in the records management system, for example. Unclear from the data is in which category ‘video conferencing’ should be placed. However, classifying video as informal gives 43% in that category; placing video conferencing with formal gives 27% of interactions as informal. Alternatively, examining the Information Type classification and extracting the proportion of person-to-person communications gives a putative figure of 23% that may be considered informal; including meetings gives 39%. We may thus say that approximately 30-40% of information flows are informal in nature; the importance of informal means of organisation is well recognised in the literature [18].

Network diagrams

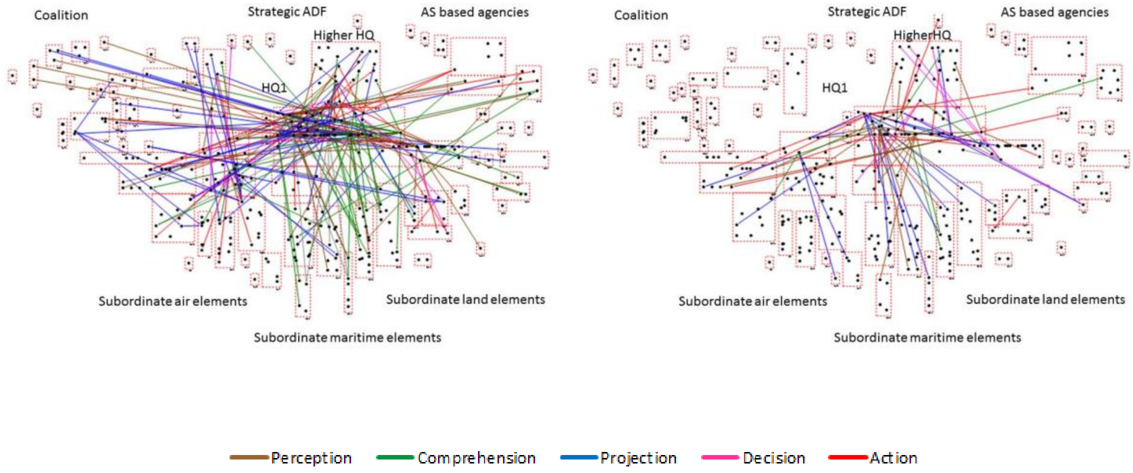
We generate networks using NetMiner™ where nodes represent the transmitter (“from”) and recipient (“to”) of a communication, regardless of the method (document, face-to-face, email, chat). Links are coloured by information function according to the following colour scheme: Brown=Perception, Green=Comprehension, Blue=Projection, Purple=Decision, and Red=Action. A number of networks are displayed in Figure 1, where we have separated according to frequency: daily (or faster), weekly (or faster, but slower than daily), monthly (or faster, but slower than weekly) and slower than monthly. Certainly, finer details are difficult to pick out here but our purpose at this stage is to provide an overall sense of the structure and density of the networks. The overwhelming observation to be made is that information is flowing across the entire system, not within units. We observe in panel (a) that the fastest –daily - cycles are dominated by ‘Projection’ and ‘Action’ as visible in the larger number of blue and red links. On the other hand, the weekly cycle in panel (b) is dominated by Comprehension and Projection, with green links quite evident. We see moreover that in panel (a), Perception, though not dominant, is more strongly linking between coalition (to the left) and tactical (lower) units with brown links more visible. Comprehension strongly figures between the headquarters and Australian-based agencies (links between centre and to the right) for daily in panel (a) weekly in panel (b). This pattern is even more visible in the less dense network for Monthly (c), with Comprehension exclusively the domain of interchanges between the headquarters and domestic agencies but Projection across the entire space with coalition elements playing a significant role. Collectively, visual inspection of these networks suggest a fast tempo of decision implementation in theatre-based groups, but a slower information gathering and understanding from theatre back to home-agencies.



(a) Daily or faster



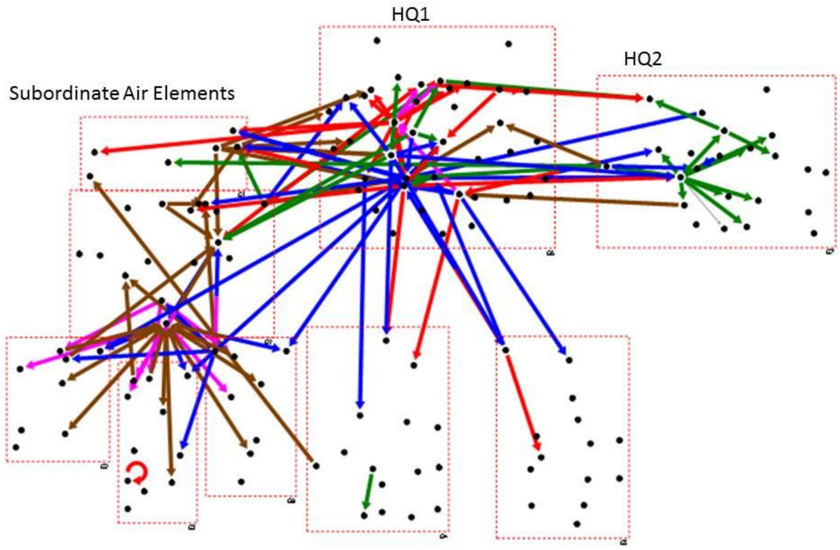
(b) Within weekly epoch



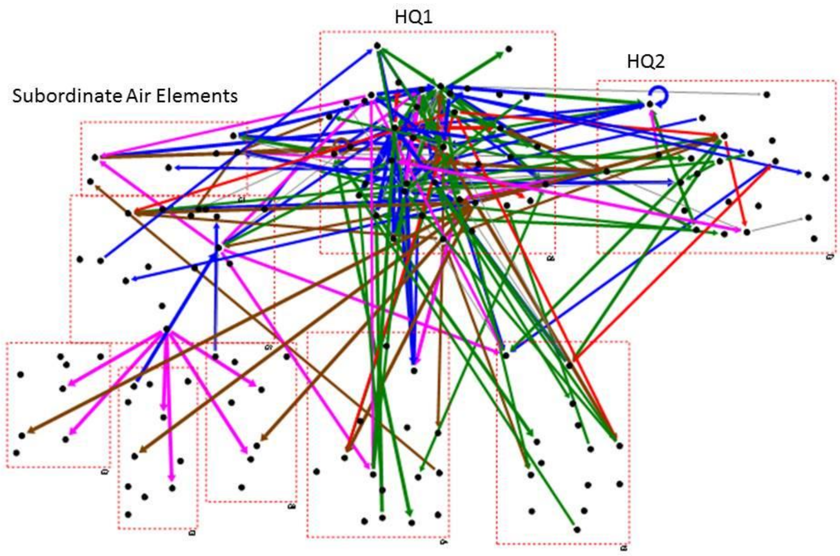
(c) Within monthly epoch (d) Slower than monthly

Figure 1 Network diagrams for entire node set broken down according to frequency.

We now show in *Figure 2* a partition of the data only showing those nodes which directly provided data in the collection; this then provides a complete coverage of inputs and outputs. The box in the top centre represents the key headquarters in theatre `HQ1', with a subordinate level, HQ2, on the right and subordinate tactical elements to the left and below. These largely consist of units managing air platforms in theatre (we give these names below). We only show the daily and weekly interactions here. We see again a dominance of flow between units rather than within units. Panel (a) shows more clearly the aforementioned localisation of information functions in different parts of the network: Perception occurs in the air-management units (brown to the left); Projection links HQ1 across all units (blue from centre out in all directions); and Comprehension largely occurs between the subordinate headquarters (green across the top). Panel (b), focused on weekly interactions, is quite different. Now Decisions are propagating through the air units and from HQ1 to immediate subordinate units (purple links across all parts of the network); and Comprehension is occurring between HQ1 and its subordinate units (green centre to the lower parts of the network). Projection, though fewer in number of links than Comprehension, occurs largely at the HQ1 level. We therefore see different stages of the OODA loop at different tempos and between different parts of the C2 system: air elements largely on a daily cycle focused around Perception and Decisions; the rest of the system at the weekly tempo focused around Comprehension and Projection.



(a) Daily



(b) Weekly

Perception Comprehension Projection Decision Action

Figure 2 Subset of nodes representing directly sampled individuals or units, separated into daily and weekly links.

We now consider the network reflecting C2 for air operations in *Figure 3*. Many of the above observations are repeated: Perception is largely confined to the lowest level subordinate air elements, Projection within HQ1 and across to its immediate subordinates, and Comprehension largely directed across the top and upwards. However, we also observe a Perception link (brown link from bottom to top on the left hand side of the network) on the daily tempo between a subordinate air element up to a node in the box placed in the top left part of the diagram. This box represents the Air Operations Centre (AOC) through which a one-star in their operational role manages air operations on behalf of the national three-star joint commander [19]. The detection of this link is consistent with a doctrinal principle common in most air-forces, of "centralised control, decentralised execution" [19].

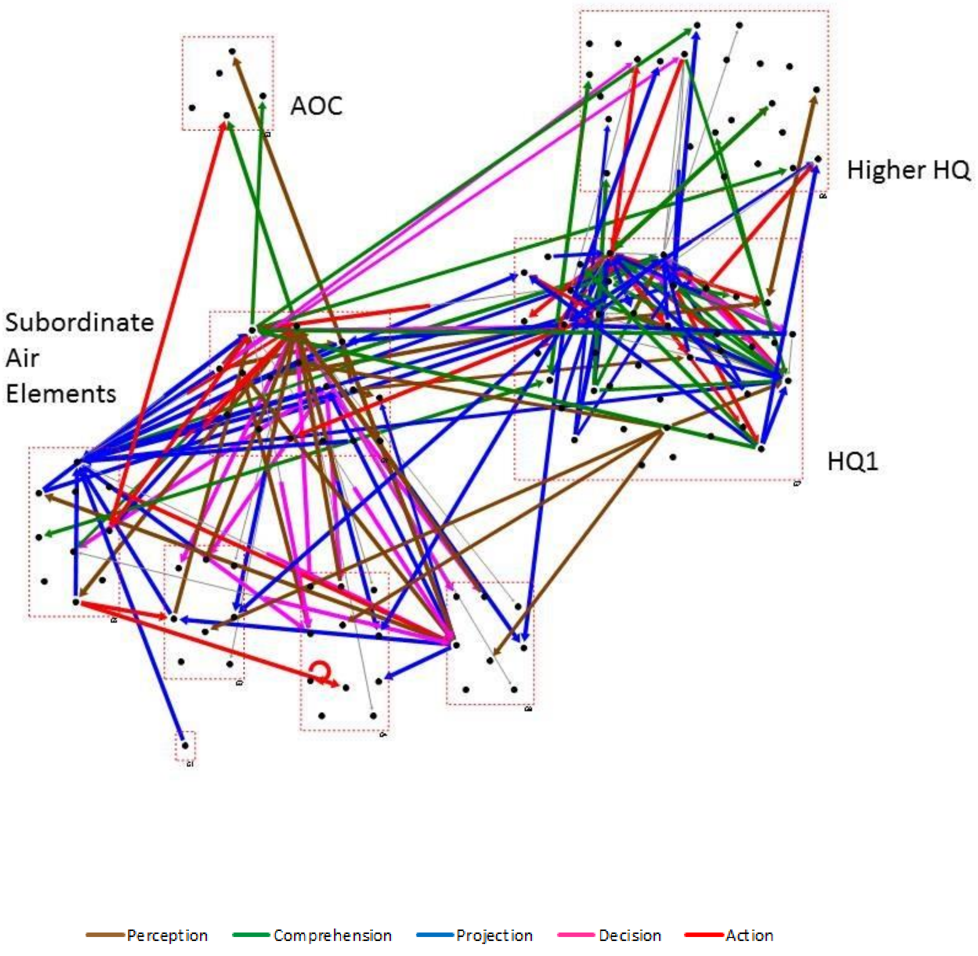


Figure 3 Subset of nodes focused on command and subordinate air elements and the two main headquarters – only daily and weekly information exchanges are shown

Finally, in our examination of the visual representations, we focus in *Figure 4* on information flow between a significant joint function in operations, namely intelligence units. The inset figures display this for three time-scales: daily, weekly and monthly. There is a dominance of Projection (blue links) across these nodes. Arguably, the intelligence function is the military discipline that provides the highest levels (in the generic sense) of situational awareness to a commander's decision-making [20]. The daily tempo (top left inset) indeed covers all three Endsley SA levels – with a tactical level intelligence staff providing raw Perception (brown) to the J2 of HQ1, Comprehension building through interactions with other nodes (green), and then Projection promulgated to subordinate units (multiple blue links from centre out). We see then a visual network representation of the deployed Intelligence Preparation of the Battlespace (IPB) process (see, for example, Joint Publication 5-0 [20] (2011) and Field Manual 34-130 [21] for analogous US elaboration of these activities).

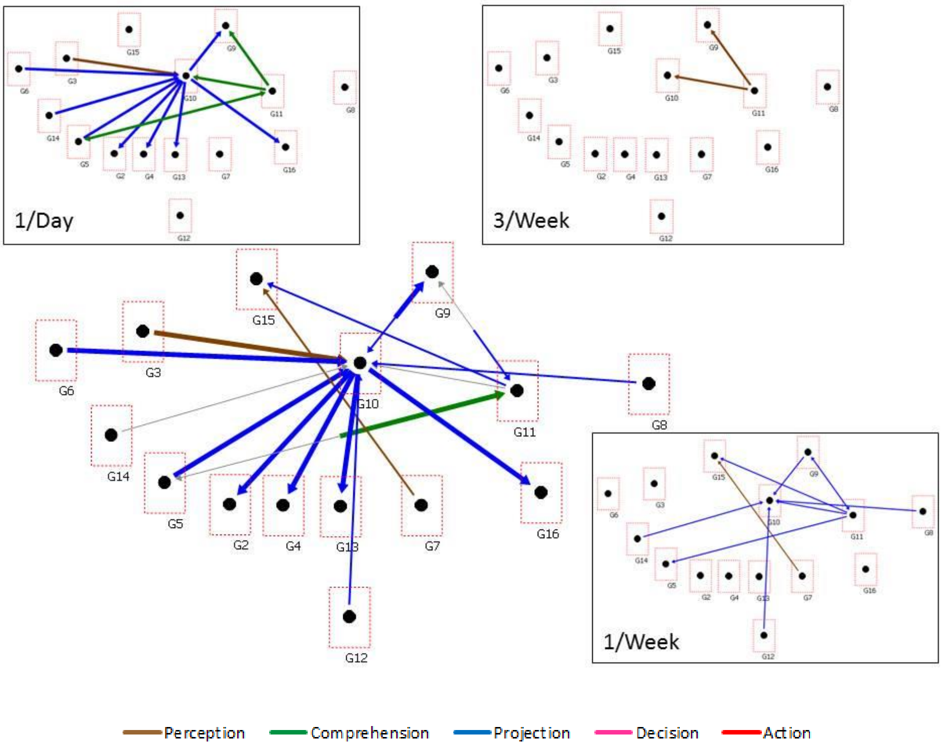


Figure 4 Nodes representing intelligence officers across the entire network with the main diagram combining daily, 3 times per week and weekly and the individual sets inset

Quantitative Social Network Analysis

Numerous metrics are available from Social Network Analysis (SNA). We focus on a select few: degree centrality, measured by in- and out-degrees of the nodes, betweenness centrality [22], and the number of loops in the network. For all these analysis we focus on the nodes constituting the network in *Figure 2*. Here we may be a little more explicit about some of the nodes, identifying Commanders and Deputy-Commanders of the various headquarters (for example C-HQ1, DC-HQ1), two subordinate officers to the commander, DOPS and DSUST (for 'sustainment') who oversee operations and personnel-logistics-information systems aspects respectively, the various J-numbers for the functional areas, chiefs-of-staff (COS), corresponding numbers for air-staff (for example A3), and finally a node 'All-HQ' when an information artefact is broadcast to an entire headquarters.

Firstly, the in/out-degrees of a node are the simply a total count of the number of links into/out-of a particular node. The normalised measures of degree centrality then, for each node *n*, are defined through the unweighted-directed adjacency matrices *A* of ones and zeroes that record the absence, respectively presence, of a link:

$$C_{out}(n) = \frac{1}{N-1}\sum_{j=1}^{N-1} A_{n,j}^{(out)} \ , \ C_{in}(n) = \frac{1}{N-1}\sum_{j=1}^{N-1} A_{n,j}^{(in)}$$

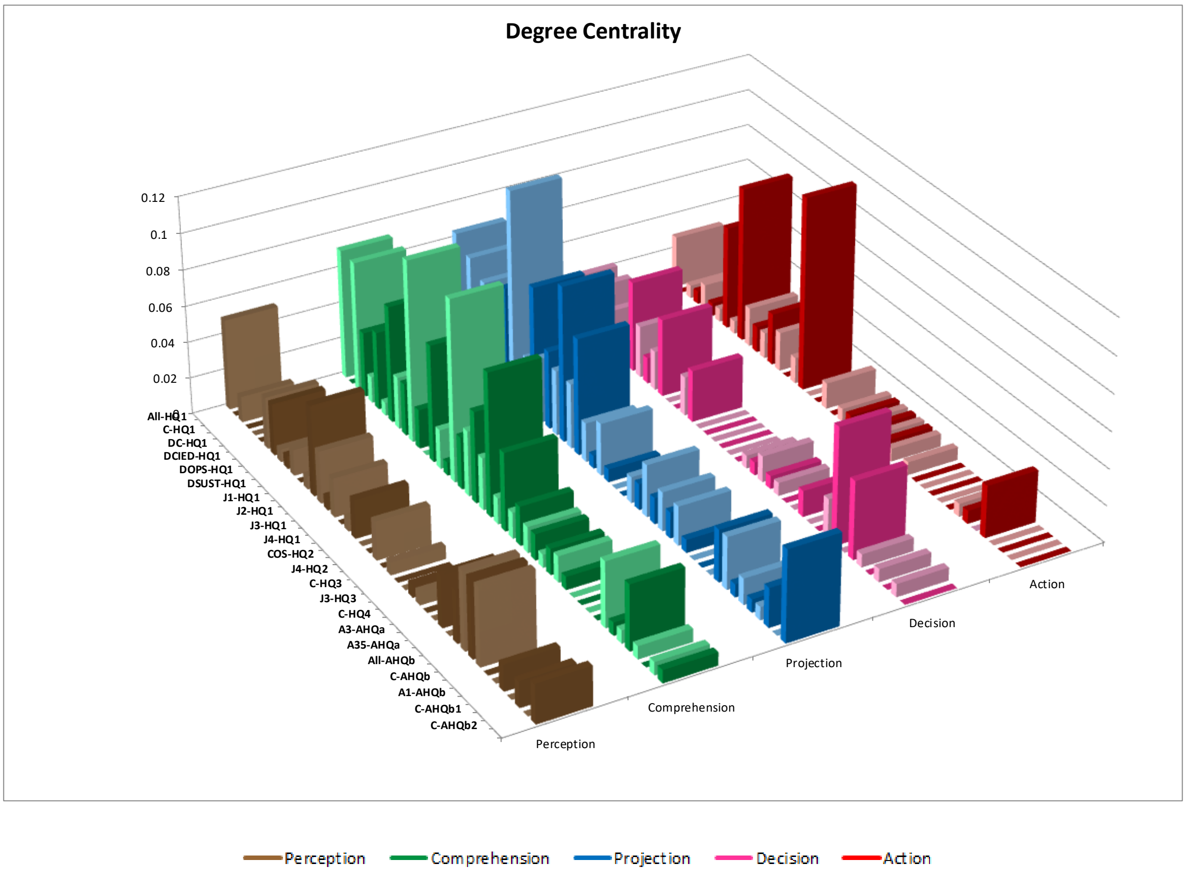


Figure 5 Degree centrality across the operational data set, with light shades indicating in-degree and darker shades the out-degree.

In *Figure 5* we show the in/out degree centralities across the operational data set as a three-dimensional bar chart; colours follow the information function convention used in the network diagrams and light/dark shaded colours distinguish in/out degree. There is much that can be extracted from here but we observe a number of key features that are difficult to discern in the network diagrams alone:

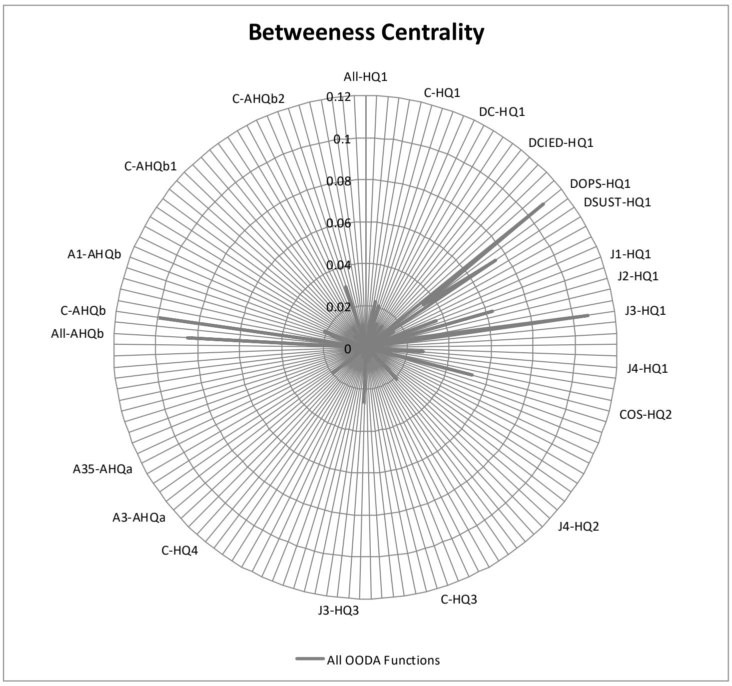
- there is a dominance of high in-degrees across Perception-Comprehension-Projection at the 'command' level in HQ1*, in other words most network activity is about reporting something or forecasting to commanders*;
- amongst the Projection counts, the largest out-degree is from the J2 with the next in size from DSUST (the cluster of dark blue blocks in the centre of the plot), *in other words the intelligence and logistics/personnel staff are those mostly trying to anticipate the future*;
- the counts for Decision are generally lower across all nodes, *in other words decisions are not generally captured in the information artefacts propagating through the network*;
- for Action the two largest degree centralities are out-degrees generated by DOPS and J3 in HQ1, *in other words staff responsible for controlling operations are pushing out documents directing action in the operating environment*;
- associated with the DOPS and J3 results is that the dominance of in-degree across the SA-based information functions shifts to an out-degree for Action, *in other words the predicate for the direction by operations staff (as per previous point) is input giving them the awareness*;
- the in-degree of 'All-HQ' type nodes is also relatively high compared to those for individual nodes, though the latter are higher, *in other words there is large amount of, though not dominant, 'broadcasting' through the system*;
- and, finally, though the degree-centralities overall are higher for the nodes in HQ1 compared to the subordinate units, of the latter the measure for Air units is relatively higher, *in other words the command of Air units plays an important role second only to the overall headquarters in theatre*.

These results further emphasise the role of HQ1 as receiving information as SA, on the one hand, but processing and articulating the decisions from this less as explicit artefacts on which data can be collected, and finally tasking sub-units through the operations staff of DOPS and J3. Projection – anticipation of the adversary - is provided predominately by the J2, but also from the sustainment functional areas where predefined schedules are more readily available. The comparative paucity of links associated with 'Decision' and the fact that the operations staff go from receiving SA input to Action output suggests there are undetected communications with commanders about their decisions that are not captured in this analysis. In other words, there many decisions are articulated in face-to-face interactions. Also, broadcasting to an entire headquarters, particularly HQ1, is large but most information flows are to individuals. Finally, and consistent with degree-centrality as a measure of 'importance' or 'power', it is clear that within this system, the senior headquarters HQ1 dominates. This points to a clear hierarchy in the C2 arrangements. However, within this hierarchy, the subordinate air units nevertheless play an important role in comparison to other sub-units. This resonates with the perception link observed in *Figure 3* for the larger dataset from the subordinate air units to the AOC and is consistent with the overall significance of Air Power in the Australia's operations in the MER at the time of the data collection.

Betweenness centrality, on the other hand, relates to paths between non-adjacent nodes (*k*, *m*) where *other nodes* on the path potentially control the interaction between *k* and *m* (for example between the most junior member of staff and the Commander in a hierarchy). Nodes with the highest betweenness centrality enjoy the most influence within the network. Labelling $g_{k,m}$ as the number of shortest paths between nodes *k* and *m* in the network, and $g_{k,m}(n)$ as the number of those that travel through node *n*, the normalised betweenness centrality for node *n* is given by:

$$B(n) = \frac{2}{(N-1)(N-2)} \sum_{1<k<m<N} \frac{g_{k,m}(n)}{g_{k,m}}.$$

Thus, whereas degree-centrality measures importance in a power or hierarchical sense, betweenness measures the significance of bridging nodes which 'glue' a structure together.



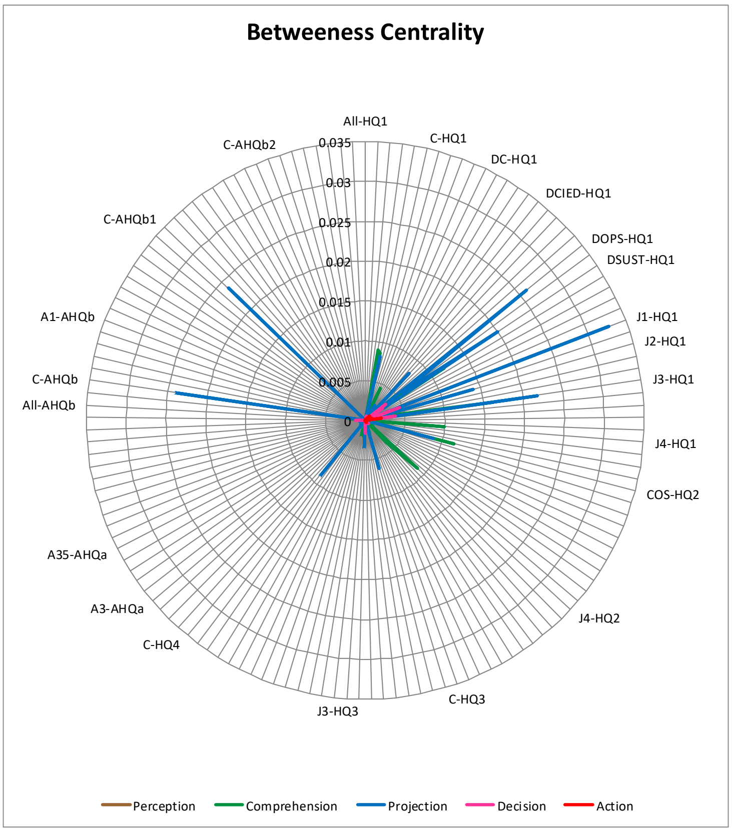


Figure 6 Radar plot showing the betweenness for each node in the operational data set; combining all Information Function values (top) and separating according to information function (below).

In *Figure 6* we plot the betweenness results combining and separating information functions as a radar plot. We separate these here because of the quite different scales between combining and separating the OODA levels, and we show both because of the aspects in which they are similar and yet different. We see in *Figure 6* that the largest spikes in betweenness when combining OODA levels come from the subordinate staff to the commander of HQ1: DOPS and J3 particularly, then director for sustainment (DSUST), and the COS in HQ2, and then the commander of a subordinate air unit, A-HQb, and broadcasts to all in that unit. This pattern is repeated for the *projection* function when OODA levels are separated, with the exception of the commander of a further subordinate air unit, AHQb1.

Noting the meaning of betweenness in SNA as indicating the 'glue', we see that the immediate subordinate staff officers to the commander of HQ1, DOPS, DSUST and J3, are those sources of glue in the C2 system. *And they perform that gluing function by re-transmitting projection within the SA spectrum.* Indeed, the similarity between the top and bottom plots of *Figure 6* emphasises that the bonding of the C2 system, over and above its hierarchical structure observed earlier, is at the higher SA level. Within this interpretation, we see that filtering so that only projection is shown reveals that the commander of the subordinate air unit, AHQb1, performs this same bonding function.

Finally, we compute the number of loops in the network, which may be taken as a proxy for the complexity of the system (as in the cyclomatic or cyclometric number in software development). The importance of loops, as opposed to paths, is also significant since the values of the information function category are points in a cognitive *cycle*. Again, using the in-built NetMiner™ functionality, we extract the statistics shown in Table 3.

Table 3 Count of number of loops

Information Function	Perception	Comprehension	Projection	Decision	Action	All
No. of Loops	1	17	10	2	1	1285
No. of 3-hops	1	7	3	2	1	80
No. of 4-hops	0	5	2	0	0	265
No. of 5-hops	0	5	5	0	0	940

The table identifies the number of separate loops *entirely within* an information function (for example, there are 10 separate loops that are entirely within the Projection level, with three consisting of 3 hops, 2 of 4 hops and 5 of 5 hops). In the last column we show the number of separate loops where a hop can involve a change in the information function, *both advancing in the OODA loop and going in reversing*. There is a key, remarkable, result in these numbers: within any OODA level the number of loops is very small (the largest is 17 within the Comprehension function), suggesting low complexity. Allowing for changes across all OODA levels (up and down) in counting, the number of loops is large. This indicates high complexity when OODA levels change. The number of hops around any one of these loops is between 3 and 5 (bottom three rows). Longer loops of 5 hops dominate, given the count of 940 across all OODA levels. We recall the earlier clarification that many of the cycles in this data are around different decisions and issues. Notwithstanding this, from the perspective of any single information function or OODA state, the network is very 'simple' while seen over all information functions it is genuinely complex. The disparity of three orders of magnitude between any one of the information function counts (1-17) and the total count (1285) emphasises that there is some change in information function – there is change of OODA loop states – moving around a cycle on the network. (This analysis by itself cannot yet show that around a cycle there is only *progress forward* in an OODA loop.)

Conclusions

This study was a rare opportunity to collect rich data on the information flow in a complex *in vivo* military operational environment. The classification scheme to describe information exchange in terms of the function, type, means and network provides a straightforward, intuitive breakdown of the key characteristics. This paper discusses inferences drawn regarding decision loops in command and control. However, the data has also been used for planning theatre information infrastructure and analysis of formal vs informal communications.

The Observe Orient Decide Act Weighted Network (OODAWN) model was found to be extremely valuable for characterising the flow of information within deployed ADF units in the Middle East Region. We see that the deployed nature of operations brings a substantial proportion of information flows as informal in nature. Nevertheless, the formal nature of the organisation shines through with hubs of high centrality. The functional staff officers provide the betweenness, indicating their role in both transferring and enhancing information, and managing their own resources. Of these, the J2 plays a major role in higher situation awareness. This dominance in 'projection' is followed by staff functions, such as personnel and logistics, that work with well-defined schedules to anticipate the future. Below the role of the commander of HQ1 there are numerous power centres through the C2 system. There is value-add in enabling chains of communications to enable staff to progress through the OODA loop. Finally, the unique features of air power doctrine also leave their mark in the instantiation of the C2 system through its inherent communication flows particularly between tactical and strategic levels. These are all behaviours one expects of this C2 system, and our ability to detect these in the weighted network analysis of OODAWN validates the approach.

Though we have focused on validation of the OODAWN approach here, and identified things that are ``right'' with the C2, there are insights from this analysis that may in turn be the basis for changes in the conduct of the C2. Given that this work was initiated in support of a commander we must be circumspect in detail here. Firstly, we pointed out that artefacts capturing 'Decisions' were fewer in number compared to the other OODA states, visible in the network diagrams presented here and the centrality analysis. As stated, this may be partially explained by the property that senior leaders prefer to formulate decisions `in the head' or in face-to-face meetings with staff. To this extent there is a case for more artefacts articulating decisions to enable future traceability and accountability. Secondly, we observed through our analysis that the vertical hierarchy of the C2 arrangements was strongly evident. Given the complexity of coalition operations in the region, particularly given the nature of insurgency/ISIS networks [23], the approach of Contingency Theory [24] or C2 Agility theory [25] suggests there is an argument for greater network-centricity, in other words a degree of flattening of the C2 structure. Finally, the result that Air Force C2 doctrine leaves its imprint in the OODAWN analysis provides utility in the testing of the appropriateness of this C2 against a spectrum of mission types – a subject of on-going discussion in the C2 and Air Power literature [26-28].

Future work is still required to develop validated metrics that use the information function weighting in OODAWN where we have used quite well-known SNA metrics here. For example, in [16] we introduced a measure of SA-gradient through paths in an SA weighted network. An analogue may be developed here where now, given the cyclicity of the OODA loop, one would seek to measure, for example, forward momentum through OODA (or the degree of backtracking). Generalisations of betweenness in this direction are also possible, where one searches for nodes on shortest paths through the network but where, for example, the weight must only increase through the OODA loop. The opportunities for quantification of C2 in this intersection of SNA and conceptual C2 models are manifold. We previously alluded to Contingency Theory and C2 Agility theory which provide the closest thing to a normative theory of what such networks should look like. Future work is nevertheless required to cast these in the form of an OODAWN representation.

Nevertheless, the method is now available for on-going evaluation and analysis of operations. This is because the model offers commanders both a high fidelity view on the state of their current C2 structure and opportunities for its evolution; OODAWN identifies where change should be introduced and measures the impact of that change.

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