LOA5: a new five-dimension model to design automatic systems

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***Abstract*—We chose the contract net protocol (CNP) to let humans express their consent over the allocation of goals to UAVs in a realtime context. It raises a common level of automation (LOA) issue: how to make humans dependable in a realtime context. Most approaches are based on a deadline, like the sixth level of the Sheridan LOA classification.**

In order to properly design our implementation, we created our own LOA model : LOA5. We believe that this model can help to design any automatic system, regardless of the field.

We present here this model.

***Index Terms*—LOA, LOA3**

INCREASING levels of autonomy in Unmanned Aerial Vehicles (UAV) are expected to reduce the need for human intervention in operations[2]. However, UAVs are not a substitute for human involvement in the battle-space. Crucially, human control of UAVs is axiomatic for military relevance[3]. Since human operators must remain in UAV systems, the level of automation (LOA) has to be discussed[4].

We chose the contract net protocol (CNP) to let humans express their consent over the allocation of goals to UAVs in a realtime context. It raises a common level of automation (LOA) issue: how to make humans dependable in a realtime context. Most approaches are based on a deadline, like the sixth level of the Sheridan LOA classification. In order to properly design our implementation, we created our own LOA model : LOA5. We believe that this model can help to design any automatic system, regardless of the field.

We present here this model, LOA5. In section I, we present other LOA models. In section II, we present the details of our own model. In section III, we use one of our applications, Aerial[13], do test how LOA5 can help to get a good overview of automated systems. In section IV, we expose our conclusion.

I. Other LOA models

A. One-dimension models

The most famous levels of automation are the ten ones proposed by Sheridan and Verplank in 1978, we refer to them as the S&V LOAs. For later reference we detail them in table III as they were by Cummings[1].

TABLE III
How Cummings presents Sheridan & Verplank (1978) Levels of Automation

Automation Level	Automation Description
1	The computer offers no assistance: human must take all decisions and actions.
2	The computer offers a complete set of decision/action alternatives, or
3	narrows the selection down to a few, or
4	suggests one alternative, and
5	executes that suggestion if the human approves, or
6	allows the human a restricted time to veto before automatic execution, or
7	executes automatically, then necessarily informs humans, and
8	informs the human only if asked, or
9	informs the human only if it, the computer, decides to.
10	The computer decides everything and acts autonomously, ignoring the human.

Other models exist, especially in aeronautics where levels of automation has been long addressed. Pilots (7.3.1.3 in [3]) tend to view computer autonomy simply as either automatic, with or without status feedback; or semi-automatic, telling what will happen and asking permission to proceed; or advisory, providing information only. The PACT system (Pilot Authorization and Control of Tasks) was created for pilot interaction and delegation of adjustable LOA [7]. It considers six levels. The Advisory Group for Aerospace Research and Development (AGARD) considers eight[8]. In table II we sum up these LOA views.

B. Multi-dimension models

Previous models are one-dimension, they are like a simple ladder to rate the autonomy as a monolithic property. But most of this systems are heterogeneous, they rely on several concepts derived from autonomy. For instance, the model of Sheridan and Verplank relies on four derived concepts, as shown in table I :

- Decision : the autonomy to decide what alternative out of two is better.
- Authority: the autonomy to decide that an alternative must be carried out.
- Action: the autonomy to carry out an alternative.
- Information: the autonomy to decide what to tell out of what is known.

The model of Sheridan and Verplank is not complete because too many cases are not covered by these ten levels, even when only these four dimensions are taken into account. For instance automatic systems could carry out the alternative, like in level 5, even when alternatives are just narrowed down too a few and that human operators must still make the final choice themselves, like in level 3. Basically, these dimensions shoud be seen as independant and allow many more designs.

A model with three dimensions is LOA3 [9]. Its dimensions are authority, abstraction and aggregation.

- Authority captures how much independence the automation has with respect to decision-making - e.g., the

TABLE I
THE TEN LEVELS OF AUTOMATION OF SHERIDAN AND VERPLANK

<table>
<tr><th>Lv</th><th>Decision</th><th>Authority</th><th>Action</th><th>Information</th></tr>
<tr><td>1</td><td>Human operators compute alternatives and select up to one.</td><td rowspan="5">If any, the alternative selected by human operator must be carried out.</td><td rowspan="4">If any, the selected alternative is carried out by human operators.</td><td rowspan="4">Automatic systems have nothing to tell human operators</td></tr>
<tr><td>2</td><td>Automatic systems compute alternatives. Human operators select up to one.</td></tr>
<tr><td>3</td><td>Automatic systems compute alternatives and select up to a few ones. Then, human operators select up to one.</td></tr>
<tr><td>4</td><td rowspan="2">Automatic systems compute alternatives and select up to one. Then, human operators select up to one.</td></tr>
<tr><td>5</td><td rowspan="6">If any, the selected alternative is carried out by automatic systems.</td><td rowspan="3">Automatic systems tell what they do to human operators.</td></tr>
<tr><td>6</td><td rowspan="5">Automatic systems compute alternatives and select up to one.</td><td>If any, and if not canceled by human operators by a deadline, the alternative selected by automatic systems must be carried out</td></tr>
<tr><td>7</td><td rowspan="4">If any, the alternative selected by automatic systems must be carried out</td></tr>
<tr><td>8</td><td>If asked, automatic systems tell what they do to human operators.</td></tr>
<tr><td>9</td><td>Automatic systems decide what to tell human operators out of what they do.</td></tr>
<tr><td>10</td><td>Automatic systems do not tell human operators what they do.</td></tr>
</table>

need to ask permission vs. informing the user vs. full independence.

- Abstraction captures at what level the automation is tasked - e.g., higher, more abstract tasks vs. finer-grained, more concrete tasks.
- Aggregation captures how much of a resource is tasked at a time - e.g., single platform vs. flight vs. swarm.

Our own model is LOA5 and it has five dimensions. It must not be mistaken with an extension of LOA3 since it share only the authority dimension with LOA5. The authority dimension remains the backbone of every LOA view. And in every authority dimension, there is a threshold above which the automatic system no longer needs explicit human approval to start proceeding.

II. LOA5 MODEL

A. Description

Our model has five dimensions. Note first that we do not use aggregation and abstraction as dimensions like LOA3.

We consider that different parts of a system may have different automation settings. We do not see automation as a monolithic property of the whole system. We believe that part of thinking about a system is understanding the distinct levels of automation of its compounds. Conversely, when several compounds share the same automation settings, it is convenient to aggregate them. But aggregation does not affect the settings, it is merely a consequence of the settings. Thus, we do not see aggregation as a dimension to define automation, even if we use it as a tool.

As well, and unlike LOA3, we do not consider that abstraction is a fiting dimension. Being more abstract in LOA3 means that more alternatives are considered, since less directives are provided, and sometimes that more alternatives are filtered, due to implicit directives that are deduced from explicit directives. In LOA3, computing alternatives and filtering them are both handled with the decision dimension.

1) Decision captures how many alternatives are discarded solely on the base of the appreciation of the automatic systems. This dimensions has a first inactive level, when automatic systems are inactive, an three active levels.
   - At the first active level, the automatic systems compute alternatives and no alternative is hidden to human operators appreciation. If many alternatives are available, they can easily flood the computer operators.
   - At the second active level, the automatic systems compute alternatives and select the a priory best ones. It makes it easier for human operators. It is relevant when the one best alternative cannot be surely identified due to parameters that cannot be solely evaluated using numbers. For instance, when operating UAVs, some decisions are better made by human operators and are the very reason why humans must remain in UAVs systems.
   - At the third active level, the automatic systems can compute on their own the best alternative. Some systems, like Playbook, are confident that humans can fully and mathematically express the way they process information, and then that computers can rely on this mathematical expression to find the best alternative. We are not that confident and we use the former level (the second active one) within Aerial.

TABLE II
LOAs VIEWED BY SHERIDAN AND VERPLANK, BY PILOTS, BY PACT AND BY AGARD

LOAs viewed by Sheridan & Verplank	**LOAs viewed by pilots**	**LOAs viewed by PACT**	**LOAs viewed by AGARD**
Level 1: Humans do the whole job.	∅	Commanded	Level 1, No Automation: *e.g.* a car parking break or a car power steering.
Level 2 – 4: Computers select actions and humans implement them if they approve. A higher level narrows the selection.	Advisor	Level 1, At Call: Pilots are assisted by computers at call. Level 2, Advisory: Pilot are continuously assisted by computers.	Level 2, Manual Augmented: the automatic system – *e.g.* an airbag control unit – is entrusted with low level activities. Level 3, Manual Augmented and Limited: the automatic system – *e.g.* an anti-lock brake system (ABS) – can limit humans. Level 4, Cooperative: the automatic system – *i.e.* a cruise control in cars – takes part in high level activities. Level 5, Automated Pre-Select: the automatic system can play a set of pre-programmed actions.
Level 5: Computers select actions and implements if humans approve.	Semi-automatic	Level 3, In Support: Pilots are backed up by computers that act if they are allowed.	Level 6, Automated Select: Computers propose to play a set of actions. An example is an automatic track-keeper, the navigator select way points to follow, the vessel determines the optimal track, finally the navigator accept, correct or reject this track.
Level 6: Computers select actions and implement if humans do not disapprove by a deadline.	Automatic	Level 4, Direct Support: Computers are backed up by pilots who can revoke computers' actions.	Level 7: Autonomous Manned Operation
Level 7 – 10: Computers do the whole job. A higher level means a more autonomous feedback (*i.e.* computers decide what to tell humans).	∅	Automatic	Level 8: Autonomous Unmanned Operation

Indeed, Aerial is meant to be an implementation of the second level in order to outmatch Playbook for the quality of human input.

2) Authority captures how much independence the automatic systems have to start carrying out the selected alternative. This dimensions has a first inactive level, when automatic systems are inactive, and three active levels.
   - At the first active level, the automatic systems cannot start carrying out the selected alternative if human operators do not approve explicitly. In some circumstances, this explicit consent can indeed be implicit. For instance, if like in S&V LOA 3 human operators select a final alternative out of the alternatives proposed by the automatic systems, one can assume that human operators agree that this final alternative must be carried out.
   - At the second active level, the automatic systems start carrying the selected alternative on their own, but human operators can stop them. The main issue is how long human operators have to do so before the automatic systems start proceeding and after they start proceeding. In S&V LOA 3, it is assumed that human operators have plenty of time before the automatic systems start proceeding. But in real life, even within a cooperative system, the physical constraints may make difficult to grant them plenty of time. For instance, when operating realtime a fleet of UAVs, UAVs continue acting while human operators think, they consume resources, they often move away from where they are and they can take measures that cannot be undone. Thus we consider that this level is especially challenging. We talk more about it in the second part of section III.
   - At the third active level, the automatic systems start carrying out the selected alternative on their own, and human operators cannot stop them. That may happen for physical reasons, but not with UAVs since those are supposed to remain under remote control. We include this level because we want LOA5 to be a generic tool to address automation, not just focused on UAVs.
3) Action captures how much independence the automatic systems have to carry out the selected alternative. This dimensions has a first inactive level, when automatic systems are inactive, and two active levels.
   - At the first active level, the automatic systems and human operators help each other. This is a common situation.
   - At the second active level, the automatic systems carry out everything on their own.
4) Information captures how much independence the automatic systems have to decide what human operators must be informed about out of what automatic systems carry out. This dimensions has no inactive level and three active levels.
   - At the first level, the automatic systems tell everything to human operators. In order to not be flooded, human operators can apply filters and ask explicitly for details. Thus, we see no much practical difference between S&V LOA 7 and S&V LOA 8.
   - At the second level, the automatic systems filter on their own what they tell human operators. For instance, if the bandwidth is scarce, it makes sense to implement such filters.
   - At the third level, the automatic systems do not tell anything to human operators. It may be because information are but dull or because, in case of UAVs,

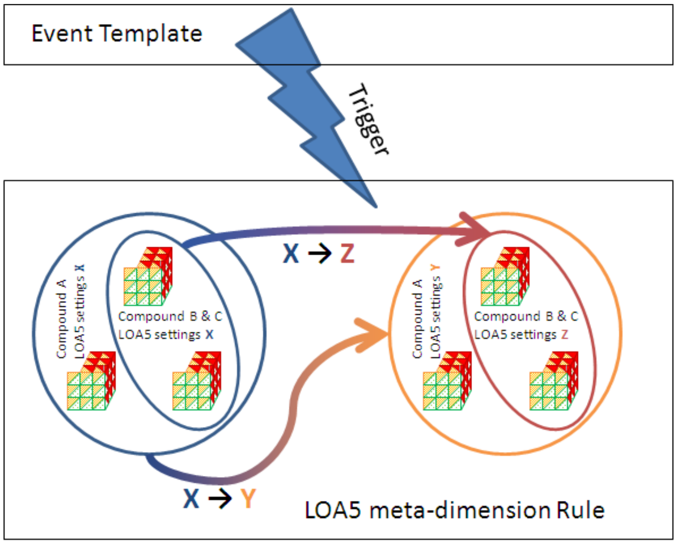

Fig. 1. Example of a rule in the LOA5 meta-dimension (fifth dimension).

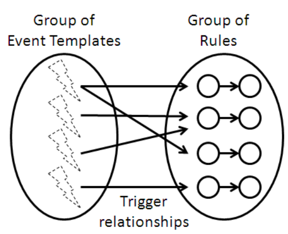

Fig. 2. Example of a policy in the LOA5 meta-dimension (fifth dimension).

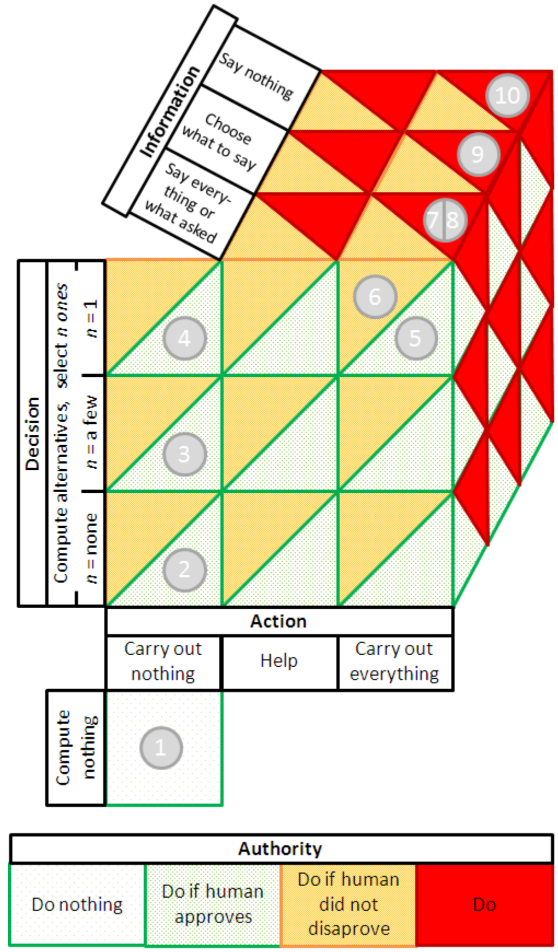

Fig. 3. How the ten levels of Sheridan and Verplank fit in LOA5.

because automatic systems must remain stealth.

These four first dimensions, out of five, can be use to define the LOA4 settings of any compound (or group of compounds) of a whole system. LOA4 settings are static on their own, but to address realtime, LOA5 has a fifth dimension : a meta-dimension. For instance, in case of emergency, some settings involving tight human control may switch to some settings with increased autonomy in decision dimension, authority dimension and action dimension. Another example is when human operators get too busy and need to delegate more to the automatic systems. How these changes apply is decided by a policy that constitutes the fifth dimension.

A policy is the set of trigger relationships from a group of event templates to a group of rules (see figure 2). The figure 1 is an example of Rule and also shows the use of aggregation even without a dedicated dimension.

B. Comparing LOA5 and other models

In the figure 3 we show how the ten levels of Sheridan and Verplank fit in LOA5. The table I helps to understand it.

The first S&V LOA is special since the automatic systems do nothing.

From S&V LOA 2 to S&V LOA 4 what changes is how the selection of alternatives is narrowed, thus the matching levels in LOA5 differ from each other in the first LOA5 dimension, the decision dimension.

From S&V LOA 4 to S&V LOA 5 what changes is how the selected alternative is carried out, thus the matching levels in LOA5 differ from each other in the third LOA5 dimension, the action dimension.

From S&V LOA 5 to S&V LOA 7 and S&V LOA 8 what changes is how the automatic systems are allowed to start carrying out the selected alternative, thus the matching levels in LOA5 differ from each other in the second LOA5 dimension, the authority dimension.

From S&V LOA 7 and S&V LOA 8 to S&V LOA 10 what changes is what the automatic systems must tell to human operators, thus the matching levels in LOA5 differ from each other in the fourth LOA5 dimension, the information dimension. The two levels S&V LOA 7 and S&V LOA 8 are similar in LOA5 because, when human operators apply filters, it does not undermine the autonomy of the automatic systems, compared with when these filters are not applied.

Other LOA systems fit also in LOA5. The case of LOA3 as been discussed when describing LOA5.

The pilot view is rather generic and LO5 is much more detailed.

Within PACT, the two first levels differ from each other because in the second, unlike in the first, the support of automatic systems is continuous. In LOA5, the discontinuity is handled by the fifth dimension, the meta-dimension.

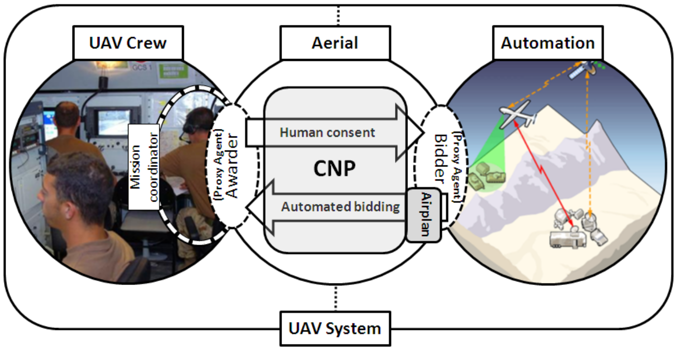

Fig. 4. Aerial within a UAV system

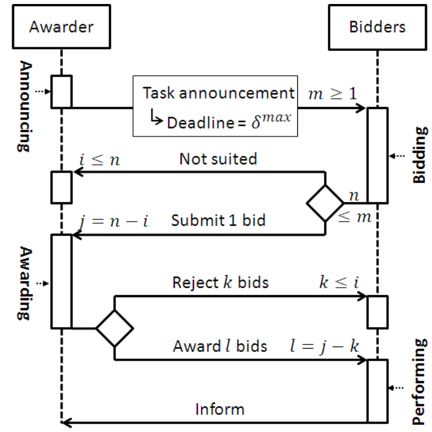

Fig. 5. Early CNP

Within PACT, the third level and the fourth differ from each other because in the second, unlike in the first, the automatic systems start proceeding on their own. In LOA5, this is handled by the second dimension, the authority dimension.

Comparing LOA5 with AGARD is less straightforward because the first levels of AGARD involve low level compounds and allow high overall autonomy. It means that AGARD use aggregation as a dimension, like LOA3, when LOA5 does not.

Nonetheless, LOA5 can address the same questions than AGARD. For instance, a cruise control in a car is level four in AGARD model. The fifth dimension, the meta-dimension, of LOA5 allows the driver to switch it off or on. When it is active, it work as follows.

- It does not decide what speed must be maintained, but it decides how to maintain this speed, thus it is at the first active level of the decision dimension in LOA5.
- It does not need to ask or wait for human agreement, thus it is at the third active level of the authority dimension in LOA5.
- It carries on its task on its own, thus it is at the second active level of the action dimension in LOA5.
- It has nothing to tell the driver, thus it is at the third level of the information action in LOA5.

This list may go on but at this point it should be yet clear that LOA5 is at least as complete as other models. We will now explain how one our own applications, Aerial[13], can be see through this LOA5 model.

III. Aerial in LOA5

A. Aerial and CNP

How Aerial is embedded in a UAV system is shown in figure 4. It is basically a multi-agent systems with two agents, the first one is the group of human operators, the second one is the group of automatic systems. These two groups interact through a tender protocol, the Contract Net Protocol (CNP). The CNP was created by Smith[5] and Sandholm extended it[6].

The CNP usually involves an awarder agent and several bidder agents. It works as follows:

1) The awarder make task announcement.
2) The available bidders evaluate the task announcement and submit bids if they are suited.
3) The manager evaluates the bids and awards one.

Figure 5 depicts the flow in the fashion standardized by the Foundation for Intelligent Physical Agents [14].

There are two motives to favor the CNP: it spares the bandwidth and it is intelligible.

- Our available bandwidth is scarce and the CNP has no extraneous message traffic. The control of the UAVs must be adequately addressed in the current air traffic management framework. Thus, it must bear the shortage of VHF frequency bands and limit itself to sparse and short messages[10]. Compared with other auctions (*e.g.* English auctions or Dutch auctions that are open ascending or descending price auctions), the tender is a first-price sealed bid auction that needs few messages. Furthermore, messages can be kept short and to the point through the use of the bid specification mechanism.
- Another good point of the CNP is its intelligibility because it is turn-based with only four turns: the announcing turn (awarder's first turn); the bidding turn (bidders' first turn); the awarding turn (awarder's second turn); the performing turn (bidders' second turn). However, to remain user friendly, the CNP must also convey not too many bids (see section II) and result in deterministic outcomes (see section III).

Usually, the CNP handles fully automated negotiations, we modified it to involve human operators. In Aerial, the CNP works as follows (see figure 6) :

1) The awarder triggers an automatic task announcement.
2) A single bidder evaluate the task announcement and submit several bids, if they are suited.
3) The manager evaluates the bids, optionally asks for more bids, and eventually awards one.

LOA5 is not only a model to think about automatic systems, it can also behave as a checklist to be sure that nothing is left aside when designing automatic systems.

The first dimension we cover is the meta-dimension, it is based on states displayed in figure 7. There are

- The default state (also the initial state) : when the mission begins, each UAV is untrusted with a few tasks, the best plan to successfully carry out these tasks is known. When an unforeseen event happens, a human operator may want

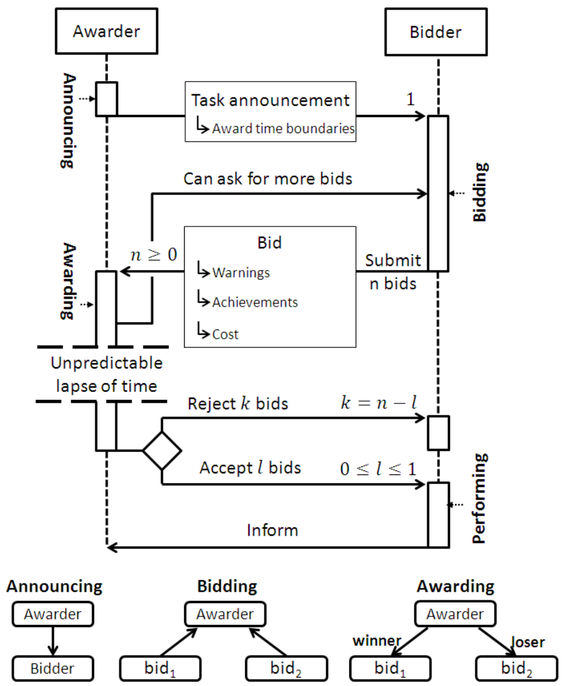

Fig. 6. The CNP within Aerial.

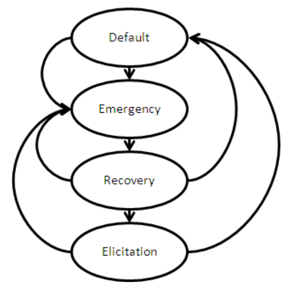

Fig. 7. The four states of Aerial policy.

a new task to be carried out as soon as possible. Then, the state becomes the emergency state. Note that in any other state, but the state of emergency, the state can becomes the state of emergency.

- The emergency state : the closest relevant UAV must come to carry out the task related to the state of emergency. To do that, this UAV can cancel tasks with lower priorities. This emergency state does not last long, it only aims to find quickly a UAV to carry out the new task. Once this UAV is found, the state becomes the recovery state.
- The recovery state : the automatic systems tries to allocate task that were just cancelled during the emergency state. To do that, tasks can be exchanged between goals. If it successful, the state becomes the default state. If it is not successful, some tasks must be definitely cancelled and this call for a task announcement about the best way to replan the mission. Many alternatives are computed and those Pareto dominated are discarded. The state becomes the elicitation state.
- The elicitation state : human operators must decide which alternative is the best one. For instance, the automatic systems may find a first alternative where a task A with a priority 1 is cancelled, and a second alternative where a task B with a priority 1 is cancelled. Since the two task A and B have the same priority, the automatic systems may choose any and proceed, minimizing for instance how much fuel is used. But a smarter approach would be to acknowledge ledge that even if A and B were rated a priori with the same priority, they may not be that equal now that one of them must be cancelled. Thus, it is better to ask the human operators who may discuss this. The talk between human operators can be supported by a few rules to help converging, like priority and veto rules. The tender will eventually end, whether because human operators have found an agreement or because they ran out of time to do so. In either case, the state becomes the default state.

The information dimension is the fourth one in LOA5 because it comes last after action, however, when thinking about automatic systems, it can be convenient to think soon about what the human operators should know. In Aerial, many alternatives are discarded before elicitation. Some are Pareto dominated and have no reason to remain. But some other are not Pareto dominated and are discarded because otherwise human operators would be flooded. When that happens, Aerial raises warnings. Then, human operators can ask to see the discarded alternatives related to a warning.

For instance, let say that we have three alternatives: cancel A with priority 2 that we note $\neg 2 : A$; cancel B with priority 2 that we note $\neg 2 : B$; cancel C, D both with priority 1 that we note $\neg 1 : C, D$. We may consider that two alternatives is as many a human operator can possibly handle. We may also consider that, even with priority 1, $\neg 1 : C, D$ is worse than $\neg 2 : A$ or $\neg 2 : B$. The point here is not too argue if these rules are relevant but rather to understand that sometimes some rules must apply even if they may not be relevant. When that happens, Aerial raises a warning and it gives the human operators an opportunity to see and select alternatives that would be definitely discarded otherwise.

The action dimension is the third one. In Aerial, we do not mind it : human operators can choose to be helped by the automatic systems, and automatic systems can rely on human skills as well.

The authority dimension is the second one. The policy of Aerial revolved around the emergency state. In the emergency state, the automatic systems have the upper hand. But the emergency state is triggered by a human operator, so the authority is very well balanced between automatic systems and human operators.

The decision dimension is the first one, and we see it last. In the default state, the decision has been made. In the emergency state, the decision is made by the automatic system after a human operator decided that some new task has a top priority. Human operators have still the upper hand since they decide *what* must be done when the automatic systems decide *how* this must be done. In the recovery state, the automatic systems have the upper hand since they are fully untrusted to discard Pareto dominated alternatives. In the elicitation state, human

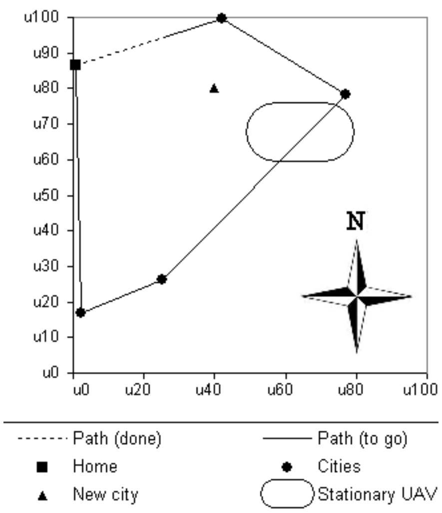

Fig. 8. Map. With a constant speed v, one space unit u is the distance a UAV can cover in one time unit u of the chart 9.

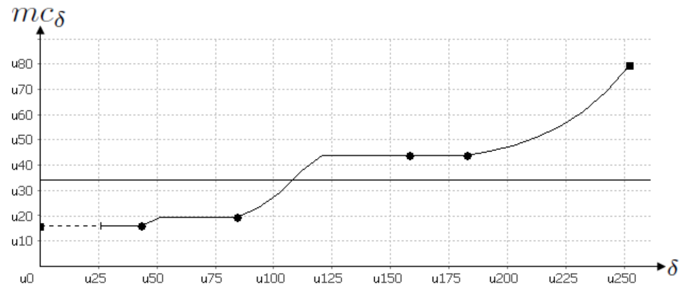

Fig. 9. $mcost(d_1, g_{n+1}, \delta)$ and $mcost(d_2, g_{n+1}, \delta)$. The flat one is $mcost(d_2, g_{n+1}, \delta)$. With a constant speed v, one time unit u is how long a UAV needs to cover one space unit u of the chart 8.

operators have the upper hand because they can ask to see over flooding alternatives. However, most of over flooding alternatives will not be watched over. Thus, the operated systems are still untrusted with a critical part of the decision process when they decide which alternatives that are not Pareto dominated are over flooding.

B. Aerial and realtime

Human operators need *commitment* to be at ease with the process. Bellow is how commitment is described by Sandholm[6]: *In mutual negotiations,* commitment *means that one agent binds itself to a potential contract while waiting for the other agent to either accept or reject its offer. [. . .] When accepting, the second party is sure that the contract will be made, but the first party has to commit before it is sure.* The commitment starts when alternatives are presented to human operators and lasts till (up to) one alternative is awarded and the other rejected.

UAVs never stop, it makes difficult to grant a commitment. In the figure 8, two UAVs may visit a new city. Human operators must decide which one is the most relevant. The most relevant one is not necessarily the closest one, it may be the best one for any other reason, like being the cheaper, or doing a better job, or being less likely to be needed by someone else. The additional distance is nonetheless a good indicator of how troublesome it is to visit this new city. This additional distance is the marginal cost $mcost$ displayed in 9.

IV. Conclusion

We have presented LOA5, a model meant to design automatic systems interacting with human operators. We have compared it with other models : we have seen that its dimensions are relevant and that some other dimensions used by other models like LOA3 and AGARD are not missed. Eventually, we used Aerial, our framework to plan and replan the mission of UAVs, to test how LOA5 can help as a checklist to analyze automatic systems. We have seen that some features are easly designed but are more challenging to be implemented. We chose as an example our implementation of the first active authority level of LOA5. This level, like in the levels two to five of Sheridan and Verplank, makes the automatic systems unable to proceed if human operator have not given their explicit consent. In a realtime context, it is challenging to grant commitment to human operators. Nonetheless, it does not undermine the merit of LOA5 as an interesting model to design automatic systems.

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