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Developing a first-approach model of Air Traffic Controllers' Mental Workload based on behavioural measures: A Theory For Modelling Air Traffic Controllers' Mental Workload

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Air Traffic Controller (ATCo) Mental Workload (MW) is likely to remain the single greatest functional limitation on the capacity of the ATM (Air Traffic Management) System. There is a need to develop computational models for monitoring real-time MW to facilitate the development of different approaches for task support. MW in the ATM domain has been attempted to be estimated and monitored using subjective, physiological and behavioural measures. However, the literature highlighted disadvantages with current subjective and physiological methodologies used to assess MW related to their impracticality in real work-environments. Therefore, what is needed is an unobtrusive MW calculation model based on ATCos' recordable behaviours that can be deployed unobtrusively in an ecologically valid environment. This research aims to offer a first-approach model of ATCos' MW based on data that can be collected from the log of the technological systems used for ATM: 1) their communication patterns and 2) their actions with the ATM technical systems. In a next stage, this model will be further validated during simulation sessions with real ATCos, using physiological measures (eye-tracking), alongside subjective measures of MW. The main outcome of this research project will be a real-time MW non-intrusive and automatic monitoring tool that would allow ATCOs and ATM systems to get adapted to task complexity variations throughout time, mitigating the disastrous effect of drops in human performance.

Keywords: Air Traffic Management, Mental Workload, Human Performance, Risk Management, Computational model

1. Introduction

In 2018, Airbus published a new forecast about the evolution of the air transport sector from 2018 to 2037 (Airbus, 2018). Titled "Global networks, Global citizens", this document predicted an annual growth of 4.4% of worldwide air traffic and described the different factors (e.g., tourism upward trend, oil prices, demographic growth, etc.) that drive air traffic passenger flights to double every 15 years. Despite the coronavirus outbreak meant a reduction of 58.3% of the air traffic compared to 2019 (Bureau, 2020), the International Civil Aviation Organization (ICAO) reported that passenger air traffic has already reached around 80% of pre-pandemic levels. Furthermore, the ICAO forecasted that air passenger demand will quickly recover to pre-pandemic levels on most routes in the first quarter of 2023 and that, at the end of the year, a 3% growth will be achieved over figures in 2019 (ICAO, 2023). Therefore, we must continue seen the future evolution of air traffic as a continuous upward trend that needs to be properly handled in order to avoid potential future security risks and guarantee flight efficiency. More specifically, in order to accommodate such future increase in air traffic density, en-route airspace capacity also needs to increase, on a proportional basis, by 1) introducing new Air Traffic Management (ATM) systems, technology, tools and procedures and by 2) supporting human performance in the ATM systems.

Air Traffic Controllers (ATCos) are responsible for managing the air traffic flying across the airspace in order to ensure their safety and efficiency. In a nutshell, ATCos need to monitor air traffic, evaluate potential risks, formulate plans to solve potential future conflicts and implement such plans (Pawlak et al., 1996), therefore, we rightly could say that ATCos are the central core where safety decisions regarding air traffic are made. ATCos frequently cope with very high demanding situations that lead them to prioritize their actions and, since cognitive processing is limited, ATCos frequently experience high levels of Mental Workload (MW) (Roske-Hofstrand & Murphy, 1998). MW and human performance are indissolubly linked, and literature research has revealed dozens of times in many different domains that mental overload and mental underload result into performance decline (e.g., Omolayo & Omoloe, 2013; da Silva, 2014; etc.). Therefore, there is an urgent need to predict MW levels experienced by ATCos while performing their ATM task and to understand what factors drive their MW, in order to be able to maintain MW under acceptable levels. Traditionally, researchers have focused their attention on identifying the set of different factors determining task complexity (e.g., Grossberg,1989; Histon et al., 2002, etc.). The idea is simple, a higher task complexity would lead the ATCo to experience higher level of MW and, for that reason, a huge effort has been made to predict MW based on a linear combination of task demand factors. However, task complexity is not the only factor affecting MW, since MW is the result of a complex relationship between task complexity and individual factors that must be considered for achieving success when modelling MW. Therefore, assessing MW goes far beyond determining task complexity levels, and implies shifting the focus towards a human centred modelling of MW. We could say that ATCo's MW is likely to remain the single greatest functional limitation on the capacity of the ATM System (Majumdar & Polak, 2001; de Frutos et al., 2019). MW in the ATM domain has been attempted to be estimated and monitored using subjective, physiological and behavioural measures. However, there is currently no accepted single method deployed in the industry to assess and monitor MW and the effect they have on performance. The disadvantages highlighted within the State-of-the-art for subjective and physiological measures is related to how obtrusive and impractical they can be to use in real work scenarios (Longo & Leva, 2018). First, they both interfere with ATCos' performance: 1) online measuring of MW require attentional resources to be focused on introspection every time subjective reports of MW are requested and 2) most physiological measures need to be collected by using intrusive equipment which would ultimately interfere with task development and even with experienced MW (Moray, 2013). Secondly, one outstanding feature of subjective measures is that they may be distorted (Hancock, 2017). For these reasons, the industry and scientific community need to develop a MW calculation model that can be based on an assessment of ATCos' recordable behavioural measures that can be deployed unobtrusively in an ecologically valid environment. The specific behavioural measures that meet these requirements are 1) voice recordings from ATCos (communication with pilots and with other ATCos) and 2) their interaction with the ATM technical systems. The main advantage of this model is to overcome current limitations of physiological and subjective methodologies explained above, primarily because communication patterns and interactions with the ATM technical systems can be analysed indirectly (and in real-time) though the logs of the ATM technical system automation, with equipment that is already an integrated tool of ATCos' tasks; in addition, those behavioural measures cannot be distorted.

This research work is the first study of a post-doc project whose aims is to develop a computational model of ATCo's MW based on the behavioural data recordable through the ATM automation, about 1) ATCos' communication patterns and 2) their recorded interactions with the ATM technical system. Such model will afterwards be validated using well-stablished physiological measurements, alongside subjective MW reports. In this study we will develop a first-approach model of the

ATCos' MW based on their behavioural patterns.

2. Related work

Prevalent MW models of ATC, such as the model proposed by Hilburn and Jorna in 2000, postulate that the different ATM factors (traffic factors, airspace factors and operational constraints) impose certain level of task demands to the ATCo, who will experience some degree of MW depending on their experience, skills and strategy followed when copying with such problems. In other words, according to these models there are different mediating factors that modulate the MW experienced by the ATCo when facing task demands. However, these models place primary value on how the different factors of the ATM environment impacts on MW and do not consider the metacognition of the ATCo (resource management and strategy selection) nor the feedback received from the system in response to their actions. In this position, it is very interesting to consider the model proposed by Loft et al. (2007), who claimed that MW experienced by ATCos is the result not only of the different ATC task-load factors (task demands), but it also depends on the strategy selected by the ATCo to cope with the situation and on whether such strategy is adequate to keep task-demands under a comfortable level of control. According to this model, task demands can be regulated by the ATCo by 1) taking action into the system for adjusting future task demands or by 2) selecting a proper cognitive strategy to reduce future task. A strategy (specific type of air traffic management) comprises a group of control activities that are carried out for achieving certain objective/s (safety, orderliness and expeditiousness). The metacognition of the ATCo drives the prioritization of the different strategies followed. Metacognition is strongly related to Situational Awareness (SA). Factors such as the awareness of possible future task demands, awareness of the available time to solve the problems and the knowledge about his/her own skills, experience and capacity would guide the prioritization of different strategies to follow, depending on the needs of the scenario faced by the ATCo. In other words, the selection of one strategy among others would be driven by prioritization of the objectives pursued by the ATCo as task demands evolve throughout time (Kirwan & Flynn, 2002). Metacognition is also mediated by either feedback and feedforward input. On the one hand, the ATCo could realize that the quality of his/her current work is being constrained by a higher time pressure and, in such case, the ATCo would prioritize a strategy based on safety over expeditiousness (e.g., the ATCo could readjust the trajectories of the aircrafts in an inefficient way but allowing a lower future need of monitoring and coordination (lower MW)). On the other hand, the ATCo could realize that a high number of aircrafts is about to enter into his /her sector, and then modify his/her strategy for managing the aircrafts that are already in their sector (e.g., the ATCo could again adjust trajectories prioritizing safety versus orderliness and expeditiousness). In addition to this, metacognition could also trigger a change in strategy from a potential unbalanced situation between the work to be done and the actual work being done.

2.1. *How ATCos modulate Mental Workload by selecting alternative strategies to perform their tasks*

MW experienced by the ATCo depends not only on air traffic complexity factors but also on cognitive strategies chosen by them to face task demands and on the quality of control that those strategies exert over the situation. This largely depends on time pressure. The ATCo knows the time he/she requires to face certain task demands and he/she can trigger a metacognitive response when time pressure is increased that would allow him/her to avoid and overload scenario by selecting an alternative strategy what would suit the particular needs of the scenario, prioritizing safety over orderliness and expeditiousness. In view of the above, it could be possible to infer the level of experienced MW by observing certain swifts in strategy that ATCos might adopt to get adapted to an increase in task demands. Some shifts in strategies that ATCo could make to adjust his/her level of mental workload will be detailed below.

The "monitoring" task allows the ATCo to maintain a clear picture about the current and future situation in the air traffic scenario. However, when the ATCo fails in such purpose, performance problems arise and security is compromised. Research has shown that ATCos regulate the amount of attention paid to single aircrafts as a strategy to decrease MW associated with monitoring. For example, a study performed by Gronlund et al. in 1998 revealed that ATCos seem to divide the flights into two categories (important vs. non-important flights) depending on the relative probability of losing future separations and they tend to pay more attention to important flights, specially under high task demands. Another clear example on this was revealed by Histon and Hansman in 2002, who stated that ATCos divide flights in standard and non-standard types, depending on whether they follow or not standard flows. Non-standard flights increase cognitive complexity and require more attention from ATCos, specially under high task demands. A third example is that ATCos may start processing flights in groups under high task demands (Histon & Hansman, 2002; Almadi & Leroux, 1995): for instance, 5 aircrafts heading west and 3 aircrafts heading east could be abstracted and monitored as 2 group of aircrafts, rather than as 8 individual flights. Such strategy would allow them to focus on the intersection between both groups of aircrafts and would let them avoid perform pair comparisons between all of them.

Conflict detection is also very related to SA and MW. Losing an appropriate SA would lead to a higher latency in detecting conflicts between aircrafts. A higher latency in conflict detection, in turn, leads to an increase in MW (e.g., Metzger & Parasuraman, 2001). The logic behind this is simple: the higher the latency in detecting a conflict, the lower the available time to plan and execute an intervention for preventing a loose in separation between aircrafts. Indeed, this situation could lead the ATCo to make urgent decisions that would disorder the ordinary traffic flow, creating future problems and, therefore, increasing MW. Higher traffic density hinders conflict detection, as ATCos require greater visual inspection and time pressure is higher, since they have less available time to make and execute decisions (attention and cognitive reasoning are divided). ATCos could regulate their MW by shifting strategy under a high task demands scenario or when anticipating higher future task demands. For instance, research has revealed that ATCos prefer using altitude information at the expense of speed and heading information (e.g., Rantanen & Nunes, 2005) for assessing the probability of future conflicts between pairs of aircrafts. In view of the above, Loft et al., (2007) suggested that ATCos could safe attentional resources by projecting lateral trajectories (using heading and speed information) only when assuring vertical separation is dubious. Hence, this strategy would presumably be enhanced under high task demands scenarios. Another strategy that ATCo use to regulate MW is the use of “critical points” for conflict detection. More specifically, standard flows normally have some critical crossing points where a higher proportion of conflicts normally take place. ATCos can reduce their MW by focusing on such critical crossing points rather than on performing pair comparisons between all the aircrafts.

When it comes to solving conflicts, ATCos would also follow certain strategies to modulate their MW. For example, under high task demands circumstances, ATCos become more conservative and solve potential conflicts immediately, making less efficient but safer decisions that require less future monitoring and coordination, such as prioritising vertical over lateral separation for solving complex conflicts (Kirwan & Flynn, 2002).

2.2. *Human performance models to explain ATCos’ behaviour change in response to task-demands*

We can assume that under certain circumstances, task demands could be so high that ATCos would not be able to modulate their MW level, even after trying to shift their strategies to more convenient ones. In such situations ATCos would be facing a mental overload situation and could start behaving in a reactive manner, which is something that should be avoided at all costs. Time pressure and SA are key factors: when time pressure is very high ATCos would not be able to keep their SA updated, they could not plan in advance, and they would start working in a reactive manner. We will now rely on two well-stablished general performance models to understand how human behaviour changes when performing tasks and facing problems under different time pressure and task-demand, those are, the COCOM of Hollnagel (1993) and the SRK model of Rasmussen (1983).

According to the COCOM model, humans can follow different strategies during problem solving depending on the ratio between available time to take an action and the time that the human requires to perform that action, which involves evaluating the situation, selecting a response and executing such response. This model distinguishes 4 different behavioural patterns: strategic, tactical, opportunistic and scrambled. If the person has plenty of available time to perform their actions, then he/she would follow a strategic behavioural pattern but if time pressure is increased, the behavioural pattern of that person would change across such patterns until reaching, ultimately, the scrambled one. Strategic and tactical are proactive behavioural patterns, whereas opportunistic and scrambled are reactive. The ATCo will always try to maintain a strategic or tactical behavioural pattern and avoid opportunistic and scrambled ones, but this is not always possible to achieve.

Interviews with ATCos made by different research groups revealed that MW associated to conflict resolution highly depends on specific knowledge about the sectors that ATCos gain as time goes on and their experience increases (e.g., Kallus et al., 1999; Neal et al., 1998). They talk about something colloquially known as “conflict solving library” that they use for solving particular conflicts. More specifically, when ATCos detect a new conflict, they compare such new conflict with the knowledge they already have, so they check that “conflict solving library” to find a previous similar situation and the associated solution, and then, they adapt that old solution to the new situation. Nevertheless, if the conflict cannot be solved in that way, then they will have to think and construct a new solution and apply it to the new situation. If that new solution succeeds, then it would be added to that library later, and that is how the library of solutions gets enhanced over time. Recovering a solution from the memory reduce cognitive cost and therefore, MW. Conversely, thinking about new solutions and implementing them requires a higher cognitive cost and, therefore, the associated MW will be higher. According to this example, MW does not only depend on the ratio between available time to take an action and the time that the human requires to perform that action, but also on the cognitive cost that such task-demands impose to the ATCo. We will better understand this on the basis of the classic Skill, Rule, Knowledge (SRK) model of Rasmussen (1983). The SRK model aims to outline human behaviour and the associated errors while performing their tasks in a human-machine environment. This model classifies human behaviour into three main categories depending on the required cognitive implication associated with the task being performed. Consequently, depending on task-demands and on the available mental resources (activation level, experience, skills, etc.) of the person, one or different levels would be taking place during task performance and decision-making process. These three behavioural categories are known, namely, as skill, rule and knowledge-based levels. In general terms, according to the SRK model, we can assume that the higher the control level reached when performing a task, the higher de level of consciousness and control over the actions carried out and the higher the cognitive cost. Therefore, skill level behaviour is more effective and economical in terms of cognitive costs but very difficult to control (automatic and unconscious behaviour), whereas, on the contrary, knowledge level is very demanding in terms of cognitive processing, but very controllable. Selecting one or another control level would largely depend on task demands (task complexity) but, more specifically, on the difficulty that such task demands would mean to a particular person (note the difference between complexity and difficulty). Therefore, the higher the difficulty of the task to a particular person is, the higher the control level would be required for solving the problematic situation and, therefore, the higher the level of cognitive complexity and associated MW. The shift between control levels is determined by an imbalance situation between task demands and the level of mental abstraction required to understand and solve the situation. To illustrate this, we will now focus on the ATM sphere. Nominal situations will normally be addressed with automatisms under the skill-based level (e.g., assuming an aircraft into his/her sector or transferring it to another sector) but, if the situation turns more difficult, then the ATCo would have to search for the optimal solution to solve the problem and avoid negative consequences. First the ATCo will use his/her long-term memory to search for similar situations already addressed in the past and if succeed (colloquially known as the “conflict solving library”), then he/she would follow the procedure/rules for solving such problem but adapting them to the new scenario (e.g., giving clearance instructions to several flights). However, if the situation is new and there are no rules/procedures stored in the long-term memory to draw upon, then the difficulty is even higher, and the operator will have to elaborate new solutions, choose the most appropriate and elaborate and apply the new procedure (e.g., non-expected military operations taking place in a big portion of the sector that would create a disorderly flow of traffic).

3. Development of the model: hypothesis and predictions

Understanding ATCos' MW involves understanding the different strategies they follow and the different hehaviours they adopt for facing external task-demands. As stated in section 2, the shift in strategy is driven by the metacognition of the ATCo: the mind of the ATCo processes in parallel many different factors (time pressure, actual and future task demands, knowledge about his/her own skills and experience, etc.) that allows them to understand the whole picture of the current situation and project the future state of the system (SA). Therefore, it would be an internal signal what would trigger that change in strategy to successfully cope with the new demands of air traffic scenario. There is something very relevant to highlight: it will never be possible to observe and quantify the metacognition of the ATCo, nor their thoughts or feelings, we cannot get inside of the mind of the ATCo and quantify their MW level, but what it is possible is to observe their behavioural patterns in order to infer their internal states and therefore, their MW.

At this point, and based on the previous sections, we will develop a first approach real-time model of ATCos MW, based on behavioural measures that could be gathered automatically and in real time from the logs of the ATM technical systems. We have argued that the sets of variables that meet the requirements needed belong to three different categories of interaction between the ATCo and the ATM systems: 1) communication with pilots, 2) coordination with other ATCos and 3) interaction with the ATM technical systems. Therefore, we will now make predictions and hypothesis about each different set of variables that will be tested in the following stage of the project.

3.1. *Communications with pilots: hypothesis and predictions*

3.1.1 Form of the communications: this set of variables refers to the different features of the communications that reflect concrete manners of verbalizing them but have not relation with the content of the message.

Frequency of communications: A higher MW would be reflected as an increase in the frequency of communications with pilots (number of communications per unit of time). Therefore, the overall number of communications will increase. We can calculate this variable by computing the number of communications per unit of time. We predict that frequency of communications would follow an upward linear trend.

Duration of communications: A higher MW would be reflected as an increase in the duration of overall communications and a decrease in the duration of overall silences per unit of time. We can calculate this variable, for example, by computing the overall duration of communications per unit of time. It can also be computed as a ratio between the overall duration of communications and the overall duration of silences per unit of time. A higher score in such ratio would reflect higher MW. We predict that duration of communications would follow an upward linear trend.

Communication response latency: A higher MW would be reflected as an increase in the response latency of ATCos to pilot requests, that is, ATCo would take longer time to respond to pilot requests. We can calculate this variable by calculating the time that the ATCo takes to respond to the pilot requests (subtracting the time at which the pilot issued the request to the time at which the ATCo verbalizes the answer to the request). We predict that response latency would follow an upward exponential trend.

Speech velocity: A higher MW would be reflected as an increase in speech velocity. An overloaded ATCo needs to issue more amount of information in shorter time and, therefore, they would start talking faster. We can calculate this variable by dividing the number of words of overall communications per unit of time. A higher score would mean a higher speech velocity. We predict that speech velocity would follow an upward logarithmic trend.

Control events length: A higher MW would lead the ATCo to shorten the length of control events in communications. Overloaded ATCos would use shorter messages to communicate the same amount of relevant information in the less possible time. This could be done by using shortcuts: less words and less letters for issuing the same control event. For example, the length of callsigns (e.g., “Scandinavian Airlines you’re identified” could be shortened by using less words (e.g., “Scandinavian you’re identified”) or even by using contractions (e.g., “Scandy, you’re identified”). We can calculate this variable by counting the number of letters per control event, however, we must consider that this would highly depend on the type of control event issued to the pilot so comparations must be done within each type of control events.

Control events grouping: A higher MW would lead the ATCo to group control events in the same communication. In other words, the ATCo would issue more than one control event in the same communication. We can calculate this variable by counting the number of control events issued per communication.

3.1.2 Content of the communications: This set of variables refers to the specific content transmitted through communications, that have not relation with the form of the message. Despite the content of communications can be very variable, the content that could somehow reflect MW can classified according to different aspects.

Use of accessory information: A higher MW would lead the ATCo to eliminate all the elements that are not strictly linked to the performance of their ATM tasks (e.g., greetings, polite words, etc.). This variable is similar to the “control events length” variable explained above. Both variables aim to shorten the length of communications in order to issue more quantity of relevant information per unit of time, but while “control events length” refers to the form of the communication (use of shortcuts for issuing the same control event), this variable refers to the content (reduction of non-relevant information). We can calculate this variable by computing the number of words issued in each communication. However, we must consider that this would highly depend on the type of control event issued to the pilot.

Appearance of mistakes: A higher MW would lead the ATCo to make a higher number of mistakes during communications. Mistakes could be related to the language, callsign, route, location, etc. This could be calculated by identifying and computing particular words or phrases that would reveal the occurrence of a mistake made by the ATCo while issuing instructions and clearances. Some specific words/phrases could be: “correction”, “disregard”, “sorry for the confusion”.

Confusion words: A higher MW would reduce the SA of the ATCo and this would lead to a higher confusion that would be reflected verbally. This variable could be calculated by identifying and computing specific words or phrases that would reveal a state of confusion. Some specific words/phrases could be: “say again”, “report position”, “read back”.

High task demands related words: A higher MW would lead the ATCo to use words and phrases that reveal high task demands. This could be calculated by identifying and computing specific words or phrases that are associated to high task demands. Some specific words/phrases could be: “break break”, “expedite”, “I say again”, “words twice”.

Complaints from pilots: An increased response latency of ATCos to pilot requests could lead pilots to start complaining. This variable can be calculated by identifying and computing specific words that would reveal complaints from the pilots.

Use of specific strategies to modulate MW: This variable might be the most challenging one to consider for the development of the MW model. As we have deeply described in section 2.1, ATCos are capable of modulating their MW by choosing particular strategies to face task demands. Therefore, if we were able to identify and compute the use of specific strategies commonly followed by ATCos when experiencing particular levels of MW, we could then infer MW levels associated to such particular strategies being used. Strategies can be related to monitoring, conflict detection and conflict resolution. However, while monitoring and conflict detection strategies cannot be reflected through communications, conflict resolution strategies might be reflected. The strategies that we will test are the following.

(i) **Vertical separation priority**: Under high task demands circumstances, ATCos prioritize using vertical separation instead of lateral separation for solving complex conflicts. Therefore, a higher MW level could be reflected as an increase in the number of flight level change control events issued to pilots, over speed and heading change control events. This can be calculated as a ratio between the number of flight level changes by the summatory of the number of heading changes plus the number of speed changes.

ii) **Clearance priority:** Under high task demand circumstances, ATCos would prioritize issuing clearance control events over information control events, in order to save time. Therefore, a higher MW level would result into a reduction of the number of information control events issued to pilots. This could be calculated as a ratio dividing the number of clearance control events by the number of information control events per unit of time.

3.2. *Coordination with other ATCos: hypothesis and predictions*

When considering ACC-services, formal coordinations made through the VCSS are normally assumed by the EXE-ATCo. However, the research work developed by Villena (2012) revealed that higher task demands not only lead to an increase in the overall coordinations made by ATCOs, but there is also a change in the distribution of such coordinations: the PLN-ATCo would start assuming a big proportion of coordinations, so that the EXE ATCo can focus on traffic management tasks such as communicating with pilots for issuing instructions and clearances. In view of the above, coordinations made by the EXE-ATCo would evolve in a very particular way as MW evolves throughout time. In general terms, starting from a very low task demand situation, formal coordination activity made through the VCSS would increase as task demands increases, but at one point, MW levels would start being so high that EXE-ATCos would need to reduce their coordination activity (that would be assumed by the PLN-ATCo) in order focus his/her mental resources in managing the air traffic. We must highlight that formal coordinations made through the VCSS are the only coordinations that can be recorded and stored. For that reason, informal coordinations made in situ will be ignored in this research work. The particular evolution of formal coordination activity made by the EXE-ATCo could be reflected by the following variables:

Frequency of coordinations: from low to moderate MW the frequency of coordinations (number of coordinations per unit of time) performed by the EXE-ATCo will increase, however a higher MW would be reflected as a decrease in the frequency of coordinations. We can calculate this variable by computing the number of coordinations per unit of time. We predict that frequency of communications would follow a quadratic trend.

Duration of coordinations: from low to moderate MW the duration of coordinations performed by the EXE-ATCo will increase, however, a higher MW would be reflected as a decrease in the duration of overall coordinations per unit of time. We can calculate this variable, for example, by computing the overall duration of coordinations per unit of time. We predict that duration of coordinations would follow a quadratic trend.

Coordination response latency: a higher MW would be reflected as an increase in the response latency of ATCos to coordination requests, that is, EXE-ATCo would take longer time to respond to coordination requests. We can calculate this variable by calculating the time that the EXE-ATCo takes to respond to the coordination request. During extreme overload situations, the EXE-ATCo would even not answer to coordination requests. We predict that coordination response latency could follow an exponential trend.

3.3. *Interactions with the ATM technical systems*

The ACC-ATCo needs to interact with the AATCS in order to perform their ATM tasks. Among all the elements that comprises the AATCS, the radar screen is the one that requires the greatest attention from the ACC-ATCo, since it displays most of the information directly related to the air traffic. The set of variables that we think could reflect behavioural patterns that could be associated with different levels of MW are described below:

Overall interaction with the AATCS: a higher MW would lead the ACC-ATCo to reduce his/her overall interaction with the AATCS. This could be calculated as a reduction in the use of peripherals intended to introduce input into the system, namely, mouse, keyboard and touchpads. We predict that overall interaction with the AATCS would follow a downward linear trend.

Interaction with the distance calculator tool DAL: a higher MW would lead the ACC-ATCo to specifically increase his/her interaction with the DAL tool. This could be calculated as an increase in the activation of the DAL tool in the radar screen. We predict that overall interaction with the AATCS would follow an upward linear trend.

4. Summary and conclusion

ATCos' MW is likely to remain the single greatest functional limitation on the capacity of the ATM system. There is a need to develop computational models for monitoring real-time MW to facilitate the development of different approaches for task support. MW in the ATM domain has been attempted to be estimated and monitored using subjective, physiological and behavioural measures. However, there is currently no accepted single method deployed in the industry to assess and monitor MW and the effect it has on performance. The literature highlighted disadvantages with current subjective and physiological methodologies used to assess MW related to their impracticality in real work-environments. Therefore, what is needed is an unobtrusive MW calculation model based on ATCos' recordable behaviours that can be deployed unobtrusively in an ecologically valid environment. The first stage of this project would be to develop a real-time computational model of ATCos' MW based on data that can be collected from the log of the technological systems used for ATM: 1) their communication patterns and 2) their actions for the functionalities offered by the system. The second stage would be to validate the model during simulation sessions with real ATCos, using physiological and subjective measures of MW. The main outcome of this research project will be a real-time MW non-intrusive and automatic monitoring tool that would allow ATCOs and ATM systems to get adapted to task complexity variations throughout time, mitigating the disastrous effect of drops in human performance.

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