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WORKSPACE MANAGEMENT ON CONSTRUCTION JOBSITES: AN INDUSTRY SURVEY

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Abstract: Workspace collisions are the result of the unplanned overlap of resources and have proved to seriously impact the projects' performance. Yet till date, and despite the improvements of 4D modeling in the construction industry, workspace management is mostly performed manually or via 2D sketches, which fails to cover the workspaces' evolution properly. The lack of 4D implementation may be attributed due to the additional efforts that is exerted to create workspaces and simulate their movement which is due to: (1) the diversity of the previous works and lack of standardization (2) the lack of comprehensive implementation of any approach through multiple construction domains and (3) the lack of a stochastic approach to consider the variability of workspaces. Accordingly, this paper presents an industry questionnaire created to better understand the market's perspective and needs for a workspace management tool. The questionnaire covers the industry's views on the inputs and outputs mode detection and avoidance, the ranking of domains for the need of workspace management and verifies the necessity for a stochastic approach. 41 respondents replied, whom 92% have suffered from workspace collisions, and indicate that productivity was the most impacted project aspect. They also indicated that industrial projects are the most sensitive domain towards workspace collisions, and over 85% recommended stochastic approaches for workspace modeling and to consider crew specific attributes in the resolution strategies.

1 INTRODUCTION

Workspace collisions that occur on construction jobsites pose many threats to projects' performance. They are a result of weak workspace planning, which is one of the tasks that is still performed mostly mentally or at most 2D sketches, despite the progression of 4D modeling in the construction industry. Accordingly, the evolution of the workspaces throughout the project is not captured accurately, leading to the eruption of workspace collisions, which are the unexpected space overlap of resources during project execution. These collisions have recorded impacts high as 65% productivity decline to certain activities, and 30% to the entire project (Sander et al. 1989, Dawood and Mallasi 2006). As well as property damage, accidents, and corresponding cost implications (Rohani et al. 2018, Getuli and Capone 2018, Kim et al. 2018, Hosny et al. 2018). Hence, with the rising complexity nowadays, it is a must to model workspace in 4D. Unfortunately, the industry is still facing some difficulties with such task.

Hartmann et al. (2008) reviewed 26 cases of 4D models developed in different construction projects and found out that they were mainly used for design review and construction visualization purposes mainly, with very little to rare use for operational or performance analysis (Hartmann et al. 2008). As, most of the current 4D Models only contain the building components linked with activities, and don't contain any representation of the other resources (equipment, labour, etc.) (Jongeling and Olofsson 2007). Also, there are very few commercial software in the market that can represent these resources, model them, and detect the collisions (Perez et al. 2016). Consequently, previous researchers have mentioned the additional effort and time practitioners must exert to be able to develop a space-loaded model from scratch (Hosny et al. 2018, Kassem et al. 2015). Guevremont and Hammad (2018) suggested five different LOD stages, where collision detection was achieved at the most detailed stage LOD4-5+, with an hour-minute time unit for scheduling. This LOD is 2 stages higher than 4D models developed for the contractual baseline at bidding (LOD2-3) (Guevremont and Hammad 2018). Additionally, for preparing the models for workspace management, previous researchers have distinct differences in their methodologies, have not tested them on all domains nor on multiple projects, and have not accounted for uncertainties that may arise on construction jobsites.

The diversity in previous works may be attributed to the choices of parameters to serve as the inputs for workspace modeling, the outputs produced to illustrate the collisions and to be used for optimization process and the duration and frequency of simulation to detect workspace collisions in a project. Furthermore, most of the approaches were usually tested on only one project which was either residential or commercial and not on other projects in the same domain or other domains. Hence, the resilience of these approaches as a standardised method for workspace management is questioned, due to the lack of comprehensive testing and the choice of domain selection. Accordingly, this paper presents the results of an industry questionnaire conducted to identify the market needs for workspace management as the stepping stone for the creation of a standardized comprehensive approach that considers uncertainties.

2 PREVIOUS WORKS

2.1 Inputs for Workspace Modeling

The inputs for workspace modeling and detection ranged from generic site information, to activity specific parameters. For example, Thabet and Beliveau (1992), and Winch and North (2006) utilized the workspace volume as the main input, and its ratio to the available space. Other Works added a differentiation between the spaces occupied by resources and created workspace types (Riley and Sandivo 1995, Akinci et al. 2000, Wu and Chiu 2010, Marx and Konig 2013). Space criticality and taxonomies acted as additional inputs in later works, to prioritize the workspace types (Mallasi and Dawood 2006, Hosny 2013). Adding to these were the activities' schedule information, where some researchers would test for collisions only after checking the activities concurrency in the time schedule (Kassem et al. 2015, Moon et al. 2014). Moreover, others used syntax analysis to explain the relation between the different workspace types for activities (Getuli and Capone 2018). On the other hand, some approaches focused only on the topological relations rather the geometry, and others used the spatial information from previous projects that was acquired by site acquisitions technologies (Song and Chua 2005, Zhang et al. 2015, Su and Cai 2018). However, none of the previous works considered any human related inputs.

2.2 Outputs for Collision Resolution

The outputs produced for collision resolution ranged from simple notification of collision to a multi criteria function that would evaluate the severity of the workspace collision to set the priority for resolution. For example, some researchers focused on congestion by presenting the ratio between the demanded space and the available space, without considering any specific activity relation information (Thabet and Beliveau 1992, Winch and North 2006). Other approaches produced activity specific information such as the ratio between the original workspace volumeactivate and the colliding volume (Akinci et al. 2000). Adding to that, was the duration ratio to explain the time activities suffered interferences (Guo 2002). Later, these ratios were coupled with a congestion measurement of the entire space (Kassem et al. 2015). A more conservative approach added the "close" workspaces based upon an adjacency equation, in addition to the existing collisions (Moon et al. 2014). However, a more comprehensive perspective for resolution were the multi criterion functions that would evaluate the collisions based upon: volume, duration, interference type and severity, activity criticality, cost, etc. giving the users' a single value for each collision and its details (Rohani et al. 2018, Hosny 2013, Mallasi and Dawood 2006). The focus of all previous works was on producing outputs that would explain the activities, but none that would explain the crews handling them.

2.3 Domain Application for Workspace Management

Table 1 below shows the domains that were tested for the previous approaches developed. As perceived, the concentration was on residential and commercial projects. The type of residential / commercial projects were mostly buildings, and others were either universities, schools or a parking structure (Thabet and Beliveau 1994, Riley and Sandivo 1994, Akinci et al. 2000, Guo 2002, Mallasi and Dawood 2006, Hosny 2013, Zhang et al 2015, Rohani 2018, Su and Cai 2018). The industrial projects were incinerators, industrial buildings, and oil refineries (Yeoh and Chua 2012, Kassem et al. 2015, Getuli and Capone 2018). The infrastructure projects were mostly roads and bridges (Moon et al. 2014, Li et al. 2015, Mawlana 2015). The main observation is that none of the works were tested on more than one domain.

Table 1 Previous Domain Applications for Workspace Management

	Domain			
Researcher	**Theoretical**	**Residential / Commercial**	**Industrial**	**Infrastructure**
Thabet & Beliveau 1994		x		
Riley & Sandivo 1995		x		
Akinci et al 2000		x		
Guo 2002		x		
Song and Chua 2005	x			
Mallasi & Dawood 2006		x		
Winch & North 2006	x			
Wu & Chui 2010	x			
Yeoh & Chua 2012			x	
Hosny 2013		x		
Moon et al. 2014				x
Kassem et al. 2015			x	
Li et al. 2015				x
Mawlana 2015				x
Zhang et al 2015		x		
Rohani 2018		x		
Su & Cai 2018		x		
Getuli and Capone 2018			x	

2.4 Previous Works: Deterministic Approach

The main commonality between previous works is the choice a deterministic approach without any consideration for uncertainties or the human interactions arising from workspace collisions. The approaches assumed full compliance of the crews to either the original workspace planning, or to the resulting resolution strategy. That meant all crews regardless of their abilities, would create the same collision and react to them in the same manner, which is highly improbable, and research has provided enough evidence for Workers may have lower productivity than planned, or may not receive the materials on time, which would affect the workspace evolution (Kavuma et al. 2019). Or they may refuse to complete tasks according to their risk attitude or any other personal attribute (Pikas et al. 2012). Similarly, crews may focus more on economic return or better working conditions swaying them away from the original plan (Pikas et al. 2012). Consequently, there is a need to shift the methodologies of workspace management towards a bottom-up approach, that can set rules for crews' behaviors, capture the interactions between stakeholders and account for the dynamic conditions of the construction site (Hosny et al. 2018).

3 INDUSTRY'S PERSPECTIVE ON WORKSPACE MANAGEMENT

3.1 Questionnaire Design

Pursuant to the findings in the literature review of the subject matter, particularly the lack of diversity of the previous work in choice of the domain application (residential, industrial, commercial, etc.), the variability in the number of inputs uses, workspace types used, and outputs produced, and the consensus to approach the issue in a deterministic fashion, a questionnaire was designed to capture the industry's view of: a) the domain with the most need for workspace interferences detection and resolution, b) validate the suggested inputs from literature, c) verify that the outputs produced are consistent to practitioners' expectation, d) acquire additional inputs or outputs expected and e) most importantly, confirm the need to research workspace interferences in a stochastic fashion. The questionnaire was set out for a period of two months with 41 complete responses and nine incomplete responses (which are not considered in the statistics). The questionnaire was a total of 16 questions consisting of a mix of multiple-choice questions, five-point scale estimations, agree/disagree statements and open-ended questions. With reference to the National Institute of Standards and Technology (NIST) under the U.S. Department of Commerce, **Error! Reference source not found.** and **Error! Reference source not found.** were used to calculate the weighted average ($\bar{x}_w$) and the weighted standard deviation (sd_w) of the 5-point scale questions: (Oliver et al. 2010)

[1] $\bar{x}_w = \frac{\sum_{i=1}^{N} w_i x_i}{\sum_{i=1}^{N} w_i}$

[2] $sd_w = \sqrt{\frac{\sum_{i=1}^{N} w_i (x_i - \bar{x}_w)^2}{\frac{(N'-1)\sum_{i=1}^{N} w_i}{N'}}}$

Where N is the number of observations, w_i is the weight of the ith observation (the number of respondents in category), x_i is the value of the observation (the assigned weight for that category), and N' is the number of non-zero weights

3.2 Respondents Work Profiles, Regions of Application and Experience Years

The profiles, regions and years of experience where captured in the first four questions. Out of the 41 respondents, approximately, half were from the "Middle East and North Africa (MENA)" region, 20% from "USA and Canada", 10% from "Europe" and the remaining from "South Africa" and "Australia", with some respondents (12%) not providing any information to their location. The diversity of the respondents' regions allowed for deductions of both developing and developed countries. Accordingly, all the statistics concluded were according to three categories: MENA, USA and Canada, and Others. **Error! Reference source not found.** below shows the respondents' distribution by region and years of experience. Five categories were developed each with a five-year range starting from new graduates (zero experience) to more than 20 years of experience on the job. Then, the average of each year range was assumed to attain the statistics. The resulting average collective experience was around 13 years, with more than 70% above 10 years of experience.

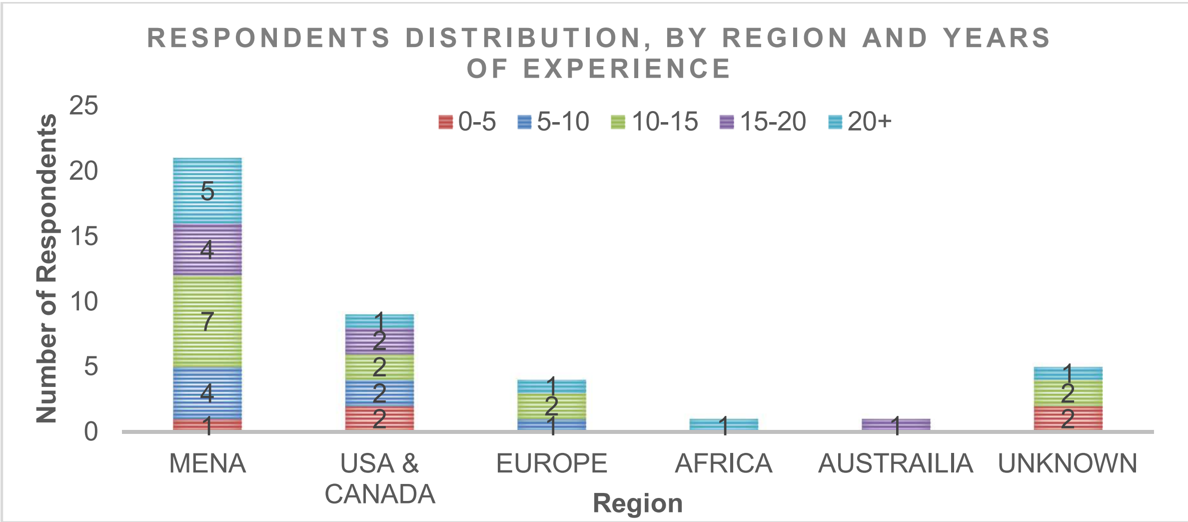

Figure 1 Respondents Distribution, by Experience Years and Region

The respondents were asked to divulge their current occupation, and the time they spent employed as either an "Owner", a "Contactor", an "Architect", etc. Almost 60% of the respondents occupied project controls positions, and 21% percent in engineering and site management positions. Additionally, over half of the collective experience of the respondents was spent as a general contractor or as a construction manager / project manager. This indicates that the pool answering the questionnaire are of the adequate knowledge and proficiency to handle the issues of workspace on construction jobsites. Respondents were also asked to reveal the degree of expertise (on a 5-point scale) in relevant domains. Table **Error! Reference source not found.** below shows the spreading of the respondents. Collectively, respondents are most experienced in "Residential" and "Commercial" construction, with "Industrial" being the third. "MENA" follows the same pattern, but not "USA and Canada", where they are most experienced in industrial construction. The weighted average "W.A" and the weighted standard deviation "W.SD" were calculated for each domain per the major regions, after quantifying the point scale from zero (being not important at all) to four (being extremely important). The "others" presented were for Infrastructure, Marine and Religious Construction.

Table 2 Respondents Expertise Spreading of Domains

	ALL			MENA			USA & CANADA			OTHERS		
	W.A	**W.SD**	**Rank**	**W.A**	**W.SD**	**Rank**	**W.A**	**W.SD**	**Rank**	**W.A**	**W.SD**	**Rank**
Residential	2.54	0.94	1	3.00	0.85	1	1.67	0.84	2	2.36	1.10	1
Commercial	2.15	0.78	2	2.52	0.89	2	1.56	0.56	3	1.91	0.91	3
Educational Facilities	1.24	0.40	5	1.33	0.50	5	1.33	0.30	5	1.00	0.48	6
Hospitals & Medical Facilities	1.22	0.62	6	1.33	0.45	5	0.89	0.55	6	1.27	0.94	4
Industrial	2.00	0.86	3	1.86	0.63	3	2.33	0.79	1	2.00	1.07	2
Electric Generating Plants	1.39	0.90	4	1.52	0.91	4	1.44	1.06	4	1.09	0.66	5
Sports Facilities	1.05	0.59	7	1.24	0.56	7	0.89	0.55	6	0.82	0.77	7

3.3 Importance of Workspace Planning

To determine the industries views of the importance of workspace management, three questions were asked: (1) if they had witnessed workspace interference before in previous projects, (2) which construction domain would need workspace management the most, and (3) which project type as well. Considering whether workspace interferences were witnessed in previous projects, 38 of the 41 respondents answered "YES". As for the construction domain, respondents were asked to indicate the importance of seven construction domains on a five-point scale like the scale used for the work profiles. “Industrial” scored a 3.34 / 4 weighted average with 0.88 standard deviation, indicating that is the most domain in need for workspace management. “Electric Generating Plants” and “Hospitals and Medical Facilities” were the second and third, with averages of 3.29 and a standard deviation of 0.79 and 0.66 respectively. The other domains suggested were “Infrastructure” and “Marine” construction. The ranking of domains per region is shown in Table 3. This ranking shows that “Residential” and “Commercial” projects are not a suitable domain to test workspace management approaches. Additionally, any approach implemented should be tested on at least “Hospitals and Medical Facilities”, and “Electric Generating Plants” as they are almost as important as the “Industrial” domain.

Table 3 Respondents' Ranking of Workspace Management Importance per Domain

	ALL			MENA			USA & CANADA			OTHERS		
	W.A	W.SD	Rank	W.A	W.SD	Rank	W.A	W.SD	Rank	W.A	W.SD	Rank
Industrial	3.34	0.88	1	3.24	0.84	3	3.67	0.53	1	3.27	1.08	2
Hospitals & Medical Facilities	3.29	0.66	2	3.33	0.63	1	3.11	0.12	3	3.36	0.99	1
Electric Generating Plants	3.29	0.79	2	3.33	0.80	1	3.22	0.52	2	3.27	0.96	2
Commercial	2.93	0.88	4	2.95	0.88	5	2.78	0.65	5	3.00	1.07	4
Educational Facilities	2.93	0.81	4	3.00	0.69	4	2.78	0.65	5	2.91	1.11	5
Sports Facilities	2.73	0.95	6	2.62	0.94	7	2.89	0.48	4	2.82	1.15	6
Residential	2.59	0.98	7	2.81	0.89	6	2.56	1.00	7	2.18	1.10	7

3.4 Impact of Workspace Interferences

To show the importance of workspace planning, the respondents were asked to estimate the impact of four workspace interference types: “Labor – Labor (L-L)”, “Labor to Material (L-M)”, “Labor – Equipment (L-M)”, and “Equipment – Equipment (E-E)”. The estimate was for schedule, safety, productivity and cost. The results shown in Table 4 indicate that “Productivity” is the most impacted aspect as it is the highest in three of the four interference types, followed by “Safety”. Additionally, it is concluded that “Equipment-Equipment” interference is the most devastating type. Among the additional impacts suggested by the respondents, “Quality” was mentioned 11 times, “Constructability” (method) mentioned six times and risk three times.

Table 4 Respondents' Estimation of Workspace Interferences' Impacts

(Interference Type) Project Aspect	All (41)			MENA (21)			USA & CANADA (9)			OTHERS (11)		
	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD
(E-E) Productivity	1	3.00	0.99	2	3.10	0.86	1	3.44	0.87	7	2.45	1.01
(E-E) Safety	3	2.85	1.14	3	3.10	1.11	5	3.00	1.05	11	2.27	1.05
(E-E) Cost	6	2.73	1.11	4	2.95	1.05	6	3.00	1.18	13	2.09	1.01
(E-E) Schedule	8	2.71	1.21	6	2.76	1.29	7	2.89	0.80	8	2.45	1.27
(L-E) Safety	2	3.00	1.05	1	3.19	0.86	8	2.89	1.31	2	2.73	1.04
(L-E) Productivity	4	2.83	0.98	5	2.76	0.81	2	3.11	1.01	3	2.73	1.22
(L-E) Schedule	7	2.71	1.00	7	2.67	1.00	3	3.00	0.91	5	2.55	1.03
(L-E) Cost	10	2.39	0.94	10	2.33	0.93	11	2.44	0.95	6	2.45	0.95
(L-L) Productivity	5	2.80	1.10	8	2.67	1.00	4	3.00	0.91	1	2.91	1.37
(L-L) Safety	9	2.44	1.16	9	2.38	0.97	9	2.67	0.99	9	2.36	1.52
(L-L) Schedule	11	2.39	1.09	12	2.19	0.99	10	2.56	1.11	4	2.64	1.22
(L-L) Cost	15	1.98	0.90	16	1.86	0.83	12	2.44	1.01	15	1.82	0.80
(L-M) Productivity	12	2.27	1.09	11	2.24	1.12	14	2.33	0.82	12	2.27	1.21
(L-M) Schedule	13	2.17	0.88	15	2.05	0.95	13	2.33	0.63	10	2.27	0.89
(L-M) Cost	14	2.07	0.91	14	2.05	0.81	15	2.11	0.85	14	2.09	1.13
(L-M) Safety	16	1.93	1.16	13	2.14	1.18	16	1.78	0.70	16	1.64	1.27

3.5 Frequency and Duration of Lookahead

Over 34% of the respondents believe that workspace interference detection and resolution must be done on either a weekly or a daily basis, which also was the case for the regions individually. However, when it came to the desired duration to detect interferences, each region had a different perspective. Collectively, the desired duration was a tie between one week or one month. “MENA” region, with an expertise more inclined towards residential / commercial domain and time employed more with general contractor, desired a duration of one week. “USA and CANADA” Region, with an experience more inclined towards industrial, and more time employed as architect / engineer desired a duration of one month. While others, with experience divided between industrial and residential, and more time employed as construction manager/project manager desired the overall project duration to detect for interferences.

3.6 Inputs for Modeling

Results of the literature review indicated the following as the most used inputs for workspace modeling: (1) workspace size, (2) Location, (3) Workspace nature, (4) Activity duration, and (5) Crew movements. Accordingly, respondents were asked for their views of such and to suggest other possible parameters with a five-point scale of “Strongly Disagree (ND)”, “Slightly Disagree (SD)”, “Neither Agree nor Disagree (NAD)”, “Slightly Agree”, and “Strongly Agree (NA), which were weighed from negative two till two respectively, and are presented in Table 5. The results showed a “slightly agree” majority from all regions to all the inputs. The additional inputs most recommended by the entire pool were “Crews’ years of Experience” and “Risk Attitude”. For MENA region alone “Crew's Speed to Devise Time Corrective Actions” and “Activity Floats (Schedule Criticality)” were of the same importance. For USA and CANADA, “Activity Type” was equally important and for others it was “Number of Workers per Crew”. These additional inputs demonstrate the respondents focus on creating more human-related parameters which indicates the need for a stochastic approach for workspace modeling.

Table 5 Respondents agreement to inputs

	All							
	Agree / Disagree						Weighted	Weighted
	ND	SD	NAD	SA	NA	Total	AV.	SD
Workspace Size (length, width and height)	0	1	5	11	24	41	1.41	0.98
Activity / Workspace Location	0	2	2	20	17	41	1.27	0.91
Workspace Nature (labor, equipment, material, etc.)	0	0	3	16	22	41	1.46	0.81
Activity Duration	0	6	1	12	22	41	1.22	1.22
Crew Movements (north-south, south-north, right-left, left-right, etc.)	0	1	6	11	23	41	1.37	1.00

3.7 Outputs for Resolution

Similar to 3.6, respondents were asked to agree on the following outputs that are used to devise resolution strategies: (1) interference volume, (2) Interference location, (3) interference duration, (4) interference type and (5) activity float. With the same approach as 3.6, the responses were analyzed, and showed a “slightly agree” or higher response for all outputs except for activity floats which scored less than one. The additional outputs recommended to be able to devise a sound resolution strategy as shown in Table 6 were “Crews’ capability to work in proximity with other crews / obstacles”, which shows that the practicality of resolution strategies depend mainly on capturing the interactions between crews of different tasks. This is a major indicator for a more bottom-up approach rather than a deterministic one. Other outputs suggested were “Number of Workspace Interferences per activity”, and “number of activities involved with each interference”.

Table 6 Respondents suggestion for additional outputs

	All			MENA			USA & CANADA			OTHERS		
Additional Outputs	**Count**	**%**	**Rank**	**Count**	**%**	**Rank**	**Count**	**%**	**Rank**	**Count**	**%**	**Rank**
Crews' capability to work in proximity with other crews / obstacles	25	60.98%	1	15	36.59%	1	7	17.07%	2	3	7.32%	3
# of Workspace Interferences	20	48.78%	2	11	26.83%	3	5	45.00%	1	4	9.76%	2
# of Activities involved	19	46.34%	3	9	21.95%	4	7	3.00%	5	3	7.32%	3
Magnitude of Workspace Interferences' impact on involved crews' productivity	18	43.90%	4	8	19.51%	5	5	6.00%	4	5	12.20%	1
Crews' relative expertise in dealing with similar workspace interferences	17	41.46%	5	12	29.27%	2	3	7.32%	3	2	4.88%	6
None	4	9.76%	6	1	2.44%	6	0	2.00%	6	3	7.32%	3
Others	1	2.44%	7	1	2.44%	6	0	0.00%	7	0	0.00%	7

4 CONCLUSION AND FUTURE WORKS

The following questionnaire reviewed the construction markets' perspective on the use and benefit of workspace management tools. Significant findings were concluded, showing that: (1) over 92% suffer from workspace collisions, (2) these collisions impact productivity the most followed by safety (3) the most devastating collision type is "Equipment - Equipment" and the most impacted domain is industrial. However, the most important findings to this questionnaire is the indication of the need to shift the modeling approach toward a more stochastic manner that would consider crews' specific attributes and their interaction with one another, which was shown in the choice of the respondents for the additional inputs and output parameters. Future works will focus on (1) testing various modeling approach to determine the most suitable to model workspaces (2) Identifying the sources of uncertainties in workspace modeling and quantifying them and (3) Considering crew specific attributes and human interaction for customization of resolution strategies.

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