Decision Support within Complex Urban Operations

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ABSTRACT

A commander's decision-making for operations in an urban environment requires support by specialized expertise and visualization assets to make best use of the process. This paper discusses the benefits of integrating decision-preparation and decision-making in the reality-virtuality continuum with special consideration of virtual reality and shows possible time savings.

1.0 INTRODUCTION

Decision-making is about taking responsibility for personnel, materiel, and the accomplishment of the mission. To offer the best possible support to the commander, the specialists in a headquarters are dedicated to support commander's in this responsibility and need state-of-the-art equipment and processes to fulfill their task. Three factors will determine military command in the future: urbanization, digitalization, and artificial intelligence. Mission command will remain the superior principle to cope with these challenges [1]. The commander's very distinct role in decision-making to ensure the: *"[…] three intimately connected functions: mission definition, mission management and mission motivation."* [2, p.69] poses a special challenge in the urban operations environment and its associated requirements [3]. Most parts of the infrastructure are not easily visible or hidden from view. How should a commander define a mission and responsibly assign tasks without really knowing the operational environment, how should his staff officers prepare decisions without knowing the necessary details of an urban area of operations? In addition to the consulting service provided by the experts of the Urban Operations Support Cell (UOSC) [4] [5], visualization is a pivotal step in the operations process to *"[…] visualize and describe the operation's end state and operational approach […] "* [6, p.1-4] To improve decision-preparation and decision-making (in the wake of the possibilities of artificial intelligence and assigning roles to it this clear separation gains significance [7]) visualization technologies beyond the limitations of the real world seem to be of uttermost importance.

State-of-the-art command and control information and battlefield management systems are primarily based on two-dimensional displays. This will remain also in the future as the majority of planning drawing will be done on maps - also from the perspectives of training and redundancy. Three-dimensional representations are emerging as e.g. Sitaware [8] or Szafran [9] show, but interconnected systems integrating the planning activities into the reality - virtuality continuum [10, p.283] are not yet available although the need that an *"[…] effective and survivable command post must exist in a nonphysical construct."* [11, p.21] has already been stated. Understanding visualization support within the above-mentioned continuum enables application of the different methods and tools in different stages of the process taking advantage of their special characteristics.

Krinizki et.al. conducted an experiment on the spatial understanding of an apartment in real space, in virtual reality and on a desktop screen. Although the results were quite similar, inexperienced users seemed to have an easier time in virtual reality, especially for unknown and complex objects [12]. It is obvious that an urban environment is many times more complicated than a simple apartment and therefore visualizations can be of great benefit. We started to work on the visualization of the hidden parts of urban infrastructure – the subterranean – already several years ago [13] and showed during our experimental research that it is a mandatory requirement and improves mission accomplishment to enter this environment virtually before the start of the operation [14].

To that end, we assume, that

- visualization will improve the quality of environmental perception of urban environments,
- visualization will reduce the time required to obtain the comprehension of the situation in urban environments,
- improvements in the content production will reduce time.

2.0 IMPROVING DECISION-MAKING WITHIN A DIGITAL HEADQUARTERS

In the following we deal with the Austrian Military Decision-Making Process (MDMP) which is conducted in accordance with the service regulations and strictly regulated in terms of process. In terms of content, a distinction is made between elementary tactics and applied tactics. Elementary tactics encompass everything that is laid down in regulations in terms of standards and procedures. It can be learned and represents knowledge and skill. Applied tactics, on the other hand, represent the application of elemental tactics in a particular situation. It builds on experience, personality and talent and is not learnable in the narrow sense, but must be developed through practice [15, p.84 ff.]. This means that a strictly regulated analog process can be regarded as fundamentally promising. However, it is only through personal practice and experience that a good and efficient result is achieved.

With digitization, especially due to the availability of AI, there is an opportunity to optimize the MDMP, while retaining the previous process steps. The goal of this optimization lies in a qualitatively better result with shorter processing time. The previous experiences made during training at the Institute of Advanced Officer Training allow the conclusion that the processing time can be reduced significantly. The increase in quality is mainly due to the fact that the staff member can concentrate on the creative part of the assessment and that all possibilities of visualization are used for this purpose. In this way, the respective assessment step is carried out in the most suitable application. Virtual and augmented reality allow a collaborative view into details hidden on conventional maps and create a better idea of the surrounding conditions. This allows even a less experienced person to achieve a significantly better result, which would otherwise only be expected in the context of the tactics used.
The subsequent figures (fig. 2-1, 2-2) show the comparison of timings in a planning procedure without and with time pressure by application of available means within our DHQ (Digital HeadQuarters). Effective working time can be reduced by 30% and 50% respectively.

Step and time allocated		Working time			DHQ / #COMANND Automation
		w.o.	w.	red.	
Issue of orders BDE	30′				Receipt of Mission (synchronized CONOPS)
	10′	10′	10′		Transfer of enemy and own forces into the system (blue-force tracking and sensor enabled)
Situation meeting	15′				
Mission Analysis	15′	15′	10′	-5′	Check situation enemy forces and assign capabilities from database
					Automated collection of contributions and meeting preparation
					Time and area of meeting engagement
Orientation Meeting	15′				
Situation Estimate #1/1	75′	75′	45′	-30′	Evaluation of the terrain (general, effects on enemy and own operations, tactically coherent terrain)
					Availability of own forces (position, status, capabilities)
					Evaluation of Enemy COA's and proposal of most likely enemy intent based on the updates recognized
					Collection of contributions and meeting preparation
					Visualization of enemy possibilities and most likely enemy intent in the AR sandbox
Intermediate Meeting #1	20′				
Situation Estimate #1/2	45′	45′	30′	-15′	Collaborative COA development (VR, S^3OMT)
					Evaluation of climate, weather and visibility
					Recommendations on battle positions and engagement areas
					Collection of contributions and meeting preparation
Intermediate Meeting #2	15′				
Situation Estimate #2	20′	20′	10′	-10′	Comparison of combat power and effectiveness
					Recommendation of most promising COA
					Determination and coverage of requirements
					Collection of contributions and meeting preparation
Coordination Meeting	10′				
	20′	20′	5′	-15′	Recommendations on the consideration of COAs
					Collection of contributions and meeting preparation
Decision Meeting	20′				
	10′	10′	10′		CDR's decisions changed in real-time within MR
Staff Meeting	10′				
CONOPS preparation	120′	120′	100′	-20′	AI-assisted synchronisation wargame
					Logistical and communication coverage
					OPLAN, OPORD generated semi-automatically
					collection of contributions and meeting preparation
Issue of Orders BN	30′				
	480′	315′	220′	95′	

Figure 2-1: comparison of the times in a planning procedure without time pressure. Working time without (w.o.), with (w.) and reduced (red.).
(Illustration by authors based on [16, p.91])

Step and time allocated		Working time			DHQ / #COMANND Automation
		w.o.	w.	red.	
Issue of orders BDE	30′				Receipt of Mission (synchronized CONOPS)
Mission Analysis	10′	10′	5′	-5′	Transfer of enemy and own forces into the system (blue-force tracking and sensor enabled)
					Check situation enemy forces and assign capabilities from database
					Automated collection of contributions and meeting preparation
					Time and area of meeting engagement
Orientation Meeting	10′				
Situation Estimate	25′	25′	15′	-10′	Evaluation of the terrain (general, effects on enemy and own operations, tactically coherent terrain)
					Availability of own forces (position, status, capabilities)
					Evaluation of Enemy COA's and proposal of most likely enemy intent based on the updates recognized
					Collaborative COA development (VR, S^{3}OMT)
					Evaluation of climate, weather and visibility
					Recommendations on battle positions and engagement areas
					Comparison of combat power and effectiveness
					Recommendation of most promising COA
					Determination and coverage of requirements
					Recommendations on the consideration of COAs
					Collection of contributions and meeting preparation
Decision Meeting	15′				
CONOPS preparation	15′	15′	7′	-8′	AI-assisted synchronization wargame
					Logistical and communication coverage
					OPLAN, OPORD generated semi-automatically
					Collection of contributions and meeting preparation
Issue of Orders BN	15′				
	120′	50′	27′	-23′	

Figure 2-2: comparison of the times in a planning procedure with time pressure. Working time without (w.o.), with (w.) and reduced (red.).
(Illustration by authors based on [16, p.92])

However, it is vital to emphasize that decisions will continue to be made by humans and that digital tools are only aids. In this context, the plausibility check of the proposed results becomes immensely important. The necessary validation/falsification is also one of the reasons why the process as such must not be changed.

Another advantage of digital support is that biasing can be avoided as far as possible. In the previous, analog processing, the enemy options were assessed by the intelligence officer, who, however, was already influenced by the results of the orientation meeting and determined the further process for the whole staff by the formulation of the enemy's most likely intent. Due to the time constraints regular verification during planning was difficult. This biasing can be overcome now, although it has to be kept in mind for future developments, that artificial intelligence is also biased.

Another neglected factor for quality improvement is the extended use of simulation. So far, it has been used only in the context of wargames, usually after decision making. However, if it is used in parallel from the first step of the MDMP it is an essential tool to increase the processing quality. Through operations research in line with the process, the assessed options are checked for their probability of success while the decision is still being made. Thus, automated prioritization and risk assessment is performed, this allows decision making according to rational, reproducible, and scientific criteria.

3.0 MAKING THE HIDDEN VISIBLE – S³OMT

The S³OMT – based on [17] – is a collaborative VR-enabled Command and Control Information System (C2IS), developed to provide deeper insight into the triple-S (Supersurface, Surface, Subsurface) environment [18] of complex urban operations. It enables its users to seamlessly move from command and control on a traditional 2D-map into the third dimension using virtual and augmented reality. Therefore, it provides a 3D version of tactical symbols (including Arrows, Polygons etc.) from the NATO APP-6(C) standard.
Figure 3-1 gives a simple example for the advantage this provides: In the traditional two-dimensional view it is not obvious if the contaminated area is within the tunnel system or on the surface above. In virtual reality this is immediately obvious, as the user's natural stereoscopic view is used to see the volume. Note that this is not transported well in the Figure, since printing this screenshot suffers from the same problem of projection to a two-dimensional surface.

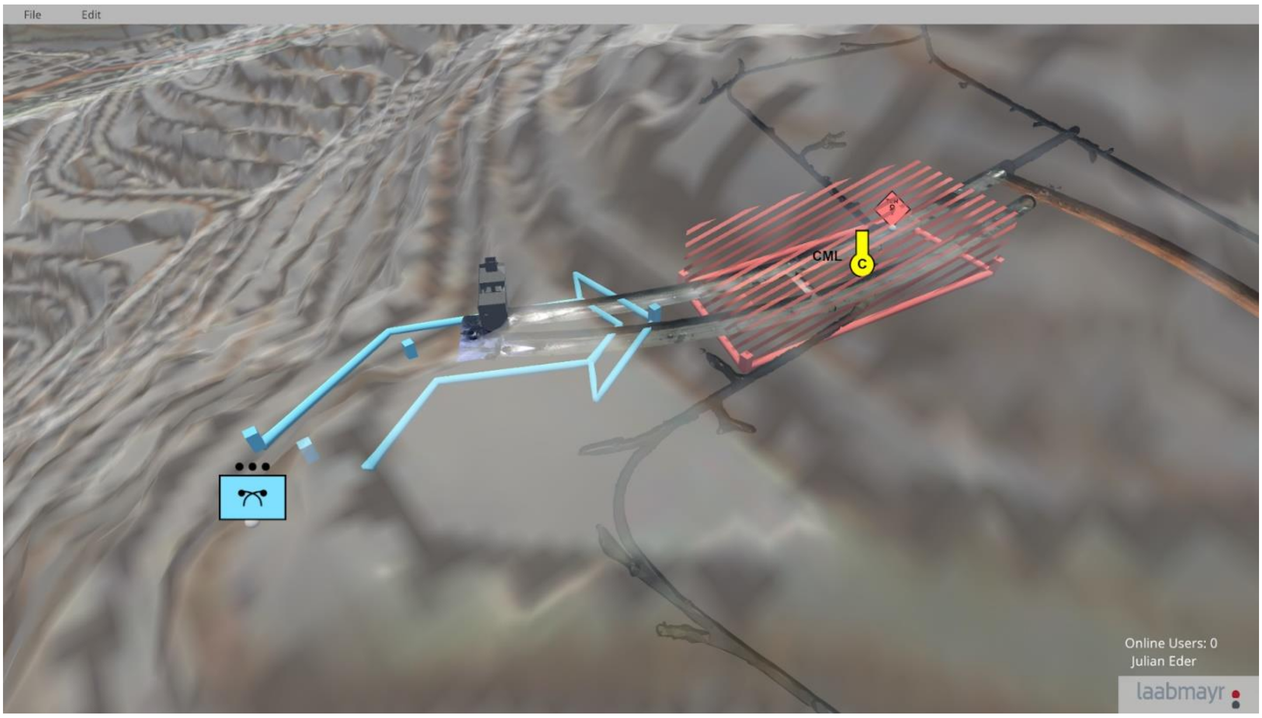

Figure 3-1: 3D representations in the triple-S environment (Illustration by Laabmayr, data: Zentrum am Berg, www.data.gv.at)

The importance of this issue rises with growing complexity within urban environments where multiple layers of subsurface infrastructure (metro-tunnels, sewage, etc.), surface and supersurface infrastructure (terrain, buildings, flight corridors, etc.) have to be integrated into mission planning. Figure 3-2 illustrates this within the virtually created city for the IRON NIKE research and development activities. Additionally, it shows the ability to integrate live feeds from various sources as e.g., geolocated surveillance cameras, which will be accessible in urban areas thereby increasing the number of reconnaissance assets. The example shows mechanized infantry advancing via the tunnels and infantry advancing on the surface.

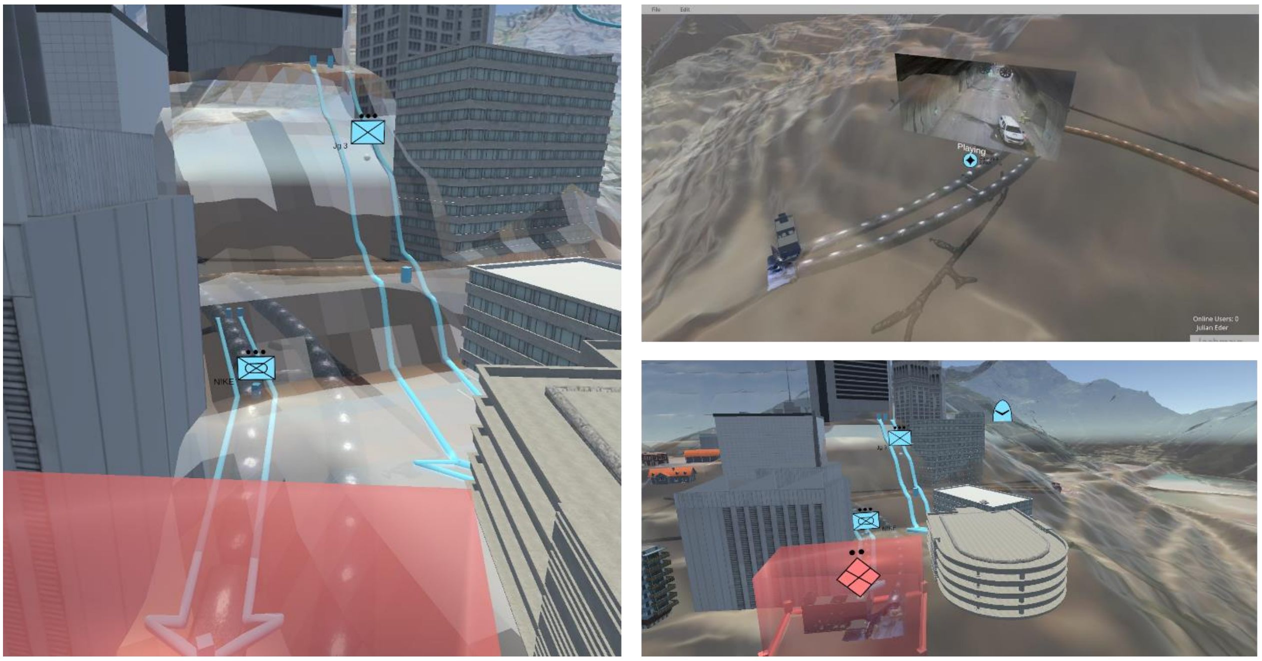

Figure 3-2: Mission planning in VR enables intuitive understanding of the complex environment by quickly taking different perspectives enables (left and bottom right). The integration of live camera feeds enriches the planning with real-time data (top right). (Illustration by Laabmayr, data: Zentrum am Berg, www.data.gv.at)

With the development of the comprehensive visualization and the rapid integration of data sources [14] the groundwork for improving the military decision making process through digitalization has been laid. The next step will be to integrate simulation and artificial intelligence tools to further enhance the ability to make more informed and better-quality decisions.

4.0 VIRTUAL REALITY – A DIGITAL INTERFACE FOR MILITARY OPERATIONS

Digitization and technological developments in the form of drones, new radar and camera technology, and sensors in general are leading to an increasing amount of information to be included in the operational command of the military, fire department, police, and disaster control [19]. The higher information density enables a more realistic and differentiated situation representation and assessment, while at the same time increasing the complexity for the operations commander, who must process this information.

This processing fundamentally consists of the selection, organization, and integration of information, which requires working memory in particular. Optimizations and advancements of multimedia design principles are required to enable the most efficient use of working memory [20]. The goal is to optimize the use of the working memory and the cognitive load for task performance.

Cognitive Load Theory (CLT) [21] divides cognitive load into three domains:

- Intrinsic Load (IL) is determined by the complexity of information (e.g., complex sentence structure).

- Extraneous Load (EL) is determined by information representation (increases, for example, when switching between documents to gather information).
- Germane Load (GL) is the part of the cognitive resource, which is used for problem solving, understanding and own mental models (increases if information is simply prepared and persons reproduce and manifest it mentally).

Thus, the goal of digital interfaces is to minimize EL and maximize GL. It is questionable whether the increase in information, which represents a potential cognitive overload, can be optimized by new technological interfaces. The targeted application of mixed realit represents a highly potent new technological interface.

Virtual reality describes the use of a head-mounted display (HMD), which creates a complete digital environment in a 360° all-around view [22]. These HMD's can differ depending on the hardware and degrees of freedom. The advantage of VR use lies in the higher immersion and presence experience of the users, which in turn can lead to a higher flow experience, intrinsic motivation, and more effective use of cognitive capacities for task performance. Nevertheless, especially before the practical application of such technological innovations in the military context, research projects must investigate the effectiveness and possible risks. This investigation of the effectiveness of VR use on decision making was a core concern of the research project described below.

The IRON NIKE research and development program [18] joins multinational civilian and military scientists from a wide range of disciplines. Within the NIKE IMMERSION research project, the influence of VR on decision quality and decision speed was investigated.

The between-subjects study included a total of N = 139 soldiers, who were randomly assigned to the experimental or control group. The task for both groups consisted of solving 10 tactical scenarios in which participants had to allocate resources within a tunnel system to solve specific military problems. Solution correctness as well as speed were measured here, which were accounted for in a decision-making score:

$$((\sum \text{Correct allocation} / \sum \text{Time}) \times \sum \text{Scenarios with correct sequence}).$$

The two groups differed only in their respective technological interfaces. The experimental group solved the scenarios by using VR and the control group used a normal desktop view. Figure 4-1 shows one of the scenarios and also demonstrates the extension of the scenario site of in total around five kilometers of subterranean infrastructure.

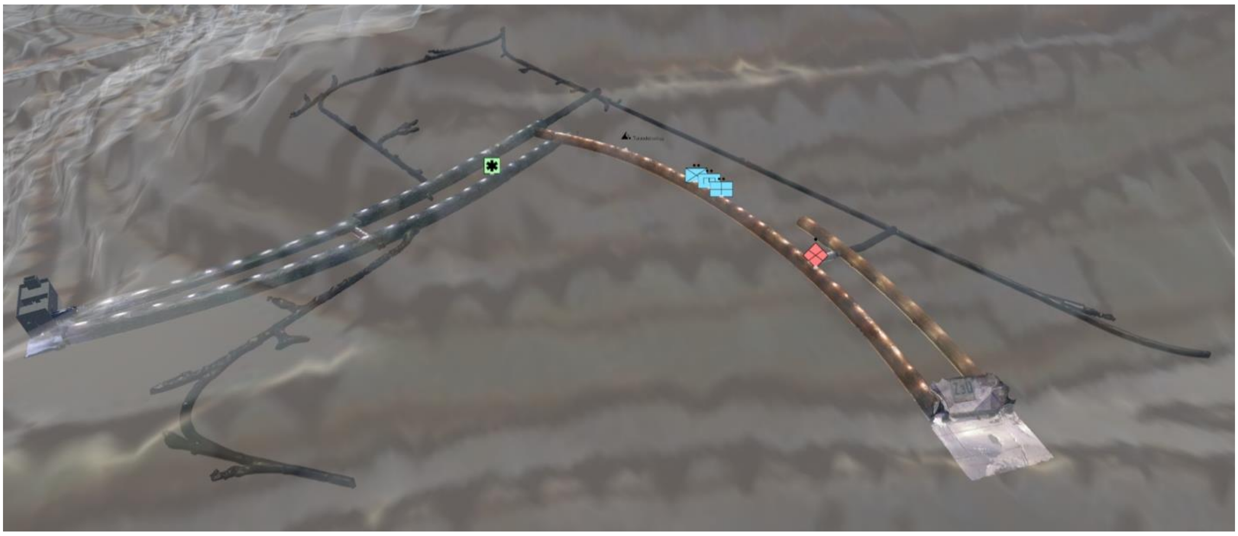

Figure 3-1: A selected scenario used in NIKE IMMERSION. It is already obvious that the perception of the situation is more lucid than using a two-dimensional representation. (Illustration by Laabmayr, data: Zentrum am Berg, www.data.gv.at/)

The results discussed here have not yet been conclusively evaluated, however, already provide information about clear tendencies. Basically, there was a high effect of VR technology on decision making. The decision-making score was on average 18.80 points higher in the experimental group. The difference was highly significant ($t(137) = 5.02$, $p < .001$) and indicated a strong effect. The initial examination of the presence experience showed that the experimental group had a significantly higher presence experience than the control group. This difference was also highly significant and showed a high effect size. In addition, perceived ease of use was shown to be an important predictor of presence experience.
Overall, based on previous findings, this study shows that VR holds great potential to be applied as a possible future technological interface in mission planning and execution. Subjects made more correct decisions in significantly less time in the VR environment. In particular, the experience of presence was a critical factor here. VR could, as hypothesized, reduce Extraneous Load and increase Germane Load. However, further research needs to be conducted on this assumption. Usability also emerges as a fundamental factor of effective use in VR. If VR is also applied in military operations, the principle of human-centered design must be applied to further optimize usability continuously.
Limitations of the study consist in the representativeness. The sample consisted solely of soldiers, so further research needs to be conducted in other organizations such as firefighters and police in order to extend the results to other emergency organizations. Additionally, this study is a clearly delineated experiment. The extent to which VR can also be used in real operations must be investigated in more realistic situations in which arrangements are also made within the operations center. In addition, it should be mentioned that VR is a new technology that basically generates interest among the experiment participants. The extent to which this factor of higher interest, which was not present in the control group (desktop use), had an influence on the results in decision making cannot be evaluated based on the results, but represents a potentially biasing factor. It is important to emphasize that the results presented here are only indicative and the final evaluation is still pending. Nevertheless, the trends are very clear. VR has the potential to more effectively utilize the decision maker's cognitive capacity through a higher level of presence experience and to enable a better situation assessment and decision making.

5.0 CONCLUSIONS AND OUTLOOK

Rising probabilities of urban operations require a thorough preparation for this extremely demanding environment. After setting the stage with regard to the state-of-the-art we discussed the Austrian decision-making process and possible time savings that we could achieve during training within our DHQ (Digital HeadQuarters) using visualization and collaboration means. The main tool for using the whole range of the reality-virtuality continuum is the Triple-S Operations Mission Tool (S^3OMT), specifically designed to enable planning in an urban environment. Finally, we have taken a look at the initial results of a study on the use of virtual reality in decision making in the S^3OMT environment. The results are promising but require further quantitative and qualitative investigation, especially in realistic decision-making scenarios. Generally, improvements are apparent in the quality of environmental perception, the time required to obtain a better comprehension of the situation and the time needed for content production during staff procedures thereby increasing the quality of mission accomplishment in urban operations.
The improvements of getting a clearer picture in less time tempt pressure on commanders to come to decisions more quickly. But we must counteract this trend. Although we can rely on technological assistance, there is still a need for thorough abductive reasoning for the commander. The time won is to be used for other activities namely conducting plausibility checks and gaining deeper insights for more profound decisions.

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