THE ROLE OF HUMAN-ROBOT INTERACTION IN ENHANCING EFFICIENCY AND SAFETY IN INDUSTRIAL ROBOTICS

Author:

Felix N. Igbeghe (Engr.)
Rivers State University
(Nkpolu – Oroworukwo, Nigeria).

E-mail:
igbeghefelix@gmail.com

Reviewers:

Ferenc Mező (Ph.D.)
Eszterházy Károly Catholic University
(Hungary)

Ildikó Pšenáková (Ph.D.)
Trnava University in Trnava (Slovakia)

...and two more anonymous reviewers

Absztrakt

AZ EMBER-ROBOT INTERAKCIÓ SZEREPE AZ IPARI ROBOTIKA HATÉKONYSÁGÁNAK ÉS BIZTONSÁGÁNAK NÖVELÉSÉBEN

E tanulmány az ember-robot interakció (HRI) szerepét vizsgálja az ipari robotika hatékonyságának és biztonságának növelésében. Hangsúlyozza a hatékonyság és a biztonság fontosságát az ipari robotikában, kiemeli a termelékenység javításában, a költségek csökkentésében és a dolgozók jólétének biztosításában játszott kritikus szerepet. Az eredményeket négy alapvető robotfeladat teljesítési idejével összhangban elemeztük. Meghatározásra került a hibaarány, az „ütközési" kockázat, az ergonómiai igénybevétel és az általános termelékenység. Az az ember-robot interakció kontextusában az egyes feladatok elvégzéséhez szükséges idő, valamint a munkafolyamat termelékenység és a biztonság növelése érdekében történő optimalizálása értékelésekor azt találták, hogy az 1. feladat átlagos feladatvégzési ideje 10,63 perc volt; míg a 4. feladat 16,39 perc volt. Ez azt jelzi, hogy egyes kritikus feladatok további erőforrásokat vagy kiigazításokat igényelnek a folyamat egyszerűsítéséhez és az általános teljesítmény javításához. A biztonsági besorolás meghatározásakor minden feladatnál a hibaarány 100%-os teljesítményből való kivonásával megfigyelhető, hogy a 2. feladat 98%-os, míg a 3. feladat 92%-os biztonsági besorolású, ez azt jelzi, hogy a biztonsági ráta feladatonként eltérő. Az egyes feladatok termelékenységi mutatóit úgy határoztuk meg, hogy a feladat teljesítési arányát megszoroztuk a feladat hatékonysági arányával. jelzi az ember-robot interakció szerepét az általános termelékenységeben, az ipari robotika hatékonyságának és biztonságának fokozásában, az ipari robotikában. Az ember-robot

interakció integrálása az ipari robotikába szinergikus megközelítést kínál a gyártási környezetek hatékonyságának és biztonságának javításához.

Kulcsszavak: feladatok elvégzésének ideje, biztonság, ütközés, ergonómia, termelékenység
Diszciplínák: informatika, robotika

Abstract

This study examines the role of human-robot interaction (HRI) in enhancing efficiency and safety in industrial robotics. Emphasize the importance of efficiency and safety in industrial robotics, underscoring the critical role in improving productivity, reducing costs, and ensuring the well-being of workers. The results were analyzed inline with the four basic robot tasks' completion time. The error rates, collision risks, ergonomic strain, and overall productivity were determined. From the evaluation of the time required to complete each task in the context of human-robot interaction and optimize the workflow to enhance productivity and safety, it was observed that the average task completion time for task 1 was 10.63 minutes; while task 4 was 16.39 minutes. This indicates that some critical tasks require additional resources or adjustments to streamline the process and improve overall performance. In the determination of the safety rating, for each task by subtracting the error rate from 100% performance, it was observed that task 2 has a safety rating of 98% while task 3 has a safety rating of 92%, this indicates that the safety rating is different with respect to a different task. The productivity metrics for each task were determined by multiplying the task completion rate by the task efficiency rate. Hence, the Average Productivity Rating was 0.7449 which indicate the overall productivity in the role of human-robot interaction in enhancing efficiency and safety in industrial robotics. The integration of human-robot interaction in industrial robotics offers a synergistic approach to improving efficiency and safety in manufacturing environments.

Keywords: tasks completion time, safety, collision, ergonomic, productivity
Discipline: informatics, robotics

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Introduction

In recent years, the integration of human-robot interaction (HRI) has emerged as a crucial factor in enhancing the efficiency and safety of industrial operations. Industrial robots have traditionally operated in isolation, performing repetitive tasks with high precision and speed. However, the advancement of technology has enabled the seamless collaboration between human operators and

robotic systems, paving ways for improved productivity, flexibility, and safety in industrial settings Silvia et al. (2022).

Efficiency in industrial operations is often measured by factors such as productivity, error rates, and downtime. According to a study by Zhou et al. (2022), the integration of HRI in industrial robotic systems has shown to significantly improve productivity by leveraging the cognitive and dexterous abilities of human operators to optimize task execution, adapt to changing environments, and address complex problems in real-time. The collaboration between humans and robots can lead to increased productivity through the allocation of tasks based on the strengths and capabilities of each entity.

Safety is another critical aspect of industrial operations that has been significantly enhanced through the integration of HRI. Industrial robots are powerful machines capable of performing tasks that may pose risks to human workers if not properly controlled. Introducing HRI mechanisms such as safety sensors, collaborative workspaces, and intuitive interfaces, can ensure the safety of both human operators and robotic systems. Research by Mohammadi et al. (2020) emphasized that human operators can provide oversight, decision-making, and intervention in high-risk scenarios, thereby reducing the likelihood of accidents and injuries.

The role of HRI in industrial operations goes beyond efficiency and safety; it also promotes user satisfaction, knowledge transfer, and skill development. According to a study by Chang et al. (2019), a collaborative work environment where humans and robots interact seamlessly fosters a culture of innovation, continuous learning, and mutual support. This not only improves the overall performance of industrial operations systems but also provides a rewarding and engaging experience for human operators.

Studies by Chen and Tan (2021) have emphasized the role of HRI in enhancing safety in industrial robotics. By integrating safety features such as proximity sensors, collision detection systems, and safety-rated control interfaces, human operators can work alongside robots in a shared workspace without compromising their well-being. This collaborative safety approach minimizes the risk of accidents and injuries, ultimately creating a safer working environment for all stakeholders, Diego et al.(2021). .

Furthermore, the research by Kim et al. (2022) explored the impact of HRI on user satisfaction and acceptance in industrial robotics. The study found that a user-friendly interface design, intuitive control mechanisms, and clear communication channels between humans and robots are essential factors that contribute to improved user satisfaction and overall system usability. By considering the human factors in HRI system design, organizations can ensure a positive user experience and foster greater acceptance of robotic technologies in industrial settings.

Recent advancements in artificial intelligence and machine learning have also revolutionized HRI in industrial robotics. Research by Li et al. (2022) demonstrated the

potential of AI-enabled collaborative robots to adapt to dynamic work environments, learn from human feedback, and autonomously improve task performance over time. This adaptive intelligence approach not only enhances efficiency but also enables continuous optimization of robotic operations based on real-time feedback and data analysis.

Aim of the Study

This study aims to examine the role of human-robot interaction on the efficiency and safety in industrial operations, underscoring the critical role in enhancing productivity and reducing costs by analyzing robot task completion time, safety rating, collision risks, ergonomic strain, and overall productivity through comprehensive industrial materials handling equipment performance metrics.

Methodology

The study leverage the qualitative research method to systematically examine the critical role of human robot interaction in enhancing efficiency and safety in industrial operation. After consulting relevant research literature to examine some of the most applicable keywords, Googlescholar and ScienceDirect databases were searched using the following keywords "human-robot interaction" and "enhancing HRI in industrial setting" and analytical measures for assessing the impact of HRI on efficiency and safety in industrial robotics.

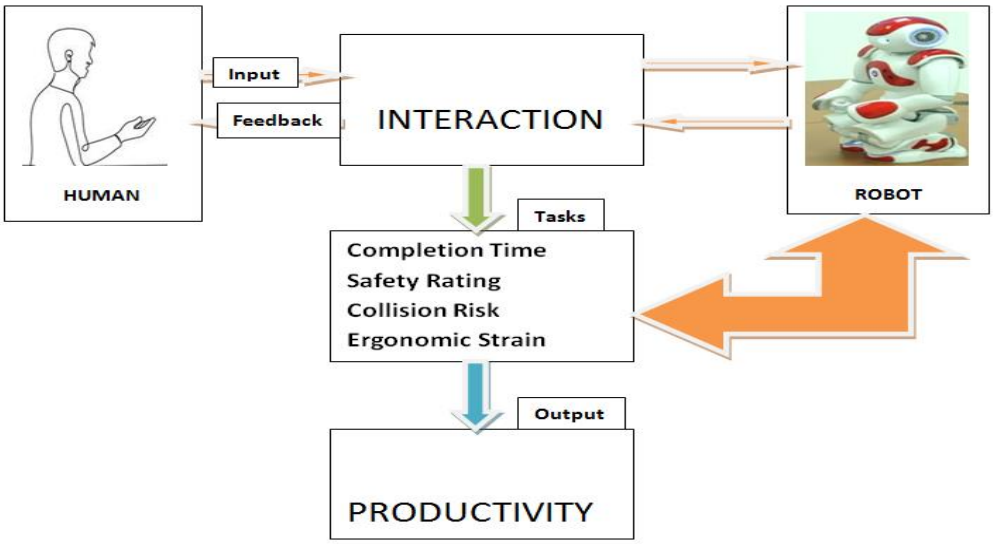
A Qualitative data gathered from industrial workers, engineers, and managers providing valuable insights into their experiences and perceptions of Human-Robot Interaction (HRI) in enhancing efficiency and safety in industrial settings were outline for analysis. The sample of qualitative data compiled from the relevant research literature on interviews and surveys conducted with industrial workers and engineers on the roles of human robot collaboration are shown in Table 1.

From Figure 1, Implementing HRI systems was a significant undertaking for a team work. It required extensive collaboration between engineers, operators, and management to design interfaces and programming that were intuitive and set up safety protocols, provide guidance and assistance to monitor the activities of the robot for the tasks execution.

Table 1: Qualitative Data of Respondent Experiences and Perceptions of Industrial Workers. Source: the Author

Robot Tasks	Completion Time (Minutes)	Error Rate (%)	Collision Risk	Ergonomic Strain	Productivity metrics (%)
Task 1	20	5	Low	Moderate	85
Task 2	15	2	Medium	Low	92
Task 3	30	8	High	High	78
Task 4	18	3	Low	Low	89

Figure 1: Critical Analysis of Human-Robot Interaction. Source: the Author



From an efficiency standpoint, HRI has been transformative. By automating routine tasks and integrating robots into the work-flows, that result to significant reductions in cycle times and increased throughput. Safety-wise, real-time monitoring and safety features have mitigated risks and improved overall workplace safety.

Analytical Method

Task Completion Time

The analytical equations for task completion time based on the quantitative data of Table 1, compiled from the relevant research literature and surveys conducted with industrial workers and engineers on the roles of human robot interaction in enhancing efficiency and safety in industrial robotics, are given by Equation (1):

(1)

$$\text{Task Completion Time} = \text{Average Task Time} + (\text{Task Priority} \times \text{Task Complexity})$$

Safety Metrics Analysis

To compute the safety rating in the context of human-robot interaction in industrial robotics based on the data of Table 1 provided, Equations (2) is applied.

The safety rating for each task was obtained by subtracting the error rate from 100% (higher error rates = lower safety rating).

(2)

safety rating = 100 – error rates

Collision Risk Analysis

Analyzing the collision risk in the context of human-robot interaction as presented in Table 1. It was given by calculating the collision risk for each task by multiplying the task likelihood of occurrence by the task exposure rating by the task consequence rating by the task detectability rating, in equation (3).

(3)

Collision Risk = Task(likelihood of occurrence) x (exposure rating) x (consequence rating) x (detectability rating)

Ergonomic Strain Impact

To compute the ergonomic strain impact in the context of human-robot interaction as presented in Table1. Equation (4) was used:

(4)

Ergonomic Strain Impact = (physical demand rate) x (mental demand rate) x (physical effort rate) x (temporal demand rate) x (effort required rate) x (frustration level rate)

The ergonomic strain impact for each task was analyze by multiplying the task physical demand rate by the task mental demand rate by the task physical effort rate by the task temporal demand rate by the task effort required rate by the task frustration level rate.

Productivity Rating Analysis

The productivity rating in the context of human-robot interaction in industrial robotics provided in Table 1, was analyze for each task by multiplying the task completion rate by the task efficiency rate.

Results discussion

Analytical Result of four basic Tasks in the context of human-robot interaction. From Table 1, the computational analysis of tasks completion times, safety rates, collision risks, ergonomic strain, and overall productivity were determine. From the evaluation of the time required to complete each task in the context of human-robot interaction and optimize the workflow to enhance productivity and safety and presented in Table 2.

Figure 2, reveal that the average task completion time for task 1 was 10.63 minutes; while task 4 was 16.39 minutes. This indicates that some critical tasks require additional resources or adjustments to streamline the process and improve overall performance.

In Figure 3, it was observed that task 2 has a higher safety rating of 98% while task 3 has a lower safety rating of 92%, this indicate that the safety rating are different with respect to different task.

Table 2: Four Basic Robotics Tasks for Industrial Operation. Source: the Author

Industrial Robot Tasks	Completion Time Analysis (Minutes)	Safety Rating	Collision Risk Analysis	Ergonomic Strain Impact	Productivity metrics (%)
Task 1	10.63	95	0.378	0.28728	0.72
Task 2	12.64	98	0.408	0.34755	0.8075
Task 3	14.72	92	0.44625	0.3585	0.6375
Task 4	16.39	97	0.6336	0.331065	0.8096

Figure 2: Performance Tasks Completed Time Analysis. Source: the Author

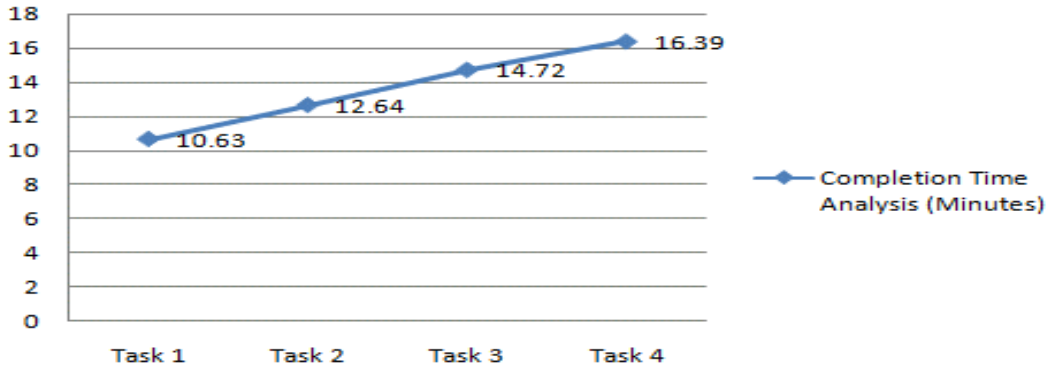


Figure 3: Tasks Performance Metrics for Safety Rating. Source: the Author

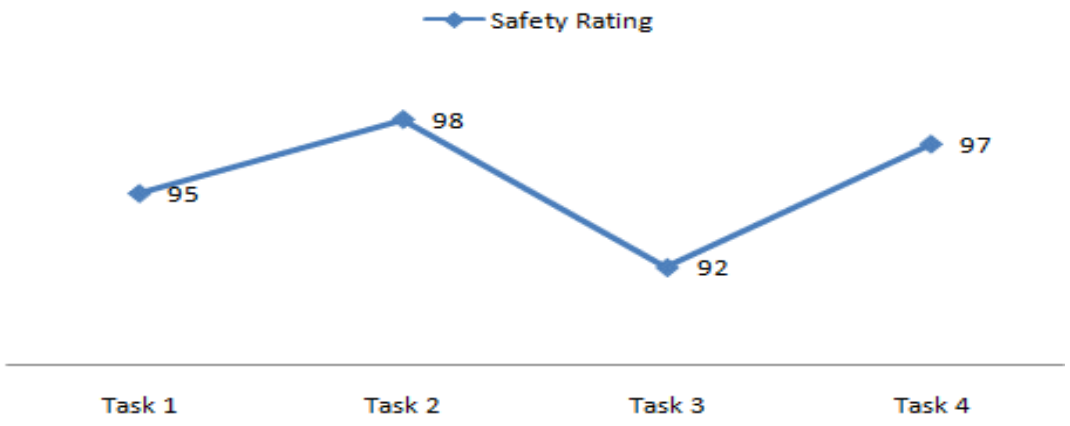


Figure 4 shows the graphical illustration of the collision risk analysis associated with the context of human-robot interaction. The graph reveals that the collision risk associated with the robotics system increases as the tasks increase.

Figure 5 reveal that the regular optimization of the interaction between human and robots have a positive impact of reducing ergonomic strain with respect to the tasks and promoting the well-being of workers.

Figure 4: Collision Risk Analysis for Robotics Tasks in Industrial Operations. Source: the Author

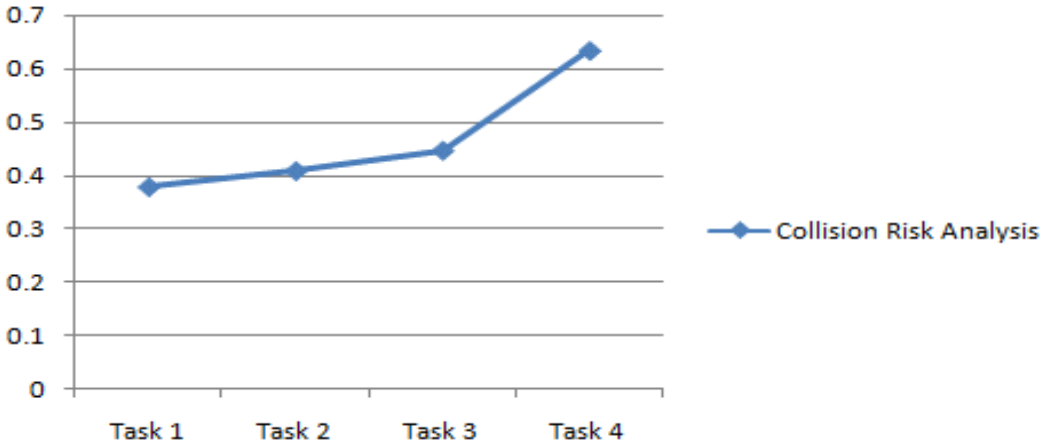


Figure 5: Ergonomic Strain Impact on HRI. Source: the Author

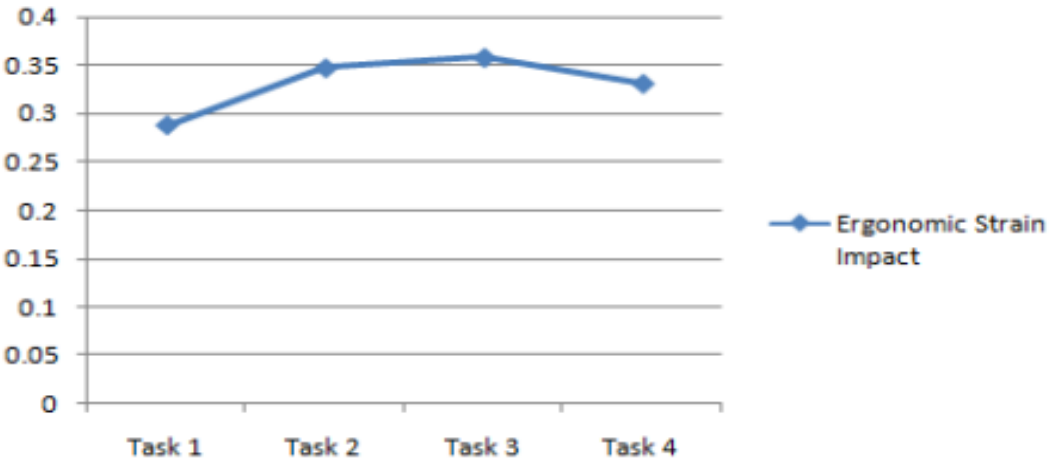


Figure 6, reveal that the Average Productivity Rating was 0.7449, which indicate that the role of human-robot interaction in enhancing efficiency and safety in industrial robotics offers a significant approach to improve productivity.

Figure 7, shows the revalidation result of the HRI performance metrics. The process indicates that the impact of ergonomic strain on HRI is significant and should be carefully considered in the implementation of robots.

Figure 6: HRI Impact on Productivity Rating. Source: the Author

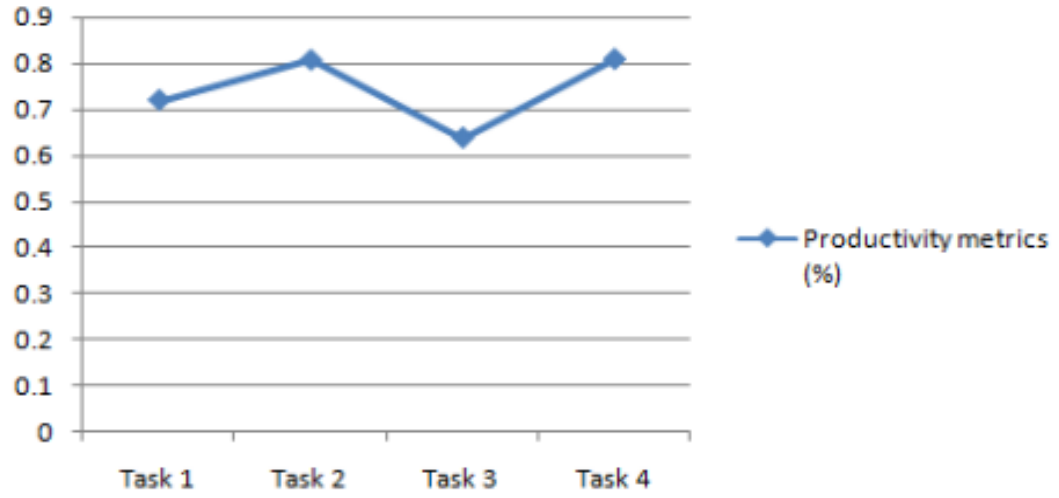
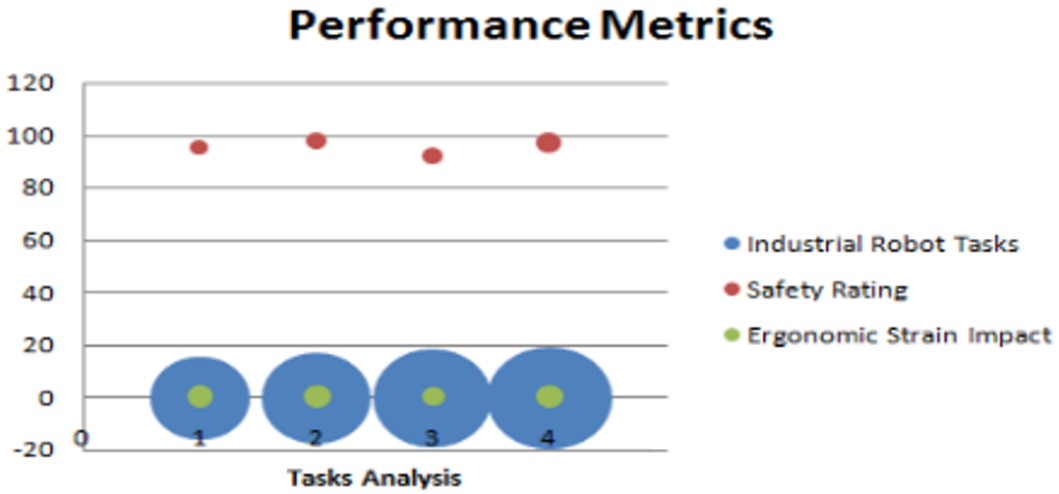


Figure 7: HRI in Industrial Operations with Difference Tasks. Source: the Author



Conclusion

In conclusion, the role of human-robot interaction (HRI) in enhancing efficiency and safety in industrial robotics is significant and multifaceted. Through collaborative efforts between humans and robots, several key benefits are realized:

1. Task allocation and coordination between humans and robots optimize workflow and minimize idle time, contributing to overall productivity and efficiency.

2. Robots can handle heavy loads and perform tasks in challenging environments, reducing ergonomic strain and minimizing the risk of musculoskeletal injuries to human workers.

3. HRI enables the delegation of hazardous or dangerous tasks to robots, reducing the risk of workplace accidents and injuries.

4. Robots can assist with ergonomically challenging tasks, such as lifting heavy objects or performing repetitive motions, thereby reducing the risk of work-related injuries and musculoskeletal disorders.

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