CHAPTER 68

Exploring the Efficiency of Lean Construction Tools in Boosting Safety on Construction Sites

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ABSTRACT

The construction industry often faces unpredictable and fluctuating processes, leading to higher risks of accidents and unsafe working conditions. This study explores how Lean Construction techniques can improve safety on Indian construction sites. It synthesizes reliable research in safety management to evaluate the potential of Lean tools such as the Last Planner System, Visual Management, the 5S methodology, and Error- proofing in promoting safety. The study identifies key managerial challenges in the Indian construction sector that impact safety. This study evaluates the impact of Lean Construction techniques—Last Planner System, Visual Management, 5S, and Poka-Yoke in enhancing site safety performance. It also examines barriers to their implementation and proposes a process map for improving site safety. To achieve the objectives, questionnaire surveys and case studies were conducted. The analysis of these data facilitated the design of a process map for implementing Lean practices to enhance safety on construction sites. The findings demonstrate that Lean Construction techniques have significant potential to improve worker safety, reduce accidents, and create safer working environments by effectively addressing existing challenges.

Keywords: Lean construction; Safety management; Lean tools; Lean and safety.

1.0 Introduction

The construction sector plays a crucial role in global economic development, contributing approximately $10 trillion annually (McKinsey Global Institute, 2017). In India, the industry is expected to reach $1.4 trillion by 2025. Construction sites are known for high accident rates, making them one of the most hazardous industries worldwide (ILO, 2020). Insufficient safety measures, low productivity, and frequent cost overruns are common challenges (Hosseini *et al.*, 2018). Developing nations face additional safety challenges due to weak regulations, untrained labor, and high unemployment rates (Tam *et al.*, 2004). The mortality rate in Middle Eastern construction is 18.6 per 100,000 workers, significantly higher than in industrialized countries (ILO, 2020).

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Inadequate adherence to safety standards and the lack of a lean culture contribute to these issues (Salem *et al.*, 2005). Accidents occur due to human errors, equipment failures, poor site management, and ineffective safety enforcement (Tam *et al.*, 2004). Human factors include inadequate training and unsafe behaviors (Choudhry *et al.*, 2007; Zhou *et al.*, 2015). Faulty equipment and lack of maintenance contribute to risks (Hallowell & Gambatese, 2009). Poor site planning and management deficiencies also lead to incidents (Jannadi & Bu- Khamsin, 2002; Waehrer *et al.*, 2007). Proper training and adherence to safety protocols reduce accidents (Tam *et al.*, 2004).

Lean construction faces challenges during implementation such as top management support, finance, education, regulations, technical aspects, and worker resistance (Forbes & Ahmed, 2010; Salem *et al.*, 2005; Alarcón *et al.*, 2005; Tam *et al.*, 2004; Sacks *et al.*, 2010; Hallowell & Gambatese, 2009). Lean culture prioritizes safety by investing in employees, promoting engagement, and implementing continuous improvements (Abdelhamid & Everett, 2000; Forbes & Ahmed, 2010; Demirkesen & Arditi, 2015).

Lean Construction aims to enhance project efficiency by minimizing waste and maximizing value (Koskela *et al.*, 2002). By integrating safety into lean methodologies, risks can be reduced, and operations can be optimized (Demirkesen & Arditi, 2015). Techniques such as eliminating waste, standardizing safety procedures, and leveraging technology improve site safety (Seppänen *et al.*, 2010). Moreover, fostering a strong safety culture is essential in an industry with high accident rates.

2.0 Research Methodology

The research methodology involves a comprehensive literature review, during which articles were located using the keywords “lean construction,” “lean culture,” “construction safety,” “lean safety,” and “lean culture for health and safety” across platforms such as Google Scholar, Science Direct, Research Gate, and Taylor and Francis.

This study begins by examining the managerial challenges associated with implementing safety measures in the construction industry. It then examines existing research on safety management and how Lean Construction might help to improve worker safety. To further assess its impact, the study evaluates the potential of Lean Construction techniques—such as the Last Planner System, Visual Management, 5S, and Poka-Yoke - in enhancing safety performance on construction sites.

However, the adoption of Lean Construction in India faces significant barriers, including a lack of awareness and the complexity of implementing lean tools in on-site operations. To address these challenges, the study incorporates findings from the analysis to create a process map that uses Lean Construction concepts to improve safety management and encourage safer construction methods.

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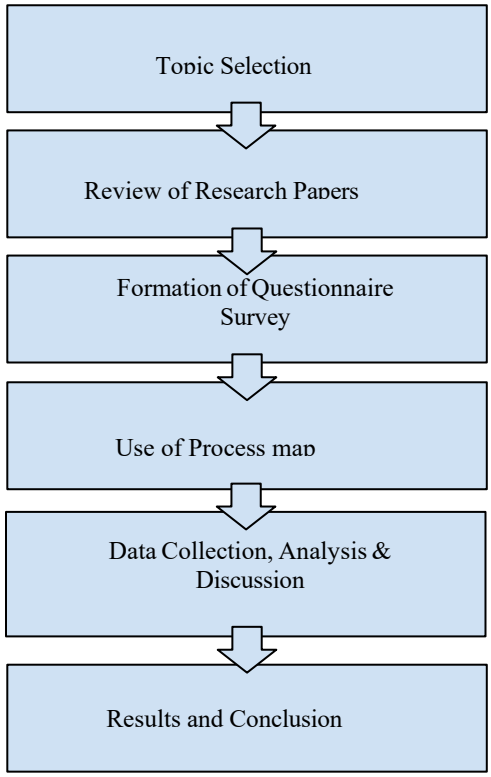
Figure 1: Research Methodology Flow Chart



A structured questionnaire survey is designed using the Delphi technique described below:

2.1 Delphi technique

The Delphi technique is a structured method for collecting expert opinions through multiple rounds of sections aimed at reaching a consensus among professionals. The participants in the study were exceptionally qualified, with the majority possessing between 2 to 10 years of experience in the construction industry. A sample size of 50 respondents was taken for a questionnaire survey.

2.2 Questionnaire survey

A structured questionnaire survey was prepared and circulated to experts, consisting of five key sections, and administered via Google Forms

- *Part 1) Personal Information:* This section gathered information regarding the respondents' educational qualifications, professional experience, years in the industry, job roles, and their engagement with safety and Lean practices.

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- *Part 2) Managerial Challenges during safety implementation:* This section seeks to obtain insights into the challenges encountered by managers within the construction sector, particularly concerning their effects on safety on construction sites. It identifies significant project management issues such as poorly organized workplace, Human error / Skilled labor shortage, Inadequate supervision, Lack of task coordination, Risk of falling objects and Organizational pressure. Additionally, it examines causes of safety issues at site like lack of training, communication issues, poor maintenance of machines, common safety hazards on-site, such as falls, equipment-related incidents, and insufficient personal protective equipment (PPE).
- *Part 3) Evaluation of Lean Construction Tools for Enhancing Safety Performance:* This section aims to assess the effectiveness of Lean Construction tools—such as the Last Planner System, Visual Management, 5S, and Poka-Yoke in enhancing safety on construction sites. A rating system from 1 to 5 (1- Strongly Disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly Agree) is utilized, and the Relative Importance Index (RII) is calculated to rank each lean tool based on its significance.

2.3 Key lean tools covered in Section 3

- *Visual Management:* Uses visual tools like charts, dashboards, and signage to improve communication, transparency, and workplace organization.
- *Last Planner System (LPS):* A collaborative planning approach to minimize waste, improve coordination, and enhance site safety through structured scheduling and task commitment.
- *5S Methodology:* A structured approach (Sort, Set in Order, Shine, Standardize, Sustain) to enhance site organization, reduce clutter, and improve safety.
- *Poka-Yoke (Error Proofing):* A mistake-proofing technique that prevents errors or detects them early, ensuring compliance with safety standards and improving efficiency in construction.
- *Part 4) Barriers to implement Lean construction tools for enhancing Safety performance:* This section discusses critical barriers to Lean Construction adoption in India, including a lack of understanding, reluctance to change, high costs, and industry fragmentation. Participants assess the challenges and rate the complexity of implementing Lean tools (Visual Management, Last Planner system, 5S, Poka-Yoke) for site safety using a scale of 1 (Easy), 2 (Moderate), and 3 (Difficult). Additionally, the Relative Importance Index (RII) is calculated to rank the most difficult Lean tool to implement on construction sites as per the responses received. They also offer solutions for addressing challenges, such as technology integration, policy changes, and training programs. By tackling important implementation issues, the insights seek to improve Lean adoption.
- *Part 5) Feedback Survey:* A feedback survey was conducted to gather respondents' opinions on promoting use of Lean tools to improve construction site safety.

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We gathered respondent data through a questionnaire survey, focusing on managerial challenges related to safety, causes of safety issues at sites, the potential impact of lean tools on enhancing safety, and the key barriers to implementing these tools. After collecting the necessary data, the lean tools were ranked using the Relative Importance Index (RII) and also assess their difficulty level based on RII.

2.4 Relative Importance Index (RII)

The Relative Importance Index (RII) is a statistical method used to prioritize factors based on expert opinions, allowing for the identification of key elements influencing a given outcome (Hosseini *et al.*, 2018). RII helps to determine which lean tools have the most significant impact on enhancing site safety (Hallowell & Gambatese, 2009).

$$RII = \frac{5n5+4n4+3n3+2n2+1n1}{A*N}$$

$$RII = \frac{\Sigma W}{A \times N}$$

Where: W = Weight assigned to each factor by respondents (e.g., 1 = Strongly Disagree, 5 = Strongly Agree) A = Maximum weight (e.g., if 5-point scale is used, A = 5)

N = Total number of respondents

Responses are collected using a Likert Scale (e.g., 1 = Not Important, 5 = Very Important) (Zhou *et al.*, 2015). The highest-ranked factors are considered most critical for improving safety using Lean Construction techniques.

3.0 Results and Discussions

In section 1, we collected the basic information of respondent like name, age, email ID, professional background, considering 2-10 years of experience and we found total 54 responses, out of 54 responses - 34 respondent (63%) have worked on construction sites without direct involvement in Lean Construction, while 20 respondent (37%) have used the lean tools at their project site. This indicates that a significant proportion of professionals—63% (34 respondents)—lack awareness of lean construction methodologies.

In section 2, we discussed the key managerial challenges in safety implementation and we got (54 responses): Poorly organized workplace – 36 responses(66.7%), Human error / Skilled labor shortage – 31 responses(57.4%), Inadequate supervision – 28 responses(51.9%), Lack of task coordination – 25 responses(45.3%), Machine failures – 23 responses(42.6%), Excessive stress – 21 responses(38.9%), Risk of falling objects – 20 responses (37%) and Organizational pressure – 19 responses (35.2%). We found the top 3 managerial challenges having major impact on safety implementation which are Poorly organized workspace, Human error/ Skilled labour shortage and inadequate supervision. We also discussed the causes of safety issues at sites: Communication issues – 38 responses (70.4%), Lack of training – 36 responses (66.7%), Insufficient PPE – 32 responses (59.3%), Poor equipment maintenance – 32 responses (59.3%), Hazardous conditions – 29 responses (53.7%), Consumption of alcohol & drugs on-site

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– 20 (37%). We found the top 3 causes of safety issues at sites were communication issues, lack of training and insufficient PPE. In section 3, We evaluated the effectiveness of selected lean construction tools to enhance safety performance, (RII) was used to rank the lean tools based on their effectiveness for enhancing safety at site

Figure 2: Last Planner System

Figure 3: Visual Management

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Figure 4: 5S

Figure 5: Poka-Yoke

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(Figure 2- Last Planner system) shows a survey result with an average rating of 3.26. The majority of respondents (40%) rated 3, followed by 22% rating 2, 20% rating 4, and 16% rating 5. A small percentage (2%) rated 1, indicating a generally moderate response with room for improvement. (Figure 3 - Visual Management shows a survey result with an average rating of 4.43, indicating a highly positive response. The majority of respondents rated 4 (49%) and 5 (47.1%), while a very small percentage (3.9%) rated 3, and no one rated 1 or 2.

(Figure 4 - 5S) shows a survey result with an average rating of 3.24, indicating a neutral to slightly positive response. The majority of respondents rated 3 (37.3%), followed by 2 (25.5%) and 4 (25.5%), while 11.8% rated 5 and no one rated 1.

(Figure 5 – Poka-Yoke) shows a survey result with an average rating of 3.02, indicating a neutral response. Ratings are fairly distributed, with 28% ratings, 4, 22% rating 3, and 18% each for 1 and 2, while 14% rated 5.

(Table 1: RII for the impact of lean construction tools enhancing safety) presents survey results evaluating four Lean tools based on respondent ratings. Visual Management ranked highest (RII = 0.886) with positive feedback, followed by the Last Planner System (RII = 0.652) in second place. 5S received a neutral response (RII = 0.647), ranking third. Poka-Yoke, with the lowest RII (0.604), showed the most mixed feedback. The results highlight Visual Management as the most well-received tool, while Poka-Yoke needs improvement. We found visual Management (Rank 1, RII-0.886) as the most effective tool with clear visual signs and organized workspaces enhancing safety. Last Planner System (Rank 2, RII-0.652) – Emphasizes proactive planning and coordination, reducing safety risks. 5S (Rank 3, RII-0.647) – Highlights the role of a structured, clutter-free workplace in improving safety. Poka-Yoke (Rank 4, RII-0.604) – Though ranked lowest, it remains valuable in preventing human errors through error-proofing techniques.

Table 1: RII for the Impact of Lean Construction Tools Enhancing Safety

Sr No	Lean Tools	5n5	4n4	3n3	2n2	1n1	Total	Total Number (N)	A*N	RII	Rank
1	Last Planner system	40	40	60	22	1	163	50	250	0.652	2
2	Visual Management	120	100	6	0	0	226	51	255	0.886	1
3	5S	30	52	57	26	0	165	51	255	0.647	3
4	Poka-Yoke	35	56	33	18	9	151	50	250	0.604	4

In section 4 it collects data related to (Part 1) barriers to implementing Lean tools for enhancing safety performance and (Part 2) the Complexity of Lean tools in implementing them on construction sites to enhance safety. In the first part, we got the following responses - Lack of training or skilled personnel – 35 responses (67.3%), Lack of awareness or understanding – 30 responses (57.7%), High initial costs – 28 responses (53.8%), complexity of lean tools and methods - 26 responses (50%), Resistance to change among workers and managers - 25 responses (48.1%), Inadequate leadership commitment - 11 responses (21.2%), Others - 4 responses (7.7).

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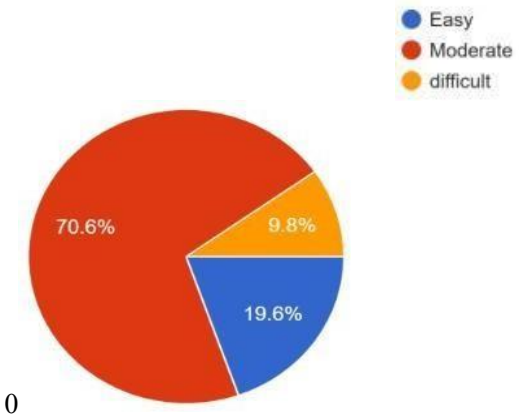
We found the top 3 barriers as Lack of training or skilled personnel (67.3%), lack of awareness or understanding (57.7%) and high initial costs (53.8%). In the second part, we are now evaluating the complexity of Lean tools in implementing it on construction sites enhancing safety using the relative importance index (RII).

The four pie charts (Figures 6–9) depict the complexity levels of lean tools in implementing on sites, which are classified as Easy (blue), Moderate (red), and Difficult (yellow). In the first chart, the majority of replies (70.6%) were rated as moderate, 19.6% as easy, and 9.8% as difficult. The second chart with 54.9% rating is moderate, 37.3% easy, and 7.8% difficult. According to the third figure, 63.5% of respondents rated it moderate, 21.2% easy, and 15.4% difficult. In the fourth chart, 60.8% rated as moderate, 27.5% as difficult, and 11.8% as easy. RII was used to rate the lean tools based on the difficulty level the respondent faced to implement (1- Easy, 2- Moderate, 3- Difficult)

Figure 6: Complexity of Visual Management



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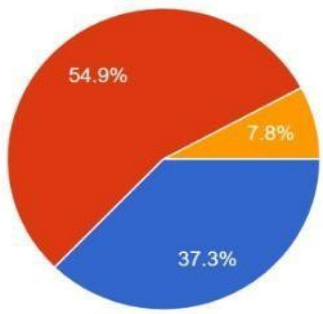
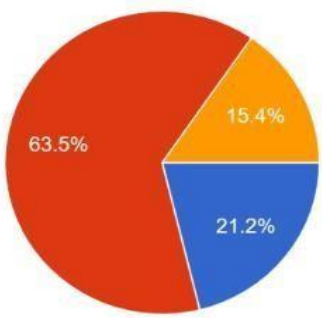


Figure 8: Complexity of 5S

Figure 9: Complexity of Poka-Yoke



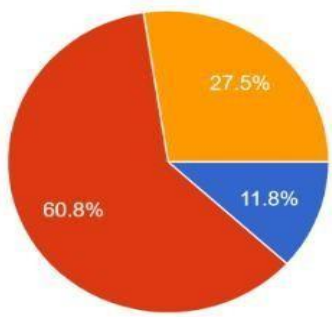


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Table 2: RII for Complexity of implementation of lean tools in enhancing safety on sites. The table evaluates the perceived difficulty of four Lean tools based on survey responses. Poka-Yoke ranked as the most difficuilt (RII = 0.431), with the highest number of respondents finding it difficult. 5S followed closely (RII = 0.389), indicating moderate difficulty. The Last Planner System (RII = 0.38) ranked second in ease of use, while Visual Management (RII = 0.345) was considered the easiest. Overall, the results suggest that Poka-Yoke is the most difficult tool, while Visual Management is the most easy.

We found that Poka-Yoke (Rank 1, 0.431) is most challenging due to reliance on specialized error- proofing mechanisms and advanced training. 5S (Rank 2, 0.389) is moderately difficult, requiring continuous commitment to workplace organization. Last Planner System (Rank 3, 0.380) & Visual Management (Rank 4, 0.345) are easier to implement, as structured planning and visual guidance are more adaptable.

Table 2: RII for Complexity of Implementation of Lean Tools in Enhancing Safety on Sites

Sr No	Lean Tools	Easy (1)	Moderate (2)	Difficult (3)	(1n1)	(2n2)	(3n3)	Total	Total Number (N)	A*N	RII	Rank
1	Last Planner system	10	36	5	10	72	15	97	51	255	0.38	2
2	Visual Management	19	28	4	19	56	13	88	51	255	0.345	4
3	5S	11	33	8	11	66	24	101	52	260	0.389	3
4	Poka- Yoke	6	31	14	6	62	42	110	51	255	0.431	1

In section 5, According to survey feedback given by respondent, Lean Construction improves safety, workflow optimization, and continual improvement. The 5S method for organization, LPS for improved planning, and VSM for spotting inefficiencies were all acknowledged by the respondents. Also, JIT reduces clutter and risks, whereas kaizen fosters a proactive safety culture. Standardized Work guarantees conformity, Poka-Yoke avoids errors, and Visual Management raises awareness of potential hazards. Large companies use these tools well, but local contractors encounter difficulties. Overall, safety, effectiveness, and long-term cost savings are increased when Lean technologies are tailored to certain stages of construction.

After analyzing the survey data, I examined managerial challenges in implementing safety measures in construction. Key Lean techniques, including the Last Planner System, Visual Management, 5S, and Poka- Yoke, are evaluated for their impact on safety performance. However, adoption in India faces challenges like low awareness and implementation complexity. These findings guided us to the development of a process map given below in (Figure 10: Process map) integrating Lean Construction concepts to improve safety management.

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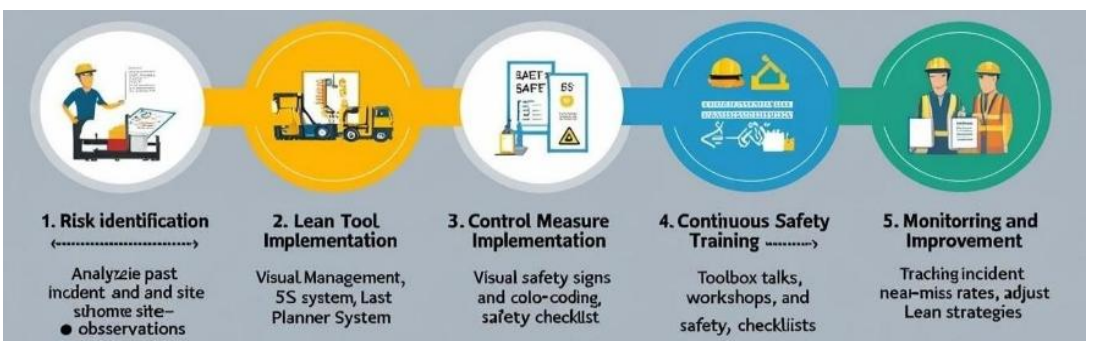
Figure 10 shows the process map shows a five-step process for safety management, depicted as a horizontal timeline.

- *Risk identification:* Focuses on risk identification by analyzing past incidents and site observations.
- *Lean tool implementation:* Involves implementing Lean tools like Visual Management, 5S, and Last Planner System.
- *Control measure implantation:* Emphasizes control measure implementation, including visual safety signs and colour-coding, alongside safety checklists.
- *Continuous safety training:* Highlights continuous safety training through toolbox talks, workshops, and safety checklists.
- *Monitoring and improvement:* Concerns monitoring and improvement, tracking incident and near-miss rates, and adjusting Lean strategies.

4.0 Conclusion

Safety management has become a crucial aspect of modern construction, ensuring overall project success. This study explores how lean construction tools can be implemented to improve safety. The present study identifies key managerial challenges, prioritizes lean tools to enhance safety, and develops a process map for incorporating lean principles to improve safety at construction sites.

Figure 7: Process Map



The respondents identified a poorly organized workspace as the top managerial challenge, followed by human error and unskilled labor as the second, and inadequate supervision as the third. The lean tool 5S could be an ideal solution for organizing the workplace, and many researchers have also found it useful for improving housekeeping. A structured training program specifically targeting unskilled labor, along with the development of

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standardized checklists, would help address the second and third managerial challenges identified by the respondents. The major causes of safety issues at the site, as highlighted by respondents, include a lack of training, poor communication, and a shortage of personal protective equipment (PPE). The collaborative approach promoted by lean philosophy is well-suited to enhancing coordination, thereby improving overall efficiency. The top three lean tools prioritized by respondents for enhancing safety at construction sites are visual management, the Last Planner System, and 5S. Since unskilled labor plays a significant role in maintaining safety, visual management techniques—such as visual boards for standard procedures and safety parks—can be effective.

The Last Planner System encourages the involvement of execution teams in planning, enabling the setting of realistic targets that prevent worker overburden and optimize the planning process. The top three barriers identified by respondents are lack of training, lack of awareness or understanding, and high initial implementation costs. This highlights the need for training in lean construction to facilitate its integration into construction practices. Respondents also rated lean tools based on their complexity, finding Poka-Yoke and the Last Planner System more complex compared to 5S and Visual Management. Therefore, firms looking to initiate lean implementation may consider starting with 5S and Visual Management, as they are relatively easier to adopt. These findings led to the development of a process map for integrating lean construction concepts into safety management at construction sites. This framework provides guidance on using lean principles to enhance safety performance. Future research should explore cost-effective strategies to promote the adoption of lean tools in construction safety management.

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