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Identification and analysis of hoisting safety risk factors for IBS construction based on the AcciMap and cases study

Yin Junjia [*], Aidi Hizami Alias, Nuzul Azam Haron, Nabilah Abu Bakar

Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, 43400, Selangor, Malaysia

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ABSTRACT

Hoisting is an essential aspect of Industrial Building System (IBS) construction. Although research on hoisting safety in China has made strides to focus on "worker," "data," "task," "site," and "accident," there still needs to be more approaches based on multi-dimensional social system thinking. Therefore, the paper aims to fill this gap. We investigated 105 hoisting accidents in China and found that hoisting accidents occurred most frequently in China's southeast coastal region; truck-mounted cranes and tower cranes were the most common types of machinery involved in accidents; hoisting load off, capsizing of crane machinery, and workers falling from height are the three most common accident types; the average impact of a single hoisting accident is approximately RMB 2.43 million direct economic loss, 1.543 deaths and 0.829 injured. This study used three algorithms (Rindge regression, Lasson regression, and partial least squares regression) to explore the impact of deaths and injuries on direct economic losses. By combining Rasmussen's risk framework with the characteristics of hoisting construction, six risk domains and thirty-six safety risk factors were identified. Finally, we used AcciMap technology to construct a qualitative IBS hoisting management model, which exhaustively presents the systematic levels and propagation paths of the influencing factors by the PDCA method. The research helps academics explore strategies to improve the safety of hoisting construction in IBS. Moreover, the study outcomes can inform the policy-making process towards promoting healthy and sustainable construction development.

1. Introduction

The United Nations predicted that the global population would reach 10.9 billion by the conclusion of the 21st century [1]. The rapid growth of the population has led to a surge in the need for faster infrastructure development, which has raised concerns about environmental sustainability. In this context, IBS (Industrial Building Systems) is increasingly seen as the future of construction due to its advantages over traditional construction methods [2]. Since prefabricated components can be produced in a controlled environment and quickly assembled on-site, they are faster and provide better quality control of the production process than traditional construction methods [3–5]. Due to less on-site construction, workers could be less exposed to hazardous conditions and less disturbed in the surrounding environment [6,7]. While the initial cost of constructing an IBS building may be higher than traditional construction methods, the time and labor savings can ultimately result in cost savings over the life of the building [8]. However, Fig. 1 shows 3626 construction safety accidents in China from 2017 to 2021, resulting in 4164 deaths, and more than 30 % of larger accidents

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[*] Corresponding author.
E-mail address: gs64764@student.upm.edu.my (Y. Junjia).

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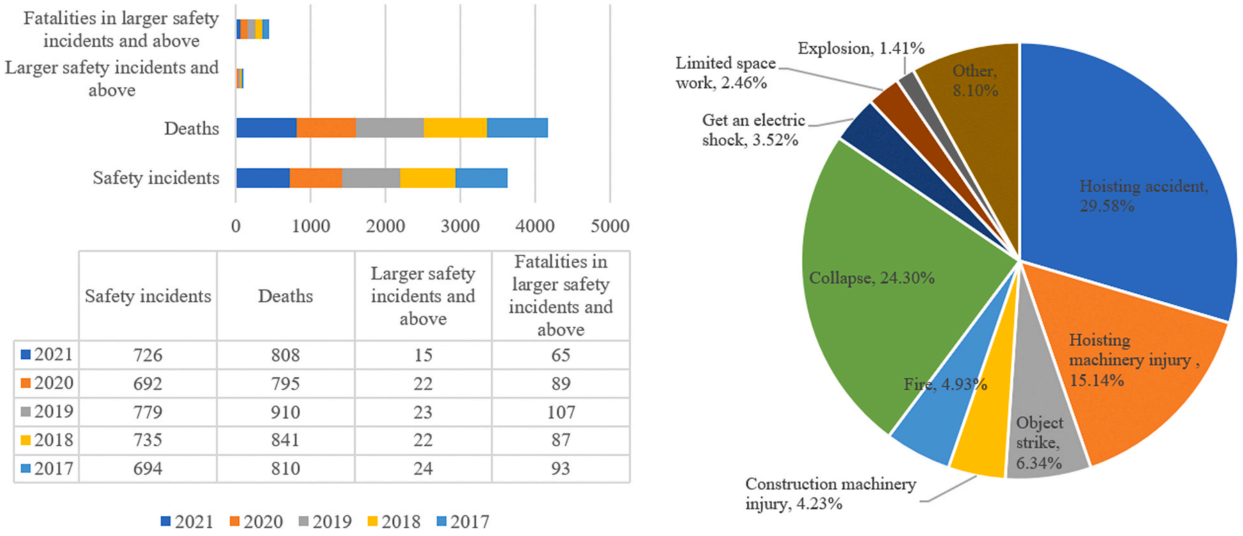
Abbreviations

3D	Three-Dimensional
AcciMap-IH	AcciMap-IBS-Hoisting
AI	Artificial Intelligence
BIM	Building Information Modelling
GNSS	Global Navigation Satellite Systems
HFACS	Human Factors Analysis and Classification System
IBS	Industrial Building System
IoT	Internet of Things
Lasso	Least Absolute Selection and Shrinkage Operator
PDCA	Plan-Do-Check-Action
PLS	Partial Least Squares
PPE	Professional Personal Equipment
RBS	Resource Breakdown Structure
RR	Ridge Regression
VR	Virtual Reality
WBS	Work Breakdown Structure
WoS	Web of Science
WSR	Wuli-Shili-Renli

are related to hoisting in 2020 [9,10]. The construction industry's status as a high-risk sector remains unchanged. Hoisting is an integral part of construction that is not limited to IBS and poses a significant safety risk to workers [11–13].

An increasing amount of scholarly research underscores the significance of risk factors in managing safety risks. Implementing appropriate controls based on these factors can mitigate the likelihood of accidents or other undesirable outcomes [14,15]. Identifying risk factors by studying accident reports or safety surveillance data is necessary, as this can effectively eliminate the influence of unstable subjective consciousness on individuals [16–18]. Hoisting processes are dynamic, multi-stakeholder, and spatially dimensioned complex systems [19–21]. However, many current risk referencing systems are static, with a single stakeholder or perspective, so risk factors in the hoisting process must be reinvestigated and analyzed [22–24].

This research uses social systems thinking to create a model for managing risks with multiple stakeholders. The following outlines the main points of each chapter. Chapter two provides a literature review on evaluating risk in hoisting. Chapter three explains our theoretical framework and research process. Chapter four analyzes sample accidents to identify the most common accident locations, the machinery involved, and resulting impacts. Chapter five presents the AcciMap-IH risk management model, which identifies risk factors in six dimensions. Chapter six discusses risk response strategies for different risk levels. Chapter seven addresses the strengths, weaknesses, and implications of the AcciMap. Finally, chapter eight concludes the study and acknowledges its limitations.



	Safety incidents	Deaths	Larger safety incidents and above	Fatalities in larger safety incidents and above
2021	726	808	15	65
2020	692	795	22	89
2019	779	910	23	107
2018	735	841	22	87
2017	694	810	24	93

Fig. 1. Number and classification of construction incidents in China.

2. Literature review

2.1. Literature collection

Web of Science (WoS) is a comprehensive and authoritative database of scholarly research containing many peer-reviewed scientific works of literature widely used by researchers, academics, and professionals in many fields, including engineering and occupational health and safety [25,26]. This paper is based on the WoS database and searches for “Hoisting risk factors” or “Lifting risk factors,” which resulted in 2433 articles. The research fields were refined and identified as “Engineering Civil,” “Engineering Multidisciplinary,” “Construction Building Technology,” and “Management.” Then, 76 papers were selected for their relevance to the topic, showing that more research on construction hoisting risk still needs to be done. Of these 76 papers, three senior academics reviewed the content of the literature, excluding review papers, book chapters, and articles that did not correspond to the topic, leaving 43 pieces for further analysis.

2.2. Bibliometric analysis

VOSviewer is a famous bibliometric analysis tool that facilitates researchers’ gaining insights into bibliographic data through various means [27]. Such an approach is beneficial in uncovering hidden patterns and relationships among data points that may take time to discern through conventional means [28]. VOSviewer can also create network visualizations of bibliographic data, which can help identify clusters of relevant studies and critical authors, journals, and keywords, facilitating collaboration between researchers and allowing them to share data and visualizations [29]. Fig. 2 shows the results of keyword clustering and co-occurrence. Based on the clustering results, the current research on hoisting risk factors is divided into three principal areas. Regarding risk data sources, the recent study on hoisting risks is based on past accident data to discover the missing management tools in on-site construction to reduce safety risks. In terms of industry context, construction is an industry with great uncertainty; therefore, different management business models bring other impacts. Design methodologies and original values are becoming increasingly important. Regarding research subjects, many studies are still dominated by human factors, including studies of workers’ postures. Secondly, the skeletal muscle risks associated with lifting tasks also receive increased attention from scholars. “Worker,” “data,” “task,” “site,” and “accident” are current hot research elements, which can be deepened in future studies.

3. Materials and methods

3.1. Research process

This study is divided into six steps.

(1) **Searching for accident samples:** The case must be typical of a hoisting accident reported in the official media with an official report full of details.

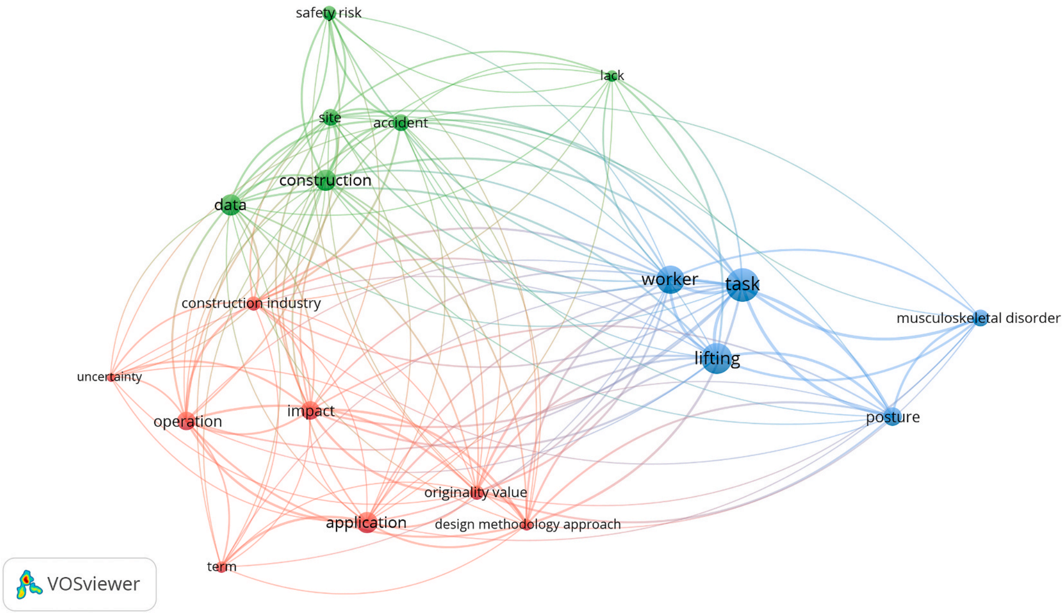


Fig. 2. Network visualization of keywords cluster.

Table 1

The sample cases of hoisting accident.

No.	Date	Province	Source
1	2022-05-03	Gansu	https://www.thepaper.cn/newsDetail_forward_17928784
2	2017-07-11	Guangdong	http://www.jieyang.gov.cn/uploads/ajj/2018-3/201832110385454913.pdf
3	2016-04-13	Guangdong	http://www.zhuhai.gov.cn/xw/ztjj/zhszdlyxxgkzl/scaqsgxxgk/scaqsgdcbgxx/content/post_1779649.html
4	2021-07-03	Guangdong	http://www.szgm.gov.cn/132100/152326/152530/152550/content/post_9230092.html
5	2017-07-22	Guangdong	https://www.thepaper.cn/newsDetail_forward_2085710
6	2017-02-19	Guangxi	http://www.wuming.gov.cn/gk/fdzdgknr/zdlyxxgk/aqsc/aqsgdcbg/t1522655.html
7	2022-04-11	Guizhou	https://new.qq.com/omn/20220726/20220726A06LV600.html
8	2015-07-18	Hebei	https://www.diaocn.com/news/show-124767.html
9	2021-06-06	Hebei	http://www.jingzhou.gov.cn/zfwgk/xxgkml/gysyjs/aqsc/aqsgdcbg/202209/t20220929_781290.shtml
10	2019-08-28	Hebei	http://www.anquan.com.cn/index.php?m=content&c=index&a=show&catid=557&id=98930
11	2017-08-16	Heilongjiang	http://www.esafety.cn/UploadFiles/upload/201803190953575806.pdf
12	2021-12-08	Hubei	https://yjgl.luohe.gov.cn/index.php?s=xinxigongkai&c=show&id=195
13	2019-01-23	Hunan	https://www.163.com/dy/article/FUI0UIFI0543A31M.html
14	2017-10-13	Jiangsu	http://101.200.85.181/index.php?a=show&catid=207&id=49971
15	2014-04-10	Jiangsu	https://www.sdtzsb.com/mobile.php/News/view/id/1665.html
16	2022-11-08	Qinghai	https://www.163.com/dy/article/HLT8JGF40552M5HQ.html
17	2017-05-14	Shanxi	https://www.sohu.com/a/403340002_739244
18	2022-02-16	Shaanxi	http://211.88.39.63/article/yw/zctz/202208/625827.html
19	2022-10-12	Shanghai	http://www.shpt.gov.cn/shpt/sgtb-yjglzdgzyjjzfwj2021/20221104/873275.html
20	2018-08-04	Sichuan	https://www.sohu.com/a/288603139_689822
21	2022-09-03	Yunnan	https://www.163.com/dy/article/HNG7HP900553V8D4.html
22	2021-08-17	Anhui	https://www.shobserver.com/wx/detail.do?id=520813
23	2019-01-23	Guangdong	https://www.sohu.com/a/405384174_656055
24	2021-09-10	Sichuan	https://new.qq.com/omn/20220129/20220129A09LOX00.html
25	2020-09-16	Xinjiang	http://img.xjsmgq.gov.cn/CMSxjsmgq/202012/202012170815051.pdf
26	2019-02-13	Guangdong	http://www.pingyuan.gov.cn/zwgk/zdlyxxgk/aqscxx/scaqsgdcbgxx/content/post_94638.html
27	2017-09-09	Sichuan	http://www.panzhihua.gov.cn/zfxxgk1/fdzdgknr/yjgl/pzhaq/1715410.shtml
28	2021-06-20	Beijing	https://zyk.bjhd.gov.cn/jbdt/auto4504_56383/auto4504_53332/auto4504_53362/sgdc/202110/t20211021_4490677.shtml?type=computer
29	2020-06-15	Guangdong	http://www.zs.gov.cn/yjj/aqsczdxxgk/scaqsgdcbgxx/content/post_1853211.html
30	2016-12-02	Guangdong	http://www.safehoo.com/Case/Case/Crane/201811/1543281.shtml
31	2019-03-31	Heilongjiang	https://new.qq.com/omn/20210611/20210611A0490W00.html
32	2018-06-13	Neimenggu	https://www.kdl.gov.cn/mobile/detail/cid/456/aid/41075
33	2020-06-29	Ningxia	https://new.qq.com/omn/20200722/20200722A0QJFK00.html
34	2020-05-24	Shandong	https://www.bjnews.com.cn/detail/159031544815792.html
35	2021-07-12	Guangdong	http://www.jiangcheng.gov.cn/attachment/0/26/26431/607521.pdf
36	2021-05-11	Jiangxi	http://www.ahjx.gov.cn/OpennessContent/show/2225602.html
37	2018-09-05	Shandong	https://www.sohu.com/a/288603139_689823
38	2018-05-17	Shandong	http://www.huancui.gov.cn/art/2022/5/30/art_64445_2848591.html
39	2022-04-16	Tibet	http://www.linzhi.gov.cn/byq/c105976/202208/147a45ac9e0e44e384d634f5c585db1a.shtml
40	2020-01-10	Beijing	http://www.bjft.gov.cn/ftq/c100014/202006/0a83f44d03824daa9bbe56123f67931b.shtml
41	2019-09-28	Fujian	http://hljjsaqxh.com/pc/index.php?c=news_detail&a=index&id=247&lid=21
42	2020-03-09	Fujian	http://hljjsaqxh.com/pc/index.php?c=news_detail&a=index&id=247&lid=22
43	2018-08-03	Guangdong	https://www.sohu.com/a/288603139_689822
44	2020-12-02	Guangdong	http://www.gdlonghu.gov.cn/stlhyjglj/gkmlpt/content/1/1935/post_1935316.html#932
45	2021-10-07	Guangxi	http://www.yfq.gov.cn/zwgk/fdzdgknr/aqsc/sgdcbg/202204/t20220414_3043675.shtml
46	2021-04-05	Hainan	https://new.qq.com/omn/20220418/20220418A0ABFQ00.html
47	2021-07-01	Heilongjiang	http://zwgk.mdj.gov.cn/yjgl/tzgg/202109/t20210922_325994.html
48	2021-03-31	Jiangsu	http://www.nanjing.gov.cn/zdgk/202111/t20211115_3191634.html
49	2018-01-26	Jiangsu	http://www.jiangyin.gov.cn/doc/2021/03/23/930784.shtml

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Table 1 (*continued*)

No.	Date	Province	Source
50	2022-05-20	Shandong	http://www.licheng.gov.cn/art/2022/7/15/art_93544_4800568.html?xxgkhide=1
51	2021-07-22	Shaanxi	http://yjt.shaanxi.gov.cn/c/2022-07-01/803804.shtml
52	2021-06-28	Shanghai	https://www.songjiang.gov.cn/govxxgk/SHSJ10/2022-01-06/06b004c4-96bd-4ce2-8fb8-355e96189b38.html?currenturl=zdly
53	2021-06-11	Sichuan	http://www.emeishan.gov.cn/emss/aqsc/202108/051f6f3f4e70456683cddb1e4b7effac.shtml
54	2021-05-09	Sichuan	http://www.guanganqu.gov.cn/gaqrmzf/c100095/2021-07/30/content_92cf3ecc0fb9496cbcaf95aa06e4b214.shtml
55	2019-10-30	Tianjin	https://webcache.googleusercontent.com/search?q=cache:3cVp1evfZvsJ: https://www.tjjz.gov.cn/zwgk/zfxxgkqjjg/yjj1/fdzdgknr26/zdmsxx26/aqsc26/202202/W020220210701781799974.docx&cd=91&hl=en&ct=clnk&gl=my
56	2021-08-06	Tianjin	https://www.tjbc.gov.cn/zwgk/zfxxgk/xxgk_wbj/zjyq_xxgk_yjglj/xxgk_fdzdgk_yjglj/xxgk_zdmsxx_yjglj/xxgk_aqsc_yjglj/202201/t20220129_5793991.html
57	2021-10-19	Zhejiang	https://zhuanlan.zhihu.com/p/460398046
58	2021-09-01	Zhejiang	http://www.ruian.gov.cn/art/2022/1/5/art_1229181511_4007248.html
59	2019-09-09	Zhejiang	https://www.cnjxol.com/jingjie/202005/t20200508_615297.shtml
60	2021-08-18	Zhejiang	http://www.hzxh.gov.cn/art/2021/12/6/art_1229417930_4002109.html
61	2020-01-07	Zhejiang	http://www.safehoo.com/Case/Case/Hit/202211/5689463.shtml
62	2020-06-17	Zhejiang	http://www.tx.gov.cn/art/2020/8/18/art_1617820_54544163.html
63	2021-01-16	Zhejiang	https://zjjcmspublic.oss-cn-hangzhou-zwynet-d01-a.internet.cloud.zj.gov.cn/jcms_files/jcms1/web2780/site/attach/0/418ded73b85347269484b5969d960833.pdf
64	2021-10-19	Chongqing	http://www.ddk.gov.cn/bm/qyjj/zwgk_56899/fdzdgknr_56901/yjgl/ydqk/202201/t20220107_10283142.html
65	2021-08-26	Chongqing	http://ws.cq.gov.cn/bm/ajj/zwgk_70287/fdzdgknr_70290/wsyjgl/ydqk/202112/t20211203_10074978.html
66	2020-05-26	Anhui	http://www.safehoo.com/Item/5689669.aspx
67	2018-08-24	Fujian	http://www.qg.gov.cn/zwgk/znsgjy/201901/t20190111_1770263.htm
68	2020-03-04	Fujian	http://www.xiangan.gov.cn/zwgk/aqsc/zffgywj_16158/202007/t20200730_738891.htm
69	2018-12-14	Guangdong	http://www.ss.gov.cn/zwgk/zdlyxxgkzl/aqscxxgk/aqsgdcbgxx/content/post_299868.html
70	2019-09-21	Guangdong	http://www.szpsq.gov.cn/xxgk/zdlyxxgk/aqsc/dcbg/content/post_7044282.html
71	2021-07-10	Hubei	http://www.zengdu.gov.cn/zwgk/fdzdgknr/shsyjs/yjgl/202112/t20211214_948574.shtml
72	2019-05-11	Jiangsu	https://www.sohu.com/a/534212269_121123785
73	2021-04-06	Liaoning	http://yjj.shenyang.gov.cn/files/ueditor/YJGLJ/jsp/upload/file/20210620/1624152104556055537.pdf
74	2021-05-07	Guangdong	https://www.163.com/dy/article/GB8U38FV0534MQ31.html
75	2019-09-30	Hunan	http://www.yuelu.gov.cn/yl_xxgk/bmxxgkml/qajj/tzgg/202005/t20200527_8134567.html
76	2020-12-06	Jiangsu	http://www.njls.gov.cn/lsqrmzf/202205/t20220517_3420615.html
77	2019-04-23	Guangdong	http://www.xiangqiao.gov.cn/czxqyjglj/gkmlpt/content/3/3659/post_3659574.html#20119
78	2021-06-09	Guangdong	http://dgsafety.dg.gov.cn/attachment/0/63/63514/3586359.pdf
79	2018-07-04	Jiangsu	http://www.wj.gov.cn/html/czwj/2018/BEAJQHIE_0915/267063.html
80	2017-06-24	Fujian	http://www.panzhihua.gov.cn/zfxxgk1/fdzdgknr/yjgl/pzhaq/1715406.shtml
81	2019-12-19	Guangdong	http://www.lg.gov.cn/attachment/0/687/687660/7848609.pdf
82	2020-11-10	Guangdong	http://www.zs.gov.cn/hjq/zwgk/content/post_1952859.html
83	2019-09-20	Anhui	https://www.safehoo.com/Item/5689767.aspx
84	2020-09-11	Beijing	https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fzyk.bjhd.gov.cn%2Fjbdt%2Fauto4504_56383%2Fauto4504_53332%2Fauto4504_53362%2Fsgdc%2F202011%2FP020201119554442439884.doc&wdOrigin=BROWSELINK
85	2022-02-10	Fujian	https://new.qq.com/omn/20220210/20220210A028UP00.html
86	2022-04-03	Fujian	http://www.xmta.gov.cn/zc/zdly/aqsc/jdjc/202207/t20220706_854563.htm
87	2021-04-22	Fujian	http://search.zhangzhou.gov.cn/cms/html/lwqrmzf/2021-08-30/1088004901.html

(*continued on next page*)

Table 1 (*continued*)

No.	Date	Province	Source
88	2020-01-07	Guangdong	http://www.yangshan.gov.cn/qyysyjgl/gkmlpt/content/1/1111/post_1111187.html#6950
89	2021-10-27	Henan	http://www.hnsc.gov.cn/public/6596531/156701.html
90	2017-11-03	Jilin	http://yjj.jlcity.gov.cn/sgdc/201909/t20190927_637417.html
91	2020-03-21	Jiangsu	http://www.lyg.gov.cn/zglygzfmhwz/sgxx/content/7b8d90b9-6bcd-4e24-83f5-c41238a0d226.html
92	2021-09-04	Liaoning	http://www.safehoo.com/Case/Case/Drop/202211/5688563.shtml
93	2022-03-09	Shandong	https://zhuanlan.zhihu.com/p/536079113
94	2020-11-27	Shanghai	https://www.songjiang.gov.cn/govxxgk/SHSJ10/2021-07-23/4860ba67-8395-4c01-9776-841a5ec6e0d5.html?currenturl=zdly
95	2020-10-18	Shanghai	http://www.jinshan.gov.cn/yjglj-sgtb/20201225/807463.html
96	2020-09-07	Tianjin	https://www.tjdl.gov.cn/gongkai/zfxxgkzl/zfgbm/dlqyjj/gknr/zdmsxx/aqsc/202012/t20201212_4932338.html
97	2022-04-23	Zhejiang	http://www.yk.gov.cn/art/2022/7/20/art_1229191721_1786802.html
98	2020-12-22	Zhejiang	http://www.shaoxing.com.cn/p/2847747.html
99	2020-03-12	Zhejiang	http://www.hzw.gov.cn/art/2020/7/31/art_1229023878_1892692.html
100	2022-05-02	Shandong	http://www.licheng.gov.cn/art/2022/7/11/art_46084_4799210.html
101	2022-06-03	Guangdong	http://www.huilai.gov.cn/attachment/0/112/112426/698171.pdf
102	2021-05-28	Liaoning	http://www.yingkou.gov.cn/govxxgk/yjglj/2021-07-29/5723f0ef-dc1f-4e7a-994b-78ac4eabf977.html
103	2020-09-20	Shanghai	https://www.pudong.gov.cn/019012011/20211102/2379.html
104	2022-07-21	Shanghai	https://xxgk.shmh.gov.cn/mhxxgkweb/html/mh_xxgk/zdly_scjg_aqsc/2022-10-17/Detail_142726.htm
105	2020-01-07	Zhejiang	http://kfq.lishui.gov.cn/art/2020/7/10/art_1229215648_2688521.html

(2) **Analyzing data from samples:** Using frequency and content analysis, we revealed important information about accident locations, primary accident types, and machinery prone to accidents. Statistical data was used to assess the impact of accidents, including the number of deaths and injuries and their effect on direct economic losses. The research used sophisticated algorithms (Ringe, Lasson, and PLS regression) to examine their relationship further.
(3) **Identifying risk factors and building a management model:** Risk factors are identified based on Rasmussen's risk framework in this paper, and a hoisting management model is constructed by applying the AcciMap technique and PDCA method.
(4) **Proposing risk response strategies:** Normative recommendations are made for each risk layer, and the application of emerging technologies is discussed.
(5) **Discussing AcciMap:** Discuss the advantages, disadvantages, and implications of the research regarding the AcciMap technology.
(6) **Concluding the entire study:** Summarize this study's main findings and shortcomings and look at future research directions.

3.2. Research materials

As shown in Table 1, these samples cover all provinces in mainland China.

3.3. Predictive models

We based on SPSSPRO software [30] and used three different algorithms to model the impact of hoisting accidents. Each regression method has strengths and weaknesses. We compared the performance of the three algorithms to provide a reference for related research in academia.

Ridge Regression *(RR)* is a regression and statistical method in machine learning. Ridge regression addresses two main problems: when the number of predictor variables exceeds the number of observed variables (predictor variables are equivalent to characteristics and observed variables are equivalent to labels), and when there is multicollinearity between data sets, i.e., the correlation between predictor variables [31,32].

The matrix form of the ridge regression analysis is as follows:

$$\widehat{\beta}^{\text{bridge}} = \text{argmin}_{\beta} \left\{ \sum_{i=1}^{N} \left(y_i - \beta_0 - \sum_{j=1}^{p} \beta_j x_i \right)^2 + \lambda \sum_{j=1}^{p} \beta_j^2 \right\} \tag{1}$$

However, its estimated biased regression coefficients tend to be closer to the actual situation, thus improving the stability and reliability of the model and providing better results for the repair and fitting of pathological data. It is analyzed in the following steps [33]:

1) The ridge plot identifies the K value, which is selected as the minimum value at which the standardized regression coefficients of every independent variable stabilize. A lower K value results in less bias, whether subjectively or automatically induced by the system.
2) The F-value is analyzed for significance ($p < 0.05$) to indicate the presence of a regression relationship.
3) Analysis of the model fit utilizing the R^2 value (The closer the R^2 value is to 1, the better the data fit to the regression line is).
4) Analysis of the significance of X; if significant ($p < 0.05$), it is used to explore the relationship between the effect of X on Y.
5) Compare and analyze the degree of influence of X on Y in conjunction with the value of the regression coefficient B.
6) Determine the equation for obtaining the model.

Lasso Regression (Least Absolute Selection and Shrinkage Operator) is an alternative to least squares for compressive estimation. Assume that the data $\{X_i, Y_i\}$, $X_i = \{x_{i1}, \ldots, x_{im}\}$ T and Y_i are the explanatory and corresponding variables corresponding to the i-th observation, respectively. Consider the linear regression model:

$$Y_i = \alpha_i + \sum_{j=1}^{N} \beta_j x_{ij} + \varepsilon_i, \varepsilon_i \sim N\left(0, \sigma^2\right) \tag{2}$$

In the usual regression structure, assuming that the observations are independent of each other or that Y_i is independent given the observations, i.e., Y_i is conditionally independent of X_i, and assuming that x_{ij} is standardized, which means $\frac{1}{n}\sum_j x_{ij} = 0$, $\frac{1}{n}\sum_j x_{ij}^2 = 1$, the Lasso estimate is:

$$\begin{aligned} \left(\widehat{\alpha}, \widehat{\beta}\right) = \arg \min_{\beta} & \left\{ \sum_i \left(Y_i - \alpha_i - \sum \beta_j x_{ij} \right)^2 \right\} \\ \text{s. t.} & \sum_j \left|\beta_j\right| \leqslant t \end{aligned} \tag{3}$$

Here, $t \geq 0$, which is the summation parameter. At this point, for all t, there is an estimate of α ($\widehat{\alpha} = \bar{y}$). Without loss of generality, it is assumed $\bar{y}= 0$ then omits α. The control of the summing parameter t makes the regression coefficients generally smaller, and if $t^0 =$

$\sum_j |\beta_j|, t \leqslant t^0$, some of the regression coefficients shrink and converge to 0, and some even equal 0.

It is widely used for fitting and variable selection in the presence of multicollinearity data. It is analyzed in the following steps [34]:

1) Determine the value of λ through the cross-validation method. λ is chosen so that the mean squared error of the lasso model is minimized.
2) Determine the variables screened by the model through the λ and regression coefficient plots, where variables with a standardized coefficient of zero are excluded from the Lasso regression model.
3) The equations and predictions of the lasso regression model are obtained, and the retained and excluded variables are listed.

Partial Least Squares Regression (PLSR) is a many-to-many linear regression modeling method that uses one set of variables to predict another set of variables. It is often used when the number of variables (columns) in both sets is large. Both have multiple correlations, and the observed data's sample size (rows) is small. The principle is to integrate the three methods of principal component analysis, typical correlation analysis, and linear regression, and to provide a regression model and some principal component analysis and typical correlation analysis in the analysis results. It is analyzed in the following steps [35]:

Standardize X and Y:

$$A = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \cdots & & \cdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix}, B = \begin{bmatrix} y_{11} & \cdots & y_{1m} \\ \cdots & & \cdots \\ y_{n1} & \cdots & y_{nm} \end{bmatrix} \tag{4}$$

1) Extract two separate groups (X and Y) Variables' first pair of components u_1 and v_1, and maximize their relevance. Suppose that the first component of the two sets of variables is u_1 and v_1 , u_1 is a linear combination of the set of independent variables, $X = [x_1, \ldots, x_m]^T$, v_1 is a linear combination of the set of independent variables, $Y = [y_1, \ldots, y_p]^T$:

$$\begin{cases} u_1 = \rho_1^T X \\ v_1 = \gamma_1^T Y \end{cases}, \left(u_{m*m} = \rho_{n*m}^T \cdot X_{n*m}, u_1 \text{ is } top_1 \text{ main components}, v \text{ same}\right) \tag{5}$$

For the purposes of regression analysis, it is required :

a) u_1 and v_1 each extract as much variance information as possible for the group of variables in which they are located.
b) The correlation between u_1 and v_1 is at its maximum.
2) Calculate ρ_1 and γ_1.

Maximizing the covariance so that the correlation between u_1 and v_1 is maximized can be calculated using the inner product of the score vectors $\widehat{u}_1$ and $\widehat{v}_1$ as follows:

$$\begin{aligned} & max < \widehat{u}_1, \widehat{v}_1 > = \rho_1^T AB\gamma_1 \\ & \text{s.t.} = \begin{cases} \rho_1^T \rho_1 = 1 \\ \gamma_1^T \gamma_1 = 1 \end{cases} \end{aligned} \tag{6}$$

Using the Lagrange multiplier method, the problem is reduced to finding the unit vectors ρ_1 and γ_1 such that γ_1 is maximized. The problem is solved by simply computing the eigenvalues and eigenvectors of $M = A^T BB^T A$, and the maximum eigenvalue of M is θ_1^2, and the corresponding eigenvector is ρ_1 of the required solution, which in turn also yields $\gamma_1, \gamma_1 = \frac{1}{\theta_1} B^T A \rho_1$..

From the standardized observation data matrices X and Y for the two sets of variables, the score vectors for the first pair of components can be calculated, denoted as $\widehat{u}_1$ and $\widehat{v}_1$, $\widehat{u}_1 = A\rho_1, \widehat{v}_1 = B\gamma_1$.

Build regressions of $y_1, \ldots, y_p$ on u_1 and $x_1, \ldots, x_m$ on u_1, assuming a regression model:

$$\begin{cases} A = \widehat{u}_1 \sigma_1^T + A_1 \\ B = \widehat{u}_1 \tau_1^T + B_1 \end{cases} \tag{7}$$

where $\sigma_1^T = [\sigma_1, \ldots, \sigma_m]$, $\tau_1^T = [\tau_1, \ldots, \tau_m]$ are the parameter vectors in the regression model, and A_1, B_1 are the residual arrays, respectively.

The least squares estimate of the regression coefficients σ_1, τ_1 are:

$$\begin{cases} \sigma_1 = \dfrac{A^T \widehat{u}_1}{\| \widehat{u}_1 \|^2} \\ \tau_1 = \dfrac{B^T \widehat{u}_1}{\| \widehat{u}_1 \|^2} \end{cases} \tag{8}$$

Replace A, B with the residual array and A_1 & B_1, and repeat the above steps until the absolute value of the elements in the residual array is approximately zero, obtaining a sum σ_1 and τ_1 for each proceeding.

3) Repeat the above steps to obtain r components.

$$\begin{cases} A = \widehat{u}_1\sigma_1^T + \ldots + \widehat{u}_r\sigma_r^T + A_r \\ B = \widehat{u}_1\tau_1^T + \ldots + \widehat{u}_r\tau_r^T + B_r \end{cases} \tag{9}$$

Substituting $u_1 = \rho_1^T X$ into $Y = \widehat{u}_1\tau_1^T + \ldots + \widehat{u}_r\tau_r^T$ gives the partial least squares regression equation $y_j = c_{j1}x_1 + \ldots + c_{jm}x_m, j = 1, 2, \ldots, p$ for the P dependent variables.

4) Multiple components were extracted for cross-validity testing. Each time the i-th observation is discarded, the least squares regression is used for the remaining n-1 observations and the fitted regression equation after considering the extraction of h (h $\leq$ r) components. Then, the j-th observation of the discarded set of independent variables is substituted into the fitted regression equation to obtain the predicted value of $y_j(j = 1, 2, \ldots, p)$ at the i-th observation. Repeating the above validation for $i = 1, 2, \ldots, n$ gives the prediction error sum of squares for the j-th dependent variable $y_j(j = 1, 2, \ldots, p)$ when h components are drawn as:

$$\text{PRESS}_j\ (h) = \sum_{i=1}^{n} \left(b_{ij} - b_{\hat{ij}}(h)\right)^2, j = 1, 2, \ldots, pY = \left[y_1, \ldots, y_p\right]^T \tag{10}$$

The sum of squares of the prediction errors is:

$$PRESS(h) = \sum_{j=1}^{p} PRESS_j(h) \tag{11}$$

in addition, a regression equation with h components is then fitted using all sample points. At this point, the predicted value of the i-th sample point is noted as $\widehat{b}_{ij}(h)$, and the error sum of squares for y_i can be defined as:

$$S(h) = \sum_{j=1}^{p} SS_j(h) \tag{12}$$

when *PRESS(h)* reaches its minimum value, the corresponding h is the number of components sought. Usually, there is always *PRESS (h)* > *SS(h)* and *SS(h)* < *SS(h-1)*. Therefore, when extracting components, it is always desirable that $\frac{PRESS(h)}{SS(h-1)}$ is as small as possible. Generally, a threshold of 0.05 can be set and the rule of determination is that a new component is helpful for regression improvement when $\frac{PREES}{SS(h-1)} <= (1 - 0.05)^2$, therefore, the cross validity:

$$Q_h^2 = 1 - \frac{PRESS(h)}{SS(h-1)} \tag{13}$$

Before the end of each calculation step, the cross validity is calculated, and h there is $Q_h^2 < 1 - 0.095^2$. Once the model has achieved the desired level of accuracy, the process of extracting components can be discontinued.

3.4. *Theoretical framework*

In 1997, Rasmussen proposed a framework for managing safety risks in complex sociotechnical systems [36]. According to him, sociotechnical systems comprise six levels: government level, regulator and association level, company level, management level, employee level, and work level. These levels interact through top-down decision flows and information feedback [37,38]. The levels are not static and are continuously influenced by the external environment, including the technological, economic, and policy environments [39,40].

AcciMap is a sophisticated method of examining incidents that employs a systematic approach [41,42]. This approach involves six levels, encompassing government policies and budgets, regulatory agencies and associations, planning and budgeting by local governments, technical and operational management, physical processes and participant activities, and equipment and surroundings [43,44]. The methodology for constructing a system level can be outlined as follows [45,46]:

1) Develop a system framework that accurately reflects the context.
2) Gather relevant cases and information to identify the risk factors that require consideration.
3) Determine the appropriate level placement for each factor and position the influencing factors accordingly.
4) Establish a causal relationship between the factors and create a cause-effect diagram by linking them through pathways.

The risk factors for this study were carefully examined and refined. Following expert discussions, a risk identification framework was developed and named AcciMap-IH (AcciMap-IBS-Hoisting), illustrated in Fig. 3. This framework requires each level to control risks to people, equipment, and the environment, directly or indirectly, following the construction industry's laws, regulations, and codes of practice. Furthermore, the decisions made at higher levels will impact the state and behavior of the lower levels. Meanwhile, information from the lower levels feeds back upwards, creating a circular flow of information. The framework not only considers the factors of the various stakeholders but also demonstrates the relationship of risk transfer.

4. Results

4.1. Location of accidents

Our collection of 105 hoisting accident cases mainly originated from the southeast coast. This region has a booming economy and a high demand for infrastructure construction. Guangdong province provided the most considerable number of sample cases, with 20. The second place is Zhejiang Province, with 11. Fujian Province closely follows them, with 8. It should be noted that Shanghai, Beijing, and Tianjin were not shown on the map due to map style limitations; their numbers are 6, 3, and 3, respectively.

4.2. Main types of accidents and equipment involved

As large construction equipment on construction sites, hoisting machines are widely used because of their large construction area and high efficiency [47–49]. The Hoisting of IBS construction has the following characteristics: (1) The components have considerable potential energy and are large, significantly raising the risk level [50,51]. (2) The multi-dimensional hoisting process links machines, workforce, technology, environment, and prefabricated components [52,53]. (3) The construction site is equipped with lifting machinery, such as a high-rise tower crane capable of handling heavy loads [54,55]. (4) Hoisting is a complex and uncertain operation requiring the cooperation of signalers, drivers, installers, and other personnel, so there is a strong demand for dynamic control [56]. (5) Risk factors will interact during the hoisting process and evolve dynamically, and accurately identifying risk factors is a prerequisite for risk assessment [57].

As depicted in Fig. 4, truck-mounted cranes were responsible for 57.1 % of all accidents. With 19 %, tower crane accidents are the second most common type. The remaining accident types, including those involving crawler, portal, and bridge cranes, account for 6.7 %, 4.8 %, and 4.8 %, respectively. Occasionally, accidents occurred involving hand chain hoists, electric chain hoists, excavators, and winches. As this sample selection can be viewed as a random sample of China, most accidents involve tower cranes, truck-mounted cranes, and crawler cranes.

The following common types of accidents occur in construction hoisting: (1) Machinery collapse can occur when a crane is overloaded or improperly installed. The crane may tip over, causing the load to fall and potentially injuring workers or bystanders. (2) Collision accidents occur when a worker or bystander is struck by a load lifted or moved by a crane. Loads may fall due to operator error, equipment failure, or other factors. (3) Workers can be electrocuted when a crane encounters overhead power lines or other electrical hazards. It can happen when the crane operator is not made aware of the location of the power lines or when the wires need to be correctly marked. (4) Workers can fall from heights while working on or near lifting equipment such as cranes or scaffolding. As

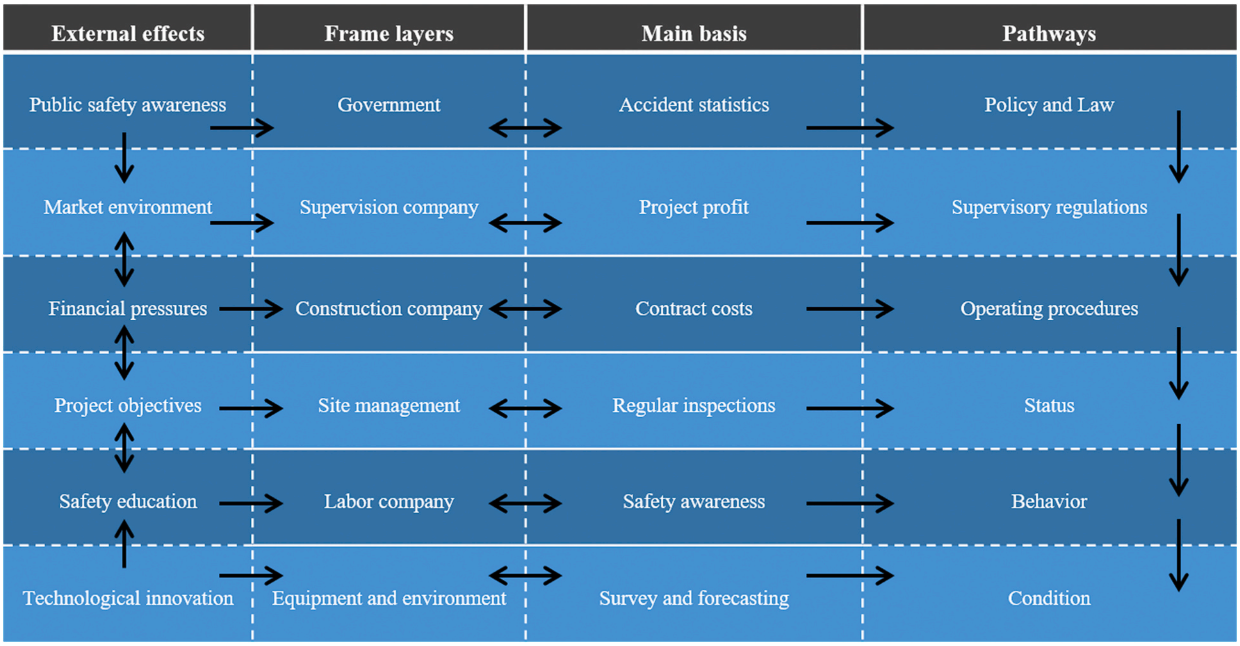


Fig. 3. AcciMap-IH framework.

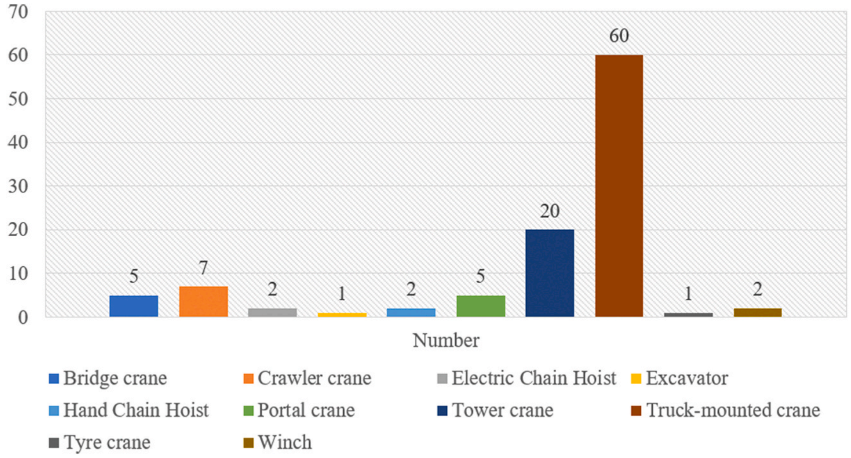


Fig. 4. The number of leading equipment in hoisting accidents.

shown in Fig. 5, the top three accident types found in this study were struck by hoisting load, collapse of machinery, and worker falls from height, with 38, 21, and 18 respectively. Other accidents combined totaled 26, including struck by the mechanical arm, electrocution, collapse of the building structure, struck by wire rope, hook falling, and squeezed by machinery. In addition, the collapse of the inspection rack and environment occurred occasionally.

4.3. *Impact of the accident*

The effects of a hoisting accident can be devastating for the individuals involved, their families, and their co-workers. Injuries resulting from lifting accidents can range from minor cuts and bruises to severe head trauma, fractures, and spinal cord injuries. In the worst cases, hoisting accidents can even lead to fatalities. The emotional and psychological toll of hoisting an accident can also be significant, especially for workers who witness or are directly involved. In addition to the human impact of lifting accidents, these events can financially impact the business. Hoisting accidents can lead to productivity loss, equipment damage, and legal liability. Businesses may be forced to pay workers' compensation, face fines from regulatory bodies, and incur costs associated with repairing or replacing damaged equipment. We visualized the data from Table 1 in Fig. 6. The mean of death per accident was 1.543, with the maximum number being 18. The peak number of injuries caused by a single accident was 33, but this was not typical. Instead, injuries were not the norm, the mean of which is 0.829. Regarding economic loss, a single lifting accident typically results in direct economic losses of RMB 2.43 million, but there are some instances where the peak exceeds RMB 18 million. Finally, spatial scatter diagrams examine the spatial relationship between the three impacts.

The data was sorted to examine the correlation between economic losses and death and injury. The closest dependent variable magnitude was utilized before regression analysis to address missing values.

4.3.1. *Ridge regression*

Algorithm configuration:

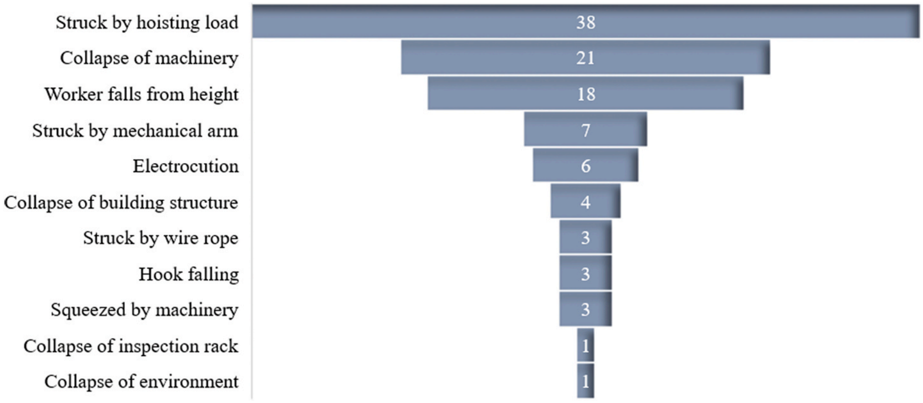


Fig. 5. The number of main types of hoisting accidents.

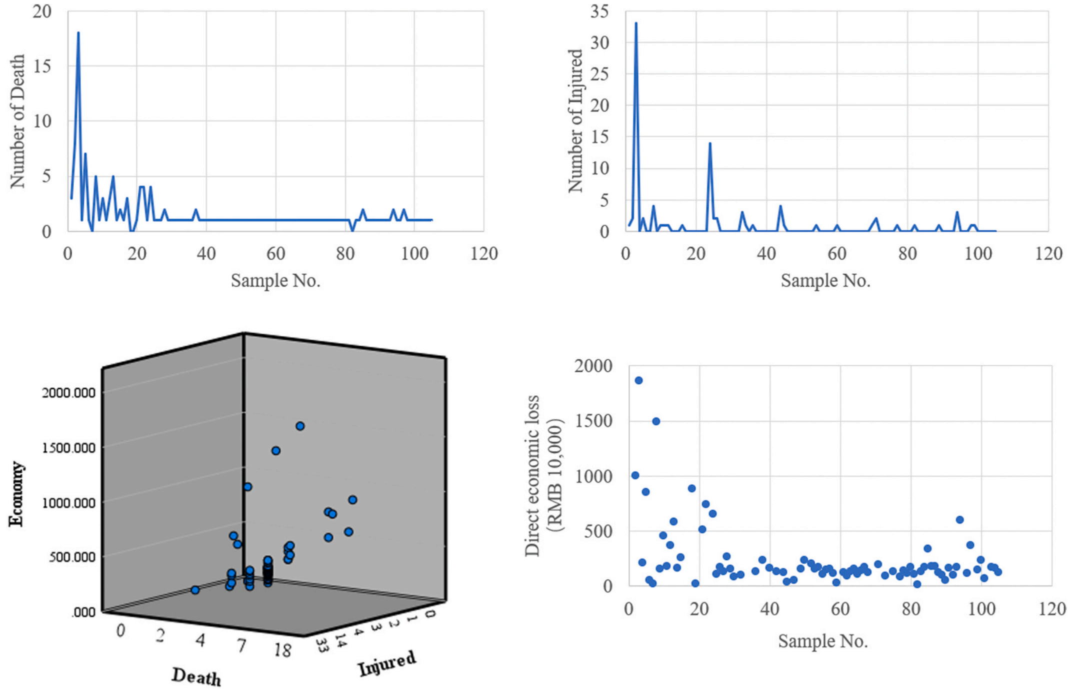
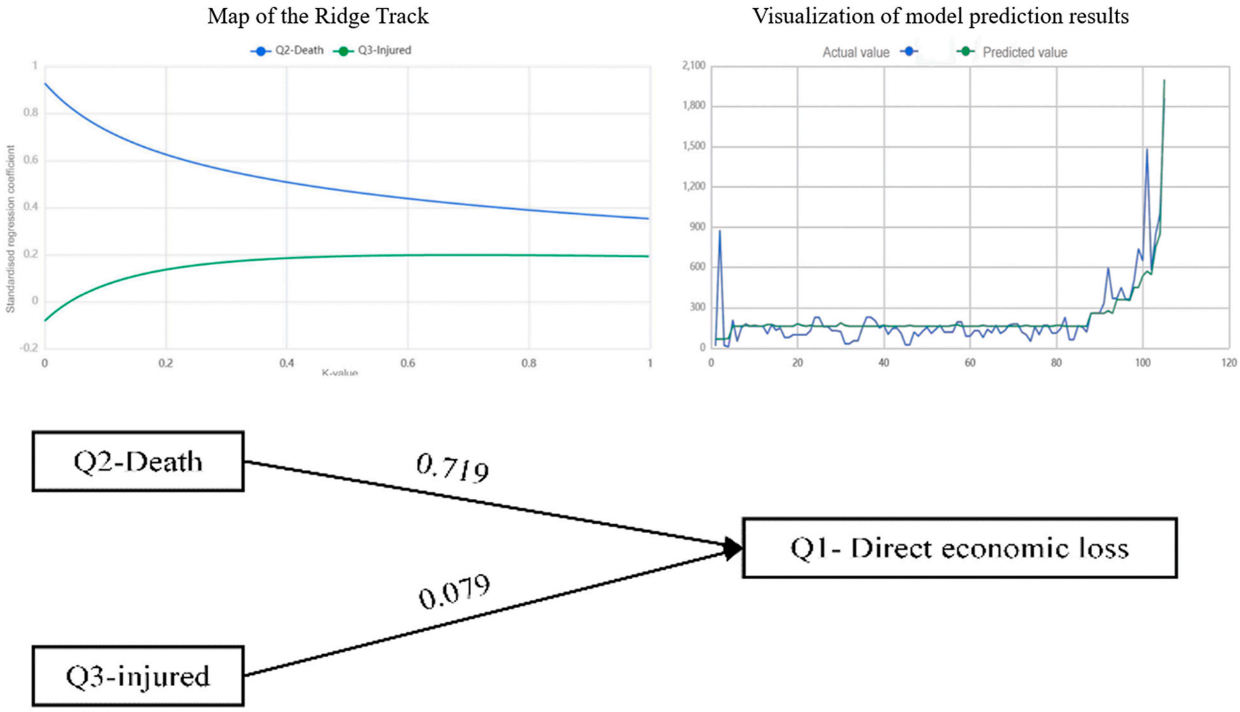


Fig. 6. The scatterplot for the impact of hoisting accidents.



Ridge regression model path

Fig. 7. Presentation of Ridge model highlights.

a) Variables: Variable X: {Q2-Death, Q3-Injured}; dependent variable Y: {Q1-Direct economic loss}
b) Parameters: k-value: {Automatic}

Fig. 7 shows a visual representation of the current model with stable normalized coefficients for each independent variable. The variance expansion factor method determined $K = 0.109$. Table 2 displays the parameters and test results, such as the model's standardized coefficients, t-values, F-test results, R^2, adjusted R^2, and more. These results were used to analyze the formulae and test the model. Remember, the curvilinear regression model requires an overall regression coefficient that is not zero, indicating a relationship between variables. To test this, the model is compared against the p-value of the F-test.

The ridge regression results show that the level presents significance based on the F-test significance p-value of 0.000***. The original hypothesis is rejected, indicating a regression relationship between the independent and dependent variables. At the same time, the model's goodness of fit R^2 was 0.729, and the model performed well.

The equation:

$$\text{Q1-Direct economic loss} = 67.403 + 96.179 \times \text{Q2-Death} + 6.093 \times \text{Q3-Injured} \tag{14}$$

The model's results are also presented in Fig. 7 as a path diagram, which includes the coefficients used to analyze the equations of this model; the raw data and fitted values of this model are presented in a visualized form.

4.3.2. *Lasso regression*

Algorithm configuration:

a) Variables: Variable X: {Q2-Death, Q3-Injured}; Variable Y: {Q1-Direct economic loss}
b) Parameters: λ-value: {Automatic}

Displayed visually in Fig. 8 is the selection of λ values through cross-validation. The vertical axis represents the model's mean square error, while the horizontal axis represents the logarithmic value of λ. To achieve minimal mean squared error, it is recommended to select $\lambda = 0.02$ and $\log(\lambda) = -3.902$. The diagram also showcases how the model coefficients transform as the logarithmic value of λ fluctuates.

The coefficients of the model are presented in Table 3. If the coefficient of a standardized variable in the model is 0, the variable is not included. The Lasso regression results show that the intercept terms and the Q2-Death and Q3-Injured were all retained, and no variables were removed from the model.

The standardized formula for the model:

$$\text{Q1-Direct economic loss} = 34.417 + 124.226 \times \text{Q2-Death} - 6.322 \times \text{Q3-Injured} \tag{15}$$

The unstandardized formula for the model:

$\text{Q1-Direct economic loss} = 34.689 + 123.971 \times \text{Q2-Death} - 6.175 \times \text{Q3-Injured}$(16)

The raw data and fitted values for the lasso regression model are also shown in Fig. 8.

4.3.3. *Partial least squares regression*

Algorithm configuration:

a) Variables: Variable Y: {Q1-Direct economic loss}; Variable X: {Q2-Death, Q3-Injured}
b) Parameters: Whether to automatically determine the maximum number of principal components:{2}

Table 4 shows how much the potential factors contribute to explaining the dependent variable. The X variance represents the information extracted from the independent variable. In contrast, the cumulative Y^2 variance (R^2) means the data extracted from the dependent variable [58], which helps determine the maximum number of principal components of the parameter. It reveals that the first potential factor alone explains 80 % of the information on dependent variables. However, when all potential factors are combined, they do not explain 80 % of the information of the dependent variable. The VIP (variable importance in projection) and the factor loading coefficients are also included in Table 4.

Table 2
Results of the ridge regression analysis.

K = 0.109	Non-standardized coefficients		Standardized coefficients	t	P	R^2	Adjusted R^2	F
	B	Standard deviation	Beta					
Constant	67.403	17.289	–	3.899	0.000***	0.729	0.724	137.473(0.000***)
Q2-Death	96.179	7.894	0.719	12.183	0.000***			
Q3-Injured	6.093	4.532	0.079	1.344	0.182			
Dependent variable: Q1-Direct economic loss								

Note: ***, **, * represent 1 %, 5 %, and 10 % level of significance, respectively.

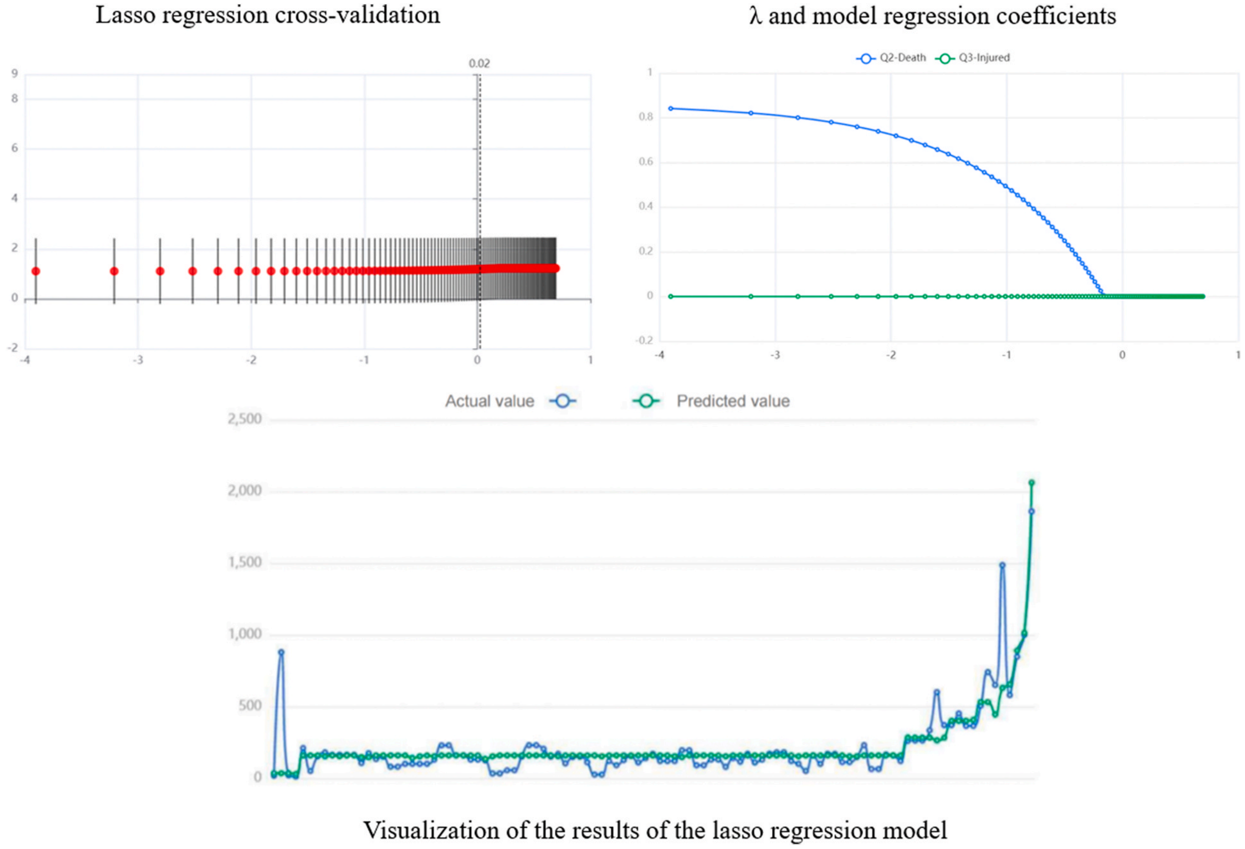


Fig. 8. Presentation of the Lasso model highlights.

Table 3
Model coefficients.

Variable name	Standardization coefficient	Non-Standardization coefficient	R^2
Intercept distance	34.417	34.689	0.744
Q2-Death	124.226	123.971	
Q3-Injured	−6.322	−6.175	

The normalized formula for the model is:

$$\text{Q1-Direct economic loss} = 34.393 + 124.248 * \text{Q2-Death} - 6.334 * \text{Q3-Injured} \tag{17}$$

4.3.4. *Comparison of the three regressions*

The advantage of Ridge regression is that it handles multicollinearity well by adding a penalty term to the least squares objective [59]. It provides stable and reliable estimates even with many predictor variables and is suitable for situations where all predictor variables contribute to the results [60,61]. However, it cannot perform automatic variable selection and does not produce sparse solutions [62,63]. The Lasso regression technique automatically selects variables by shrinking specific coefficients to zero, aiding in identifying variables and regression coefficients that minimize model prediction error [64,65]. However, it has the disadvantage of tending to select only one predictor variable among the variables of interest, which may lead to omitting important variables [66,67]. Secondly, it may not perform well when multicollinearity is relatively unstable in the presence of many predictor variables [68]. The advantage of partial least squares (PLS) regression is that it effectively deals with multicollinearity by creating new uncorrelated variables, which performs well with small sample sizes and can handle high-dimensional data [69,70]. The disadvantage of using this model is that it may overfit the data if the number of predictor variables dramatically exceeds the sample size. This method is less robust than the Ridge and Lasso models [71,72]. Comparing performance by the parameters R2 of each model, Lasson regression is the most appropriate choice, followed by Ridge and PLS regression.

Table 4
Presentation of PLS model highlights.

Explanation of variance of factors					
Potential factors	X variance	Cumulative X variance	Y variance	Cumulative Y variance (R^2)	Adjusted R^2
1	0.906	0.906	0.668	0.668	0.664
2	0.094	1	0.077	0.744	0.739
Summary of independent variables VIP					
Variables		Factor 1		Factor 2	
Q2-Death		1.115		1.092	
Q3-Injured		0.87		0.898	
Matrix of components					
Variables		Factor 1		Factor 2	
Q2-Death		0.789		−0.702	
Q3-Injured		0.615		0.72	
Q1-Direct economic loss		0.786		−0.818	
Factor loading factor					
Variables		Factor 1		Factor 2	
Q2-Death		0.72		−0.615	
Q3-Injured		0.702		0.789	
Q1-Direct economic loss		0.611		−0.636	
Results of model coefficients					
		Q1-Direct economic loss		Q1-Direct economic loss (Standardization)	
Constants		34.393		0	
Q2-Death		124.248		0.928	

Table 5
Factors of hoisting risk.

Classification	No.	Risk factors	Sources
Government	G1	Approval of construction procedures	[7,73]
	G2	Review of company qualifications	[7]
	G3	Archiving of large machinery	[7,74]
	G4	Regular monitoring	[75,76]
Supervisory company	SC1	Approval of safety management systems	[77]
	SC2	Development of site supervision system	[7]
	SC3	Division of responsibility for safety	[77,76]
Construction company	C1	Management for equipment installation and dismantling companies	[57,78,79,80]
	C2	Management for equipment rental companies	[74]
	C3	Management for labor companies	[77]
	C4	Hoisting program	[7,57,59,78]
	C5	Safety education & training	[78,81];
	C6	Completeness of emergency plans	[57,79,82]
Site management	SM1	Technical safety briefings	[77,83]
	SM2	Management of machinery use	[84,85]
	SM3	Management of machinery installation and dismantling	[86,87]
	SM4	Management of machinery maintenance	[7,57,79,88]
	SM5	Information communication	[7,89]
	SM6	Emergency rescue exercise	[90]
	SM7	Checking for components and hazards	[78,82];
Labor company	L1	Operation of driver	[91]
	L2	Operation of coordinator	[77]
	L3	Operation of rigger	[92]
	L4	Operation of signaling & command staff	[77]
	L5	Skill level	[7,57,78,79,80]
	L6	Safety awareness	[7,50,79]
	L7	Health status	[7,93]
Equipment and environment	EE1	Reliability of wire rope	[79,94]
	EE2	Reliability of the hook and reel	[7,59]
	EE3	Reliability of wheels and tracks	[87]
	EE4	Reliability of brakes	[95,96]
	EE5	Reliability of foundation	[79,97]
	EE6	Reliability of reducers	[80,98]
	EE7	Extreme weather	[7,78,79,99,100]
	EE8	Working space	[7,78,79,101,102]
	EE9	Warning signs	[7,103]

4.4. Hoisting risk factors

The study reviewed cases based on AcciMap-IH framework. The factors influencing hoisting safety risks from the government, the supervisory company, the construction company, site management, the labor company, and equipment and environment are summarized in Table 5.

The statistics of the accident cases are shown in Fig. 9. It also ranks accident factors according to the number of occurrences.

4.4.1. The factors of government

The government factors in hoisting risks include (1) Approval of construction procedures: China aims to interconnect provincial, municipal, and district-level work safety management systems to build a safety management network with up-and-down synergy, information sharing, and proactive supervision. However, there are still many management regulations that need to be clarified. More precise requirements and installation standards are required for hoisting oversized photovoltaic roof panels. Many hoisting activities are illegal due to a lack of appropriate approval procedures in urban and rural areas. (2) Archiving of large machinery: The government department inspects the appearance of large machinery and equipment, steering mechanisms, connecting devices, and other components, and machinery that does not comply with the regulations will not be inspected and qualified for construction. In some samples, old equipment was used for hoisting even though it had not been inspected and qualified. (3) Review of company qualifications: Government departments mainly review companies to optimize the business environment and regulate market conduct. We found that many parties involved in the accidents needed more qualifications, falsified qualifications from other companies, or worked without qualifications. (4) Regular monitoring: The government is responsible for consistently overseeing construction projects within its jurisdiction. The study has revealed that the multitude and magnitude of construction sites in China have resulted in a challenging and demanding task of supervision across several government departments, given the limited number of supervisory personnel, making it arduous to exercise complete control over each construction site.

4.4.2. The factors of supervisory company

The supervisory company ensures the safety of workers and persons working near the hoisting area and that safety procedures are followed. The main risk factors are (1) Approval of the safety management system: The supervisory company is primarily responsible for the safety management system, mainly auditing and inspection. For example, it audits the construction program submitted by the construction company and the professional qualifications of the management personnel of the construction unit; it checks whether the sub-projects are carried out following the approved construction program. There is a difference between a supervisor and a consultant in China, as it acts more as a technical representative of the investor at the construction site. (2) Development of site supervision system: The supervisory company should clarify the work objectives of the project supervisory body and determine the specific supervisory engineer system, content, procedures, and methods according to the actual project. Some cases show that poor supervision systems have led to ineffective supervision. (3) Division of responsibility for safety: The supervisory company needs to inspect the safety situation on the construction site, assign responsibility for any hidden dangers found, and issue a stop-work order promptly. In some cases, there were situations where the hazards were not removed promptly due to an unclear delineation of responsibilities.

4.4.3. The factors of construction company

The factors of construction companies include (1) **Management for equipment installation and demolition companies:** As cranes are dangerous equipment, construction companies manage the installation and dismantling of companies mainly by reviewing the technical plans and staffing of equipment installation and dismantling, as well as acceptance after installation. (2) **Management for equipment rental companies:** The construction enterprise's management of the leasing company is mainly reflected in the

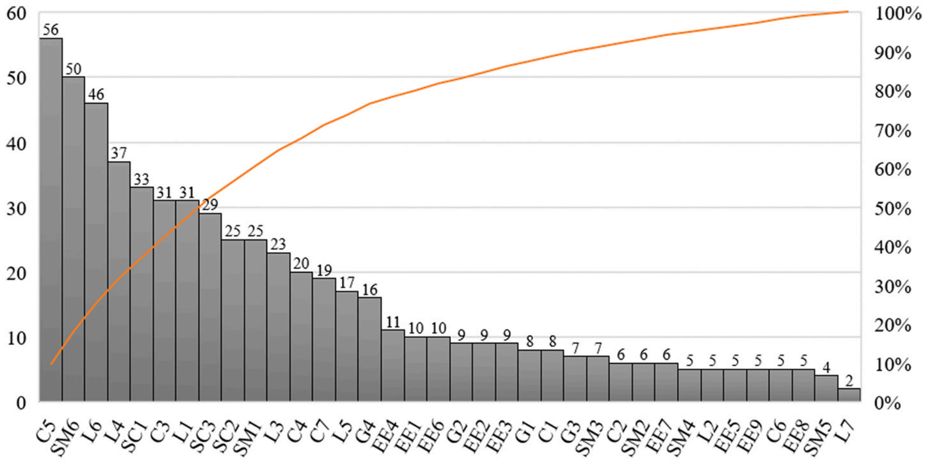


Fig. 9. Statistics on accident factors of samples.

inspection of the use records, factory information, and quality certification of the lifting equipment before it enters the site. (3) **Management of labor companies:** The high labor turnover on construction sites makes supervision difficult. Construction companies mainly examine multiple perspectives regarding qualification, reputation, capital, personnel, and performance before selecting labor teams to participate. (4) **Hoisting program:** The main hoisting program includes project characteristics, layout, construction requirements, hazard identification, and resource planning. Many cases occur due to the unreasonable lifting plan, such as the wrong calculation of the bearing capacity of the supporting surface, the incorrect calculation of the rigging, the wrong analysis of the lift object's force, and the failure to identify the hazards. (5) **Safety education & training:** Currently, three levels of education are mainly used in enterprises, including company-level education for new employees, project department-level education, and construction team-level education. The content involves personal safety, equipment safety, and work safety. However, safety education in many construction companies is a formality. (6) **Completeness of emergency plans:** There are irregularities in the emergency plans of many construction companies. A complete emergency plan should include a comprehensive emergency plan, a particular emergency plan, and an on-site disposal plan.

4.4.4. The factors of site management

The main factors of site management are: (1) Technical safety briefings: The purpose of the technical safety briefing was to help workers become familiar with the lifting equipment and technical measures used for hoisting. Some cases show a passive situation in safety management since no technical safety briefing was organized on-site for frontline operators. However, only documents were issued to the relevant departments, making operators ignorant of the risk content. (2) Management of machinery use: Lifting equipment should be used wisely on site and not be operated in violation of regulations. Some of the cases were due to overloading use, which led to the overturning of the crane. (3) Management of machinery installation and dismantling: The dismantling and installation of lifting machinery are accident-prone phases. Safety incidents due to improper dismantling and installation of substandard quality account for many samples. (4) Management of machinery maintenance: The quality of equipment management and maintenance is related to the failure rate, operation rate, work performance, and equipment safety performance. In some cases, the failure to clean, lubricate, tighten, and protect against corrosion has led to damage to the equipment, resulting in accidents. (5) Information communication: An extensive data and information base is formed due to many material types and machinery working on-site. When information is not passed on in time or correctly, incorrect component information leads to incorrect lifting operations and becomes a potential accident hazard. (6) Emergency rescue exercise: By practicing response procedures in a simulated environment, staff can become more familiar with the steps they need to take in the event of an emergency. In some cases, there was no adequate response to the accident (e.g., prompt medical attention and reporting to superiors), ultimately leading to an increase in the accident's impact. (7) Checking for components and hazards: Identifying safety hazards on site includes identifying hazards such as offenders, poor conditions, poor components. Specific hazards in case of accidents include poor visibility, interruptions in communication, workers not wearing bright-colored work clothing.

4.4.5. The factors of labor company

The main factors are (1) Operation of the driver: The driver needs to be proficient in the main technical parameters of the crane and is responsible for ensuring that the technical condition of each part of the equipment is intact. Many accidents showed drivers operating incorrectly, which could straightforwardly cause accidents. (2) Operation of coordinator: Due to the small size of the construction site in some cases and the deployment of multiple lifting devices. Due to the presence of cross radii, the coordination of multiple machines is crucial. The absence of inadequacy of coordinators has also been an essential factor in some cases. (3) Operation of rigger: The rigger is responsible for preparing spreaders and tying, hooking, and unloading prefabricated components. In many cases, the riggers failed to check the reliability of the rigging or the prefabricated elements were not tied down securely. (4) Operation of signaling & command staff: Different hoisting solutions exist for different components. The team leader is the one who supervises the use of correct procedures, methods, and requirements throughout the lifting implementation, such as the failure to check for loose connection bolts or the one-sided pursuit of progress, while simplifying the necessary marking procedures. (5) Skill level: Labor companies are responsible for providing workers with a professional qualification. The main types of work include signalers, machinery drivers, machinery installers and dismantlers, and workers in other necessary specialties. (6) Safety awareness: The safe operation of overhead cranes relies heavily on adequately functioning their brakes. These brakes have a dual role - they prevent the crane from dropping its suspended load and enable it to stop at the designated position during operation. Consequently, it becomes imperative that the brake functions correctly and does not fail during crane use. (7) Health status: The physical fitness of workers is critical, as hoisting operations are physically demanding and can expose workers to a range of hazards, including musculoskeletal disorders and falls. The psychological quality of the workforce is also essential, as the responsibility and stress involved in hoisting operations can hurt workers' mental health due to prolonged exposure to noise and vibration.

4.4.6. The factors of equipment and environment

The main factors of equipment and environment include (1) Reliability of the hook and reel: Long-term sliding of the spreader and rigging may lead to wear and tear, deformation, and even surface fatigue cracks on the hook, increasing the chance of a broken hook. Once the above problems occur, the hook will affect its reliability, and in serious cases, it may even cause the weight to fall off. In addition to the hook, the reel is an important force component of the crane. The reel in work, because of a long time and the existence of mutual extrusion and friction of the wire rope, will make the reel wear and fatigue cracks. Once deteriorated to a certain extent, this situation may cause the reel to be unable to withstand the load and rupture and even cause heavy falling and other safety accidents. (2) Reliability of brakes: The brake is a critical safety component. Properly functioning brakes are crucial to ensuring the safe use of cranes.

They serve a dual purpose: preventing the crane from dropping its suspended weight and enabling it to stop in its designated position during operation. The brake needs to operate correctly and not fail during use. Brakes can sometimes have insufficient power or even fail. This is often due to the extended use of the brakes that causes the temperature of the brake wheel to rise abnormally. Then, the tension of the brake tile becomes insufficient, leading to a complete failure or an incorrect brake functioning. If the brake tile and brake wheel are not replaced and adjusted promptly, then long-term use will cause the main spring to loosen and fall off, and in serious cases, even lead to the nut loosening and the whole tie rod falling off or the impeller of the hydraulic push rod loosening brake rotating inflexibly and other failures. In addition, brake failure may also be due to hinge jamming; brake torque tuned too large, hydraulic push rod looser cylinder lack of oil, brake tile, and brake wheel between the existence of dirt and other factors, need to be investigated one by one and carefully overhauled to eliminate the fault. (3) Reliability of wheels and tracks: In using cranes, wheels and tracks can also fail; the most common is the wheel gnawing track and trolley is not equal to the height, slipping, etc. Many factors lead to gnawing on the track, and the manifestation of gnawing on the track varies. However, the main reason is that the installation error is too large, and uneven friction and braking are not synchronized. Once the wheel gnawing track fails, the light affects the service life of the overhead crane; serious safety accidents may result. (4) Reliability of reducers: The gearbox is an important transmission system component. The reducer achieves the transmission of torque through gear meshing, and in the process of gear transmission, mechanical failures such as gear breakage, tooth pitting, tooth gluing, and tooth wear may occur. Several factors can cause failures, including the following: First, a short period of overload operation or the impact of a large impact load, resulting in fatigue fracture failure of the gear teeth due to repeated bending; Secondly, the tooth surface of the transmission meshing gear is not smooth enough, there are raised points or the lubricant is not clean; Thirdly, the temperature of the drive system is too high causing lubrication failure; finally, if particulate matter enters the contact surface of the gear mesh, then it will make the wear intensify, thus causing a potential failure. (5) Reliability of wire rope: The role of the wire rope in the crane is to cooperate with the hook, electric chain, hoist, and other equipment to complete lifting heavy objects and air movement work. Wire rope structures are highly susceptible to deformation. Hence, the operational reliability of such structures depends mainly on maintenance and monitoring procedures. Uneven force can lead to wire rope breakage, which is a direct cause of several accidents [104–106]. (6) Reliability of foundation: Choosing crane foundations is also essential. When the load-bearing foundation capacity cannot be met for lifting, the crane's stability will be directly affected. In addition, poor foundations

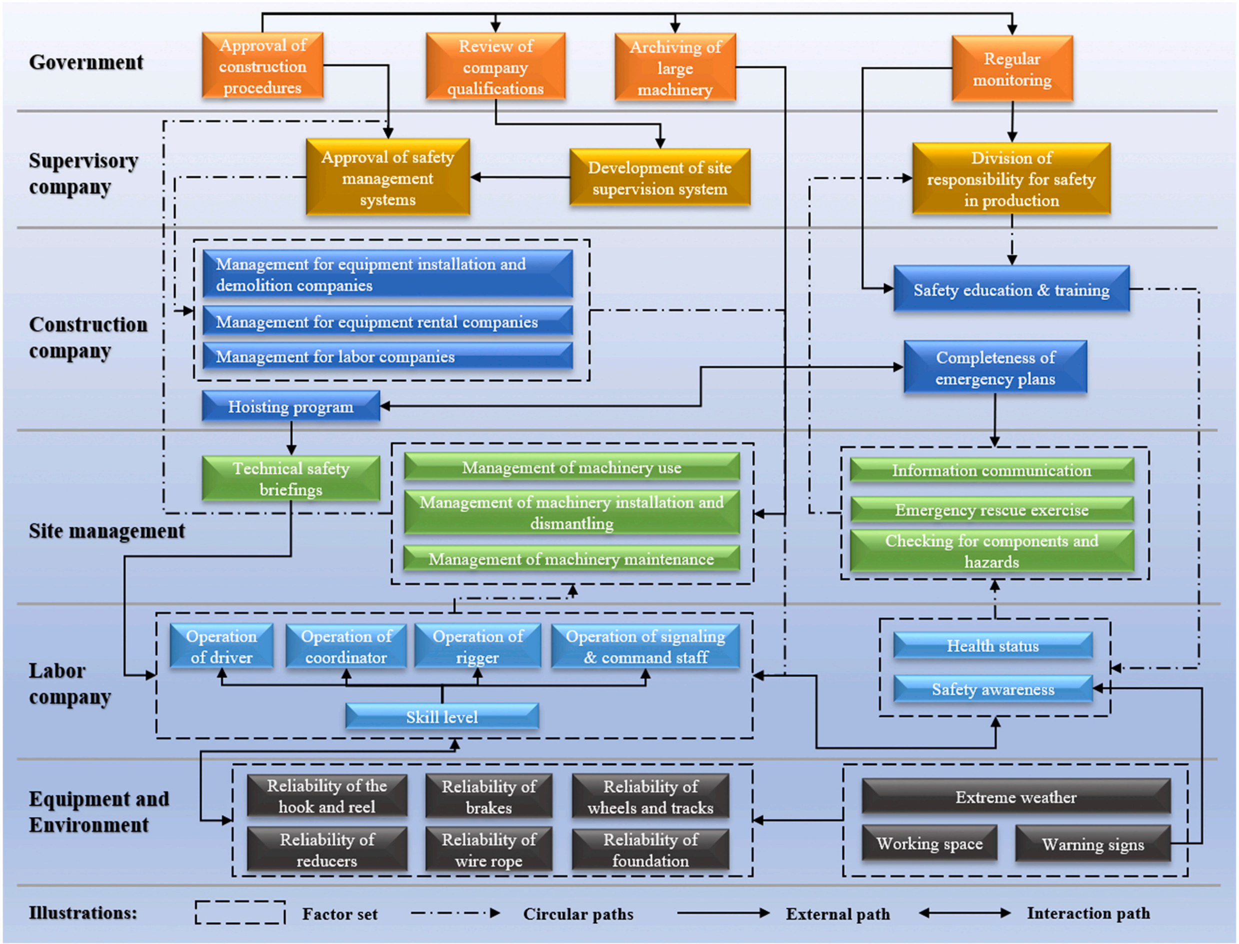


Fig. 10. AcciMap-IH theoretical model.

can lead to severe rusting of the crane and thinning of the central material wall thickness. (7) Extreme weather: Extreme weather conditions can threaten worker safety. For example, lightning may make operating heavy machinery unsafe or working at heights. Workers may also be at risk of exposure to extreme temperatures or weather conditions, which can lead to health problems. In addition, extreme weather conditions can damage hoisting equipment, materials, and supplies. For example, heavy rain or flooding can damage electrical components or cause foundation corrosion. Snow or ice can damage or collapse the scaffolding. Wind forces can cause structures to sway or vibrate, leading to damage or collapse. (8) Working space: Workspaces must provide adequate access and mobility for workers and equipment. It includes providing unobstructed access for workers to move around the site and sufficient space to store materials and equipment. Inadequate access or space can cause construction delays and compromise worker safety. In addition, the workspace must be appropriately prepared for construction work. It may include removing debris or vegetation from the site and levelling the ground. (9) Warning signs: Warning signs help identify potential hazards or risks associated with hoisting construction. For example, signs can warn of overhead hazards or mark areas where heavy equipment operates. Warning signs can also communicate important information to workers and the public. For example, signs can indicate where workers should enter and exit the workplace or communicate changes to work schedules. In addition, warning signs can be used to increase visibility and awareness of potential hazards. For example, signs with reflective materials or bright colors can help make workers and the public more aware of potential hazards, even in low-light conditions.

4.5. Hoisting risk management model

The study uses the AcciMap model to construct a hoisting accident model that identifies causal relationships and information flow between upper and lower levels [42,77]. The model is shown in Fig. 10, and we named it the AcciMap-IH (AcciMap-IBS-Hoisting) risk management model. Based on the information flow orientation, two types of information transmission paths can be identified: external and internal.

The model has two primary closed-loop circular information flows and multiple information collections. Information sets include equipment factor set, environmental factor set, personnel awareness factor set, operational factor set, system management factor set, and equipment management factor set.

We use the PDCA method to monitor the circular flow of information. The circular information path of the hoisting process is as follows: (1) **Plan:** The supervisory company is responsible for ensuring that construction hoisting operations comply with relevant regulations, such as occupational health and safety laws and building codes, designed to protect workers and the public from harm. They can influence the regulations governing how construction companies manage subcontracting companies. (2) **Do:** The construction company manages the project's rental companies, equipment installation and dismantling companies, and labor companies through an approved safety management system and ensures that the work procedures are implemented. (3) **Check:** Assess the safety of hoisting operations, review work protocols, and identify areas for improvement so that any problems or deviations can be analyzed to determine their root cause. (4) **Action:** Based on the analysis during the inspection phase, make necessary adjustments to the work protocol, hoisting plan, or equipment used. Incorporate the lessons into future safety management systems and work protocols and continuously monitor and improve information transfer paths to ensure safe and efficient hoisting operations.

The circular information path of safety policy education is as follows: (1) Plan: Develop a safety training plan for personnel involved in lifting operations, outlining responsibilities and safety education content, timing, and required resources. (2) Do: Implement the safety education program by providing training to personnel involved in the project; monitor the effectiveness of training delivery and content; provide opportunities to obtain feedback from the personnel involved. (3) Check: Evaluate the effectiveness of the safety education program based on feedback from those participating. Review the likelihood of implementing safety policies for relevant personnel through feedback on health status and safety awareness. (4) Action: Make any necessary adjustments to the safety education program based on feedback and analysis, including more communication of safety information, identification of safety hazards, and training in safety rescue drills to promote the effectiveness of safety education.

5. Discussion

5.1. Risk response strategies

Optimizing the government's monitoring system is essential for the current top-level design. The government can establish more transparent regulations and standards, such as equipment specifications, safety procedures, and training requirements [107]. According to the research, active government regulation can significantly control the risk of quality practices in companies [108]. Big data can be used for more accurate risk analysis of the industry. Furthermore, blockchain technology can enable information sharing, tamper-proofing, and privacy protection in guidance [12,109]. Government agencies must balance low supervision costs and construction safety [110].

The supervising company can improve monitoring efficiency by developing a detailed plan that helps management effectively achieve project objectives. To aid in safety instruction and decision-making, they can utilize Building Information Modelling (BIM) and Virtual Reality (VR) technologies to create virtual, visualized building environments or sites [111,112].

Appropriate risk transfer is an option for construction companies. The construction company's response option is to transfer the risk through insurance or other financial instruments. However, insurance is not a substitute for effective risk management practices [113]. Organizations can also explore cutting-edge technologies to enhance their management practices. For instance, Artificial Intelligence (AI) can be leveraged to examine data from multiple sources, such as load charts, maintenance logs, and weather predictions, to identify potential hazards and propose appropriate mitigation strategies [114]. 3D modeling and visualization tools can be used to design and plan lift operations, enabling contractors to visualize and optimize hoisting paths and minimize the risk of collisions or other hazards [115].

Numerous cases have shown that safety education and training on many sites could be more effective, and they are either coping or not educating at all. It is, therefore, essential to ensure that workers are effectively trained and supervised and that training exercises and skills assessments are conducted [116]. For example, operators need to be made aware of the performance of the tower crane's torque limiter. They were unsure if it was working, resulting in accidents caused by collaborating with it in a failed condition. Site management should ensure adequate safety and balance of the loads being lifted and develop adaptive control of the crane through real-time stability analysis [117]. IoT-enabled sensors and cameras can be used for site management to gather real-time data on operational conditions, including hoisting weight, height, amplitude, inclination, and wind speed. This technology can provide early warnings for potential hazards such as equipment failure or unsafe working practices, helping to prevent accidents and ensure safe working conditions [118].

There is an urgent need to improve the quality of the workforce. Workers overload their lifts due to a poor estimate of the item's weight or safety awareness. Turning too fast is also dangerous, as turning generates centrifugal forces. The quicker the speed, the greater the centrifugal forces and the more inclined the direction. Tilting is also a violation as it increases the tipping moment and the tension on the wire rope. In addition, there are many other improper operations, such as the wrong selection of lifting tools or points, the unreasonable selection of pulleys and ropes, and poor rope winding of rollers. When selecting lifting points, consider the load's weight, shape, and size to ensure the weight can be evenly distributed. When selecting pulleys and ropes, ensure that the pulleys are sufficiently strong and correctly aligned to minimize friction and resistance during the lifting process. Sheaves and ropes should also be regularly inspected and maintained to identify signs of wear, damage, or deterioration. To prevent poor reel rope winding performance, ensure the rope is wound correctly around the reel with no overlaps or crosses. Secondly, properly tension and thread the rope to avoid slackening or over-tensioning during hoisting. Use equipment with automatic winding systems or mechanisms to maintain consistent pressure and prevent rope slippage. Labor companies must also provide more professional personal equipment (PPE) based on innovative wearable technology, such as gloves, helmets, and straps [119]. Workers with proven operational skills can significantly reduce safety risks [120,121].

More trustworthy equipment and environments are also worth attention [46,122–124]. According to our investigation, lift equipment often operates under corrosive gas dust containing acid and alkali, long-term operation of the collision, and anti-rust paint aging and shedding, so the surface loses protection, resulting in local corrosion and oxidation, thereby reducing the strength of the structure [125–127]. Subjecting the welds of essential rods and parts to techniques such as X-ray flaw detection, ultrasonic flaw detection, or magnetic particle flaw detection is imperative. Doing so ensures the integrity and safety of the structure. Repairing the steel structure's refinishing paint and welding the webs after they have fallen off should be incorporated into the daily work [19,128, 129]. In addition, reliable safety devices, especially torque limiters, should be ensured [130,131]. In terms of the environment, in addition to high winds causing the hook to sway, heavy rainfall can quickly short-circuit the power supply [132,133]. Hollow sites such as backfill, gravel land, mud, terrain edges, and drainage canals cause uneven sinking of the legs due to the different degrees of softness of the ground. Therefore, assessing the ground conditions before setting up the crane is recommended, and consider using ground stabilization techniques if necessary. Next, use suitable crane mats (like timber/steel) to provide the outriggers with a firm and level surface [134]. Finally, follow the manufacturer's guidelines and recommendations regarding the crane's ground conditions and stability requirements. They can use GNSS-based positioning spotting systems and embedded smart sensors to accurately measure the load's weight and location on hoisting equipment [135,136]. Integrating environmental risks into a cyber-physical system can facilitate the development of a synchronized mapping of risk data between virtual and physical construction sites. This can be achieved by leveraging scenario reconstruction design, data sensing, communication, and data processing. Such an approach can enhance the overall efficacy of risk management in construction projects and lead to better outcomes [137].

5.2. Significance of the AcciMap model

Hoisting risk can significantly impact workers and projects [138]. In addition to fatalities, the personal injuries it brings include fractures, sprains, and strains, leading to long-term incapacity and reduced productivity; the resulting project delays and cost overruns cannot be underestimated [78,139,140]. A practical risk management framework is the basis for risk control [52]. Some scholars believe it needs to include prefabricated components, hoisting machinery, operating environment, operating personnel, and the cost of safety measures based on production elements [77]. The Human Factors Analysis and Classification System (HFACS) has been widely acknowledged in the academic community for its potential to identify the underlying causes of accidents effectively. Numerous scholars have highlighted the significance of HFACS in accident investigation and analysis due to its ability to provide a structured approach to identifying human error and other factors that contribute to accidents [7,59,141]. Other scholars used Systematic Theoretical Process Analysis (STAP) to construct feedback structures to identify hoisting risk factors [79,142]. The strength of AcciMap technology lies in its ability to offer a comprehensive perspective of the multidimensional aspects of accidents associated with lifting operations. This feature enables a better comprehension of the intricate interplay between various factors that culminate in such accidents. Secondly, it uses visual representations, such as flow charts, diagrams, or graphs, to depict the risk path of a lifting accident. This graphic format helps quickly understand and communicate accident sequences, making it available for training, safety audits, regulatory compliance, and prioritizing resources and interventions. It has been applied to road safety investigations, assembly error analysis in the aerospace industry, and comprehensive failure analysis of fire accidents [143–145]. However, creating accurate maps requires an in-depth understanding of lifting operations, safety procedures, and accident causation theory. The application of the

AcciMap model is rare in hoisting safety areas due to its complexity.

Therefore, the AcciMap-IH theoretical model proposed in this paper plays a pivotal role in enhancing the safety of hoisting operations. Identifying the risk path of an accident allows stakeholders to focus their efforts on mitigating specific hazards and implementing targeted safety measures. A systematic and structured model helps researchers and safety professionals understand the events leading to an accident, thus more accurately identifying risk factors and potential mitigation strategies. Finally, mapping the risk path of lifting accidents helps to identify weaknesses in systems, equipment, or human factors and enables organizations to implement appropriate controls and safety protocols.

6. Conclusion

The Chinese construction industry has been significantly impacted by accidents caused by hoisting, according to the case study presented in this paper. Remarkably, the southeastern coastal region, which is more economically developed, has been affected the most. Truck-mounted and tower cranes were the most common forms of heavy gear in accident samples. The top three accident types are being struck by hoisting loads, machinery collapsing, and workers falling from heights. Through a literature review, we found that a shortage of scholarly articles exists in this field, with the cumulative number falling short of 50. A prerequisite for problem-solving is problem identification. This research article significantly contributes to fostering the wholesome and sustainable growth of the construction industry by identifying and analyzing its associated risk factors. Thus, the risk factor system we built is crucial for controlling risk and it is comprehensive and objective, which are derived from real cases and validated by the literature. Finally, we propose measures to optimize the government regulatory system, improve construction techniques, speed up information transfer, and improve the quality of employees, which can provide theoretical guidance for managers.

There are also limitations to this article that need to be clarified. First, the cases were predominantly confined to the southeastern region of China. Second, there is still room for expanding the sample size through official channels. Future research can deepen the qualitative model proposed in this paper to construct a more accurate quantitative model, and then combine machine learning algorithms, big data, sensors, and other technologies to assess the risk.

Data availability statement

Data referenced in article.

CRediT authorship contribution statement

Yin Junjia: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Aidi Hizami Alias:** Validation, Supervision, Project administration. **Nuzul Azam Haron:** Validation, Supervision. **Nabilah Abu Bakar:** Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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