Equipment Interventions to Improve Construction Industry Safety and Health: A Review of Case Studies

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Abstract. A review was conducted of 153 case studies of construction equipment interventions, representing $6.55 million (2016 USD) of equipment purchases incentivized through the U.S. state of Ohio Bureau of Workers' Compensation (OBWC) Safety Intervention Grant (SIG) program. The source data were drawn from the applications and final reports of employers who received grants between 2003 and 2016. Outcomes were reductions in safety hazards, cumulative trauma disorder risk factors, and a score assessing quality of the intervention evaluative experience as determined through a framework developed by the authors. Items relating to the quality of the evaluative experience were manually extracted from the case study documentation. When aggregated by type of construction equipment, the risk factor reduction and evaluative quality scores were variable within and between equipment types. Equipment for cable pulling, used in the electrical trades, and skid steer attachments for concrete breaking (hydraulic breakers) both emerged as interventions ranked highly for reducing risk factors and for the evaluative quality of their case studies. Other intervention equipment types that ranked highly in both risk factor reduction and evaluative quality were concrete sawing equipment, trailers with hydraulic tilting/ramps, powered hand tools, and man lifts (boom lifts).

Keywords: Construction · Interventions · Case studies

1 Introduction

Construction work can be hazardous, and it subjects workers to a multitude of exposures and injury/illness risk factors and hazards. This is reflected in injury and illness statistics for the sector. In 2010, the rate of days-away-from-work cases in the U.S. Construction sector was 149.6 per 10,000 FTEs, which was 39% higher than the average rate of 107.7 for all private U.S. industries [1]. Though fatal injuries in the U.S. construction industry had decreased in 2010, Construction still accounted for 17.1% of the total fatal work injuries, while the sector comprised approximately 4.6% of the U.S. workforce. In that same year, workers' compensation (WC) insurance covered 124

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million U.S. workers at a total cost of $71 billion to employers, with benefits of $28.1 billion in medical payments and $29.5 billion in benefits to workers [2].

Occupational safety and health (OSH) and risk control programs have recognized the need to address sources of workplace hazards to improve safety and health outcomes [3]. Overexertion due to lifting, being struck by an object, and falls to lower level are the leading causes of nonfatal workplace injury costs [4]. Accordingly, OSH agencies and insurers have interest in assessing the effectiveness of prevention approaches to address the leading causes of workplace injury/illness and to promote the adoption of interventions that are effective in reducing injury/illness burden. The U.S. State of Ohio Bureau of Workers' Compensation (OBWC) Safety Intervention Grant (SIG) program is a grant program in which employers who apply for and are awarded a grant receive matching funds at a multiple of 3:1 (this varied from 2:1 to 4:1 over the program years) for the purchase of equipment to address workplace health/safety [5]. SIG program participant employers must submit a one-year final report describing their experience with the intervention equipment. Thus, the program is one of few that are administratively structured to incentivize employer acquisition of equipment interventions to address safety and health hazards and that systematically collect information about experiences with the equipment. The OBWC SIG program provides an opportunity to assess aggregated employer experiences through individual documented case studies.

In a previous report Wurzelbacher et al. [3] analyzed the accepted claims experience among 468 Ohio employers receiving OBWC SIG program grants from 2003–2009. SIG program participation was demonstrated to reduce workers' compensation (WC) claim rates and costs in most industries. Construction was one industry that was not associated with reduced claims rate in response to SIG participation. However, that analysis [3] examined only the injury claims experience and was a programmatic level assessment that was less able to discern effectiveness of specific types of intervention equipment.

The purpose of the present analysis was to develop and apply a systematic framework by which the SIG experiences could be reviewed and evaluated to assess equipment intervention effectiveness in the Construction industry. The assessment considers additional information beyond the WC claims experience that grantees submitted to OBWC in the reporting of their experience with the equipment. The investigators have interest in the assessment and communication of Construction solutions to industry stakeholders who would benefit by the translation of intervention research findings.

2 Methods

2.1 Source Documentation

Employer-submitted grant applications and final reporting documentation (case studies) for Safety Intervention Grants (SIGs) awarded between 2003–2016 were compiled by the Ohio BWC in March 2017. Final reports are submitted at least one year after the intervention award, so there were few 2016 awards with a final report at that point in time. Case study documentation was organized and keyed by an anonymous application ID number, which served as the linkage between the original application, final reporting documentation, and background information about the grant award: employer category size, amount of grant funding match, and National Council on Compensation Insurance (NCCI) classification code number. The NCCI code is a four-digit classification system, with variation by U.S. state, describing the nature of the business operations for the purpose of assigning collective actuarial risk and for rate administration [6]. The NCCI classification code number of the affected work group, as defined by the employer on the application, was used to crosswalk to an established Construction industry trade/specialty.

At the time that the source documentation was compiled, there had been 368 SIG awards for the purchase of intervention equipment by employers with NCCI classification codes corresponding to Construction sub-industries. However, 134 of those were awarded in 2015 and 2016 alone, and many of these did not yet have final reports submitted by employers at the time of this analysis. (A small percentage of employers fail to submit final reports.) In the present review, there were 224 Construction SIG awards for which reporting materials had been submitted by the grant recipient employer. Of these, 52 grant awards were excluded due to: (1) shop-based equipment/machinery not used on a Construction job site; (2) equipment for lifting construction vehicles and heavy equipment for the purpose of maintenance; (3) equipment for the purpose of hot water heater, furnace, and other home appliance delivery; (4) equipment for landscaping work; and (5) sewer jetting system equipment. Further, 19 of the 224 SIGs were excluded because of significantly incomplete reporting documentation. In total, there were 153 SIG experiences included in the final review.

2.2 Data Extraction

A data extraction form was developed and subjected to peer review by three subject matter experts with background in OSH intervention evaluation, specifically in Construction. The form was based on assessing the quality of evaluative aspects of employers' experience with the intervention equipment in terms of exposure/risk factor reduction, employee acceptance (e.g. usability), and employer return on investment (e.g. productivity, cost/benefit). This information included how the employer's experience demonstrated reductions in risk factors, potential risk transference, employee and management acceptance/adoption of the intervention, and impact of the intervention on productivity/quality. Extracted items were operationalized with the intent to minimize subjective interpretation on the part of the single analyst who read the case studies and performed the data extraction.

A risk factor reduction score for SIG experiences that reported complete baseline and follow-up assessments was based on semi-quantitative instruments for systematically assessing cumulative trauma disorder (CTD) risk factors and safety hazards. Direct subtraction of the follow-up score from the baseline score using these instruments yielded the net change (positive reduction in risk factors). Information on these instruments is available from OBWC.

Equipment purchase costs were extracted from the grant budget and financial documentation in the application, and equipment purchase costs are inflation adjusted to 2016 U.S. dollars (USD) using the Producer Price Index for *Other Heavy Machinery Rental and Leasing: Construction Equipment Rental and Leasing* (Federal Reserve Bank of St. Louis). Intervention equipment cost per affected employee was calculated for single-equipment case studies based on the number of affected employees - those who perform the work for which the new equipment will be used. The affected employee count was a determination made by the employer in the grant application.

2.3 Data Analysis

Primary outcomes were reduction in CTD and safety risk factors and the evaluative evidence quality score, with the individual SIG experiences (case studies) as the unit of analysis. SIG experiences were grouped according to single-equipment SIGs (n = 105) and multi-equipment SIGs (n = 48). Single-equipment SIGs were classified as those in which grant funds were used to purchase a single piece of equipment or an integrated system consisting of a primary piece of equipment and related attachments. Multi-equipment SIGs were those in which multiple pieces of equipment were purchased that were not used as an integrated system in a single construction task. In rare instances did the case studies differentiate risk factor reduction based on individual equipment use. In the single-equipment SIGs, a more straightforward association can be interpreted between the single piece of equipment as an intervention and changes in risk factors.

Change scores for CTD risk reduction and Safety risk reduction between the pre- and post-intervention assessments were z-transformed, and converted percentiles are reported to allow comparisons between the two different scales (CTD risk assessment instrument, Safety assessment instrument). To report on equipment type in aggregate, the mean percentile for the equipment classification was calculated.

Based on the data extraction items, we report Evaluative Evidence Quality Scores for the SIG experiences - intended as a basis for ranking case studies according to attributes believed to be important to establishing evidence of intervention effectiveness (see Table 1). These scores were not considered appropriate for parametric statistics and the median rank was calculated to report on equipment type classifications in aggregate.

3 Results

Equipment purchases were classified according to 13 broad types of construction equipment based on function and mode of operation. Further refined classification of the broader skid steer attachments and walk/ride-behind powered equipment resulted in 25 sub-classifications of equipment (see Table 2). Single-equipment SIGs were then aggregated according to this equipment classification. Multi-equipment case studies were not aggregated according to equipment classification to report quality score or CTD/Safety risk factor reduction. In some multi-equipment intervention grants, there were up to 18 distinct types of equipment purchased spanning multiple classifications. Thus, the row counts by equipment type for multi-equipment SIGs in Table 2 do not

Table 1. Determination of SIG Evaluative Evidence Quality Score. A total of 100 points was possible.

Injury Claims Experience (20%)

- (10%) Was there one, or more, claims indicated for the baseline period?
  No = 0; Yes = 10
- (10%) Was there one, or more, baseline claims that would be *plausibly prevented had the intervention equipment been in place?*
  No = 0; Yes = 10

Risk Factor Abatement Experience (40%)

- Are *CTD, Safety, or IH Risk Factor*s compared in a consistent manner (baseline and follow-up comparable) addressing exposure(s) affected by the intervention?
  none = 0; qualitative description in narrative = 15; BWC instruments (or other quantitative instruments) = 40

Acceptance/Adoption Experience (15%)

- Does the report contain any description of employees' acceptance/non-acceptance of the intervention?
  No = 0; Yes = 15

Work Productivity Experience (15%)

- (10%) Are effects on productivity described?
  none = 0; qualitatively = 5; quantitatively = 10
- (5%) Is a return on investment calculation reported (generally on the CBA form, or in report narrative)?
  No = 0; Yes = 5

Work Quality Experience (5%)

- Are effects on work quality described?
  none = 0; qualitatively = 3; quantitatively = 5

Training (5%)

- Was there evidence of training conducted?
  no description of actual training conducted and no training costs incurred = 0 ; actual training described in narrative = 3; CBA lists training costs incurred = 5

sum to the total of 48. Multi-equipment SIGs were evaluated differently because of their inherent co-intervention effect, where the effect of individual pieces of equipment cannot be determined. Multi-equipment grants were often a combination of equipment types related to different tasks for a given trade. For example, walk-behind roof cutting systems were frequently purchased in combination with a walk-behind hauling system.

Figure 1 shows raw change scores (pre-intervention minus post-intervention) in Safety and CTD risk assessments by equipment type for single-equipment case studies. Higher change scores reflect greater reduction in risk factors. Table 2 ranks equipment classifications (aggregated across single-equipment SIGs) based on the median evidence quality scores. Columns also list reduction in CTD and safety risk factors by percentile. Table 2 also lists single-equipment SIG costs per affected employee. These summary measures indicate that cable-pulling equipment used in the electrical trades were effective in reducing CTD risk factors and were also associated with grant experiences scoring higher in evaluative quality. This equipment was also associated

Table 2. Summary of Safety Intervention Grant case studies (Construction industry) aggregated by equipment classification.

	Single-equipment							Multi-equipment	
Equipment classification	Sum equip cost (2016 US Dollars)	# Single equip SIGs	Mean equip cost per employee† (2016 USD)	Median evidence quality score (Rank)		Mean percentile CTD risk reduction	Mean percentile safety risk reduction	Sum equip cost (2016 USD)	# Multi equip SIGs associated
Skid steer attachment - other	100,067	1	5,559	85	**(1)**	28.3	–	47,851	3
Skid steer attachment - augering	90,408	2	3,749	83	**(2.5)**	34.2	–	31,132	1
Cable pulling systems	174,780	5	800	83	**(2.5)**	71.0	–	55,698	3
Concrete sawing (not hand tools)	258,521	5	3,068	78	**(4)**	54.8	34.1	24,686	3
Skid steer attachment - rotary grinding	12,647	1	1,405	75	**(5)**	40.4	–	0	0
Powered hand tools	136,170	4	1,138	70.5	**(6)**	27.1	83.1	760,179	26
Vacuum and or hydro excavation	135,403	2	5,043	65.5	**(7)**	46.9	75.3	0	0
Skid steer attachment - concrete breaking	82,057	4	998	65	**(8.5)**	62.3	83.1	22,548	2
Trailers (hydraulic tilting/ramps)	67,457	2	5,092	65	**(8.5)**	84.0	–	65,544	4
Manlift (boom lift)	995,977	14	5,766	63	**(10)**	59.5	60.9	32,460	1
Conduit bending	29,860	1	459	60	**(11)**	14.2	–	70,685	5
Lift gates	38,763	4	222	59	**(12)**	24.1	–	3,151	1
Bulk material transfer/dispensing (tar & adhesive applications)	139,337	4	2,651	58	**(13.5)**	31.3	21.9	23,415	2
Other	511,337	13	2,468	58	**(13.5)**	45.1	11.4	218,362	20
Scissor lift/mast lift	700,945	16	2,648	57	**(15)**	58.7	26.4	169,971	4
Trailer restraints	8,225	1	191	55	**(16)**	–	–	0	0
Scaffolding/platform	632,305	12	2,945	49	**(17.5)**	37.5	58.9	69,005	4
Fall protection systems (carts, etc.)	58,308	4	489	49	**(17.5)**	–	64.0	104,280	7
Walk/ride behind (powered) - trenching	6,736	1	192	48	**(19.5)**	89.3	32.8	0	0
Walk/ride behind (powered) - screeding	186,316	3	3,047	48	**(19.5)**	79.7	–	0	0
Cranes/hoists (other than manlifts)	162,802	3	6,103	45	**(21)**	18.3	–	51,620	4
Skid steer attachment - asphalt cold planer, tiller, brooms, etc.	32,225	2	1,710	44	**(22)**	63.1	–	0	0
Walk/ride behind (powered) - cutting/removal of roof material	7,657	1	219	30	**(23)**	–	–	136,355	10
Walk/ride behind (powered) - hauling	–	0	0	–		–	–	76,853	7
Walk/ride behind (powered)- other	–	0	0	–		–	–	17,161	3
	4,568,303	105						1,980,957	48*

*The column total shown does not reflect the sum of rows because these SIGs had multiple equipment classifications associated.

†Mean equipment cost/employee is the total equipment cost for the grant divided by the affected employee count. This is averaged for the equipment classification category.

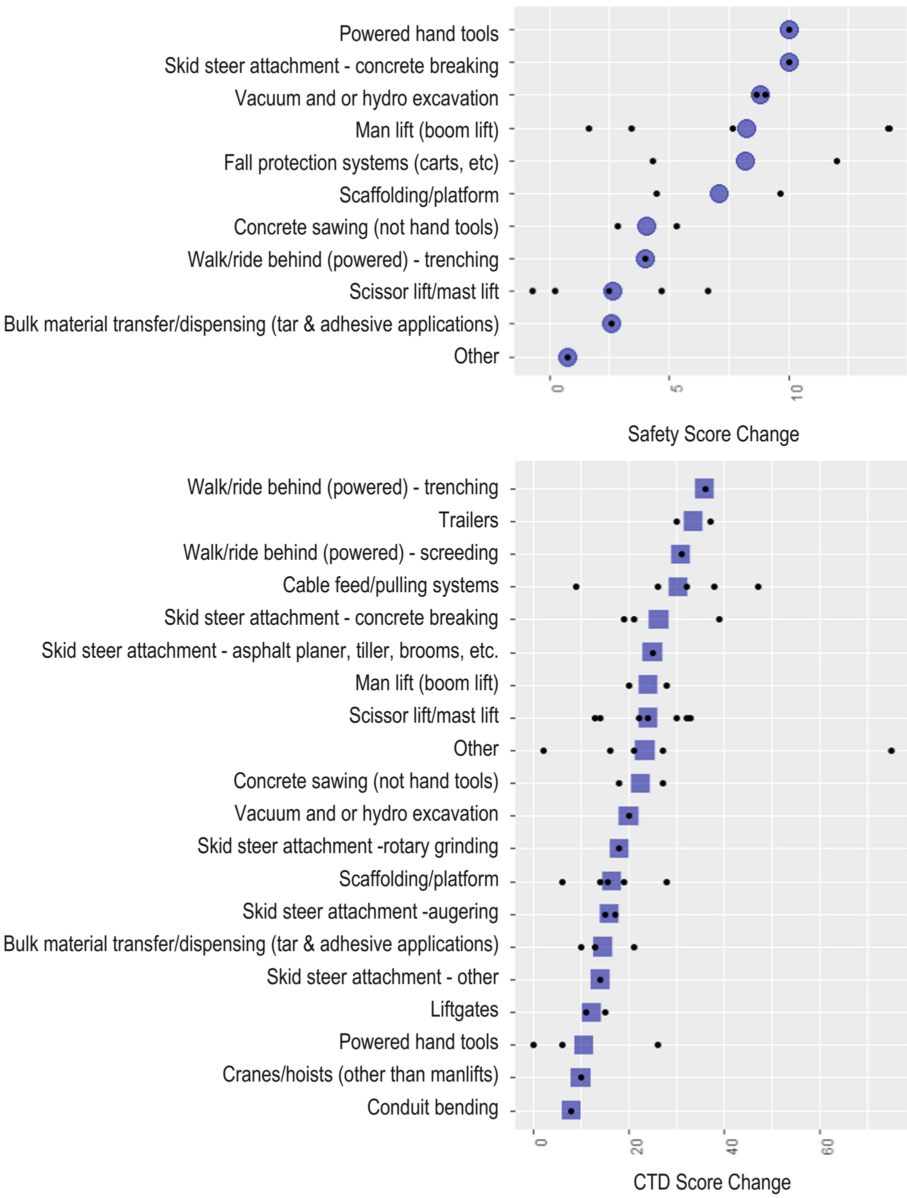

Fig. 1. Changes in safety hazard scores and CTD risk assessment scores (pre-intervention score minus post-intervention) by equipment type. Larger blue points are the group mean by equipment type (smaller black points are individual case studies).

with a low cost per affected employee. Skid steer attachments for concrete breaking (hydraulic breaker) also ranked relatively highly in reducing risk factors (CTD and safety risk factor reduction) and scored highly for evaluative quality. Concrete sawing equipment, trailers with hydraulic tilting/ramps, powered hand tools, and man lifts (boom lifts) were associated with evidence quality scores above the median for all equipment classifications AND above-average scores for either CTD or safety risk factors.

Detailed budget information showed that $6.55 million (in 2016 dollars) in Construction equipment purchases were made from the employer contribution and SIG funds across the 153 grants reviewed (see Table 2). Seventy percent of that total ($4.57 million USD) were single-equipment purchases, and the remaining 30% ($1.98 million) were associated with multi-equipment grants. Forty-three percent of the $6.55 million USD was spent on equipment for work at heights (i.e., scissor lifts, mast lifts, man lifts, boom lifts, scaffolding, non-man lift hoists). This equipment represented 45 of the 105 single-equipment grants, and another 13 multi-equipment grants (of 48) included one of these types of equipment. Equipment for working at heights or transferring of materials to heights tended to be more expensive (in terms of cost per affected employee) in addition to comprising the most commonly purchased construction equipment in the SIG program.

4 Discussion

There are several limitations that affect interpretation of this analysis. The SIG program award eligibility criteria and reporting requirements experienced some changes and were not consistent over 2003–2016. Prior to July 2009, a grant could only be awarded to an employer who had experienced at least one compensable injury claim in the defined affected employee group. As the program was expanded to have a more preventive focus, OBWC revised eligibility requirements so that grants could be awarded to proactively address risk factors, even in the absence of injury claims. In early program years, the application required employers to document all injury claims occurring in the affected employee group, regardless of injury causation. Correspondingly, we observed some baseline injury claim descriptions for which the subsequent equipment intervention was not believed to have any plausible mechanism of prevention. This influenced the decision to place greater emphasis (criteria weighting) on the risk factor reduction experience and less on the injury claim experience.

Employer grant recipients were tasked with determining whether the newly acquired equipment could have potentially introduced new hazards (or exacerbated an existing hazard) in the job/task. Even though employers were asked to anticipate potential new risks in the grant application, newly introduced risks were infrequently described in final reporting, and employer grantees may not have had the necessary health/safety knowledge regarding potential risks to make this determination. It is conceivable that new risks *may* have been introduced for some equipment; for example, new battery-powered hand tools and larger motorized equipment that might be more difficult to lift, carry, or maneuver.

Intervention cost per affected employee was highly, and inversely, related to employer size. Equipment purchased by larger employers was associated with lower cost per affected employee because larger employers had higher numbers of employees in the affected employee group. Equipment interventions that fundamentally alter a construction process, such as the adoption of a walk-behind machine for trenching with a single operator versus multiple employees performing hand digging, may reduce risk factors for employees beyond just the operator of the equipment. However, with other equipment, such as powered hand tools, the beneficial effect may only be realized by the user(s) of the piece of equipment. Defining an affected employee group size may not be straightforward, and there may have been incentive to overestimate the affected employee group size in the application phase. Relatedly, employers documented affected employee *hours* simply as the affected employee group's collective work hours and did not account for actual employee time exposed to the specific tasks and the hazards that were actually mitigated by the intervention.

Cost-benefit analysis (CBA) considerations, as documented by employers, were often incomplete. For example, past leasing costs of equipment were not included in the cost of doing identical work before the new equipment was procured. Equipment depreciation was not factored into the contractors' analyses. A number of reports clearly described a productivity increase in the narrative while not assigning any monetary value to this in the quantitative CBA worksheet. There were case studies in which discrepancies existed between productivity gains described in the narrative and monetary valuation of productivity gains in the CBA worksheet.

5 Conclusion

This review of case studies allowed us to aggregate experiences of multiple employers evaluating similar or identical Construction equipment. Case studies in aggregate provide more compelling evidence than an individual case study in regard to the effectiveness of specific equipment interventions. However, this review illustrates that there are still challenges in demonstrating efficacy of equipment interventions – even from aggregated case study experiences within a program specifically established to improve health/safety outcomes. From the evaluative data extracted in this review of employer case studies, we conclude that electrical cable pulling equipment, skid steer attachments for concrete breaking (hydraulic breakers), concrete sawing equipment, trailers with hydraulic tilting/ramps, powered hand tools, and man lifts (boom lifts) were associated with higher reductions in risk factors and case studies with stronger evaluative quality. In a forthcoming publication, we plan to explore how case study reporting can be improved to strengthen evidence demonstrating equipment intervention effectiveness. A similar methodology is being adopted for case study reviews with other types of workplace equipment.

Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, or the Ohio Bureau of Workers' Compensation.

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Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)

Volume II: Safety and Health, Slips, Trips and Falls

Springer

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Preface

The Triennial Congress of the International Ergonomics Association is where and when a large community of scientists and practitioners interested in the fields of ergonomics/human factors meet to exchange research results and good practices, discuss them, raise questions about the state and the future of the community, and about the context where the community lives: the planet. The ergonomics/human factors community is concerned not only about its own conditions and perspectives, but also with those of people at large and the place we all live, as Neville Moray (Tatcher et al. 2018) taught us in a memorable address at the IEA Congress in Toronto more than twenty years, in 1994.

The Proceedings of an IEA Congress describes, then, the actual state of the art of the field of ergonomics/human factors and its context every three years.

In Florence, where the XX IEA Congress is taking place, there have been more than sixteen hundred (1643) abstract proposals from eighty countries from all the five continents. The accepted proposal has been about one thousand (1010), roughly, half from Europe and half from the other continents, being Asia the most numerous, followed by South America, North America, Oceania, and Africa. This Proceedings is indeed a very detailed and complete state of the art of human factors/ergonomics research and practice in about every place in the world.

All the accepted contributions are collected in the Congress Proceedings, distributed in ten volumes along with the themes in which ergonomics/human factors field is traditionally articulated and IEA Technical Committees are named:

I. Healthcare Ergonomics (ISBN 978-3-319-96097-5).
II. Safety and Health and Slips, Trips and Falls (ISBN 978-3-319-96088-3).
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Altogether, the contributions make apparent the diversities in culture and in the socioeconomic conditions the authors belong to. The notion of well-being, which the reference value for ergonomics/human factors is not monolithic, instead varies along with the cultural and societal differences each contributor share. Diversity is a necessary condition for a fruitful discussion and exchange of experiences, not to say for creativity, which is the "theme" of the congress.

In an era of profound transformation, called either digital (Zisman & Kenney, 2018) or the second machine age (Bnynjolfsson & McAfee, 2014), when the very notions of work, fatigue, and well-being are changing in depth, ergonomics/human factors need to be creative in order to meet the new, ever-encountered challenges. Not every contribution in the ten volumes of the Proceedings explicitly faces the problem: the need for creativity to be able to confront the new challenges. However, even the more traditional, classical papers are influenced by the new conditions.

The reader of whichever volume enters an atmosphere where there are not many well-established certainties, but instead an abundance of doubts and open questions: again, the conditions for creativity and innovative solutions.

We hope that, notwithstanding the titles of the volumes that mimic the IEA Technical Committees, some of them created about half a century ago, the XX Triennial IEA Congress Proceedings may bring readers into an atmosphere where doubts are more common than certainties, challenge to answer ever-heard questions is continuously present, and creative solutions can be often encountered.

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