SAFETY IN LEAN OPERATIONS: THE EFFECT OF TOTAL PRODUCTIVE MAINTENANCE AND WORKERS' AUTONOMY

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Total Productive Maintenance (TPM)[1] is a constitutive dimension of Lean Production Systems (Shah and Ward, 2007) and a driver of competitive advantage in World Class Manufacturing. By connecting maintenance and production and creating cross-functional synergies (McKone et al., 2001), it contributes to continuous improvement in operational efficiency, product quality, productivity, safety, employees' morale and customers satisfaction (Brah and Chong, 2004).

Operations management scholars widely agree on the co-existence of a technical and a social aspect in the nature of TPM programs. While the technical aspect mainly relates to charts, records and operations practices, the social aspect refers to Human Resources Management practices, employees' involvement, participation, motivation and autonomy.

TPM activities and routines rely on empowered workers, who can speak up and directly participate to the development, design and control of their own work standards (McKone et al., 2001). The implementation of TPM endows workers with ownership over processes and machines. However, while the influence of workers' autonomy and empowerment over the TPM-Performance linkage has been widely acknowledged, it has been scantly explored empirically. This is particularly true in the area of safety management, with occupational safety relatively underrepresented in performance studies on the interactions of TPM with managerial factors, such as employees' involvement, *vis-à-vis* other performance dimensions such as quality, cost and delivery (McKone et al. 2001).

Consequently, the mechanisms through which the technical and the social components of TPM implementation programs affect Occupational Health and Safety on the workplace do represent an under-investigated area of research. This seems at odds with the growing interest on socially sustainable operations and workplace sustainability - within which occupational health and safety play a key role, as well as with the recent calls for more rigorous and theory-based research on the topic, able to complement the extant rich body of specialist and practice oriented research (Pagell et al., 2013).

This paper intends to contribute filling this gap by addressing the following research questions: What is the impact of TPM on occupational safety? How do TPM and employees' autonomy interact in affecting Safety outcomes?

We integrate Lean Operations, TPM, Work Psychology and Safety literatures to explore occupational safety in workplaces where TPM programs are implemented. We

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[1] "TPM is designed to maximize equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance through motivation management or voluntary small-group activities." (Tsuchiya, 1992, p. 4; McKone et al., 2001, p.40)

investigate the direct and interaction effects of TPM and workers' empowerment, autonomy and participation on occupational safety in Lean Operations Systems. We conduct a single-firm, multi-plant and multi-production department study. We conduct extensive field research to collect and analyze, at the production department unit level, primary data from one of the world's largest tyre producers in 9 plants located in 7 countries. We find support for positive direct and interaction effects of TPM and workers' empowerment, autonomy and participation on occupational safety.

THEORY AND HYPOTHESES

TPM and Safety

TPM practices prevent interruptions on the production line through the elimination of equipment downtime and breakdowns and increase workers' involvement and autonomy over maintenance activities, with positive outcomes on equipment availability, effectiveness, quality, reliability and safety.

Safety and Health constitute one of the eight pillars of the successful implementation of TPM programs. The improvement of workplace environmental conditions, the reduction of accidents and the prevention of hazardous events are crucial performance objectives embedded in the foundations of TPM activities. First, a technology-driven mechanism is in place. Second, TPM implementation affects occupational safety developing skills and human capital. Third, cognitive and motivational mechanisms can also be associated to TPM thus leading to improved workers' safety.

Hypothesis 1 follows.

Hypothesis 1: TPM has a positive and direct relationship to occupational safety.

Work standardization, Employees' Participation and Safety

Workers' empowerment, participation and voice mechanisms contribute to the diffusion of a safety culture (Veltri et al., 2013) and are associated to positive safety outcomes in lean production systems (Parker, 2003).

Hypothesis 2 follows:

Hypothesis 2: Workers' Autonomy and Participation in developing their own work standards have a positive and direct relationship to occupational safety.

Moderation Effect

Implementing TPM in a context of high workers' autonomy promotes information sharing and collaborative problem solving with a subsequent reduction in waste and a better employment of resources. Consequently, via improved fairness and procedural equity perceptions, they are more powerful in affecting safety performance as they tend to be more frequently and effectively translated into actual behaviors.

Thus, we hypothesize that workers' empowerment, autonomy and participation over work standards amplify the effect of TPM on safety:

Hypothesis 3: Workers' Autonomy and Participation positively moderate the relationship of TPM to occupational safety.

Figure 1 summarizes the research constructs and the theoretical model comprising the research Hypotheses.

Insert Figure 1 about here

METHODOLOGY

Research Setting

We conducted a single firm study, in one of the world's leading tyre manufacturer, operating in the consumer and industrial market segments worldwide. This setting is ideal to the scope of our investigation. Indeed, the company started its Lean Journey in the early 1990s, giving particular attention to TPM implementation (tyre manufacturing is a capital-intensive production process) and to workers autonomy and empowerment, in order to pursue better performance and a more effective organizational learning.

Data and Sample

Nine plants were selected for the study. After a first random draw of 10 out of the total 19, the authors discussed with the top Operations Management team of the company and the sample was adjusted as follows: nine plants in seven countries with two in Italy, one in UK, one in Germany, one in Turkey, one in Romania, one in Argentina and two in Brazil. The unit of analysis of the study are the individual production departments internal to the plants (internally defined as 'Mini-factories') and corresponding to each of the five typical phases of the tyre production process: Banbury, Semi-Finishing, Building, Curing, Finishing. We initially obtained a sample of 44 production departments (Mini-factories). Because of missing data (some respondents did not complete the research protocol) the final sample is constituted by 32 observations.

Over the period 2008-2009, the authors traveled extensively visiting one or more time the sampled plants, collecting data as a part of a larger study.

The research protocol was administered as a survey to two respondents: the plant manager and the production department manager.

Measures

Dependent variable

Safety (t). Number of lost-time injuries occurred at the Mini-factory level in the year 2009. These are the occupational injuries resulting in one or more days of inactivity away from work. The measure is readapted to match the one used by the firm as safety performance parameter according to the industry standards.

Independent variables

Table 1 reports a detailed description of the measures, scaling and reliability analysis.

Control variables

Details about the Control Variables appear in Table 2.

Model Specification

Accidents on the workplace can be considered rare and unintentional events. Hence, consistently with the nature of our dependent variable, a count measure assuming non-negative values, we adopted a Poisson regression model, in line with other studies on occupational safety.

RESULTS

Table 3 shows the results of the Poisson Regression Model. Since results are consistent, we will analyze Model 4 as the more complete version of our tests. As expected, TPM is significantly negatively related to the number of accidents. The marginal effect size on the number of accidents of one additional point on the TPM implementation scale in the average Mini-Factory is – 0.76. Hence, Hypothesis 1 is fully supported. Autonomy and Participation is significantly negatively related to accidents in Model 3 and 4, thus supporting Hypothesis 2. At the mean, the elasticity of the number of accidents to a one-point increase in the implementation of workers' empowerment and participation practices is – 2.03 (Model 4). Hypothesis 3 is also supported. Indeed, our findings show that Autonomy and Participation significantly and positively moderate the relation of TPM to occupational safety.

Insert Table 3 about here

Figure 2 presents the estimated effects of the theoretical model.

Insert Figure 2 about here

DISCUSSION

In this paper we presented and tested a model of the association of TPM to occupational safety in manufacturing. Our findings support that not only the technical dimension of TPM programs contributes to the creation of safer workplaces. Indeed, the nature of TPM is tied to a social dimension concerning workers' autonomy over work processes. This dimension has a direct positive effect on safety as it contributes to foster workers motivation and knowledge development. Additionally, it positively moderates the effect of TPM technical activities as it enhances workers' skills, motivation and opportunity to perform their job safely fully enacting TPM safety guidelines.

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FIGURE 1

Theoretical Model

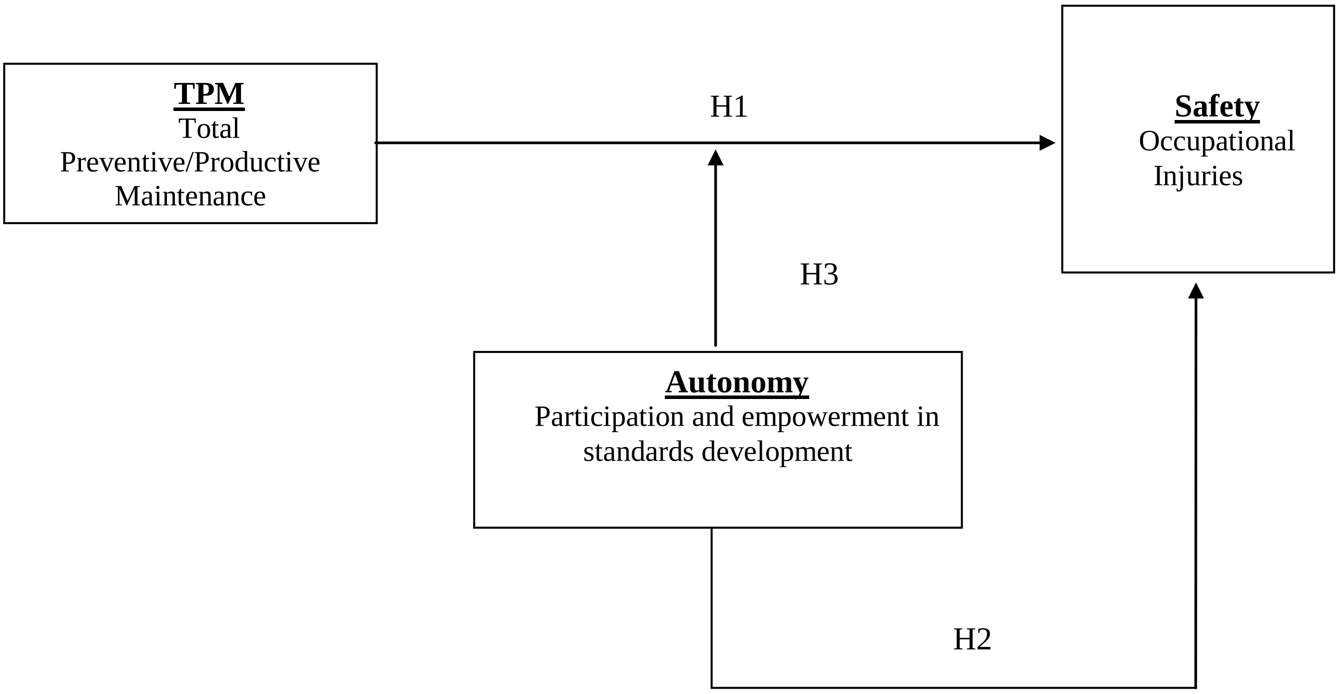

FIGURE 2

Estimated Effects of TPM and Autonomy on Safety

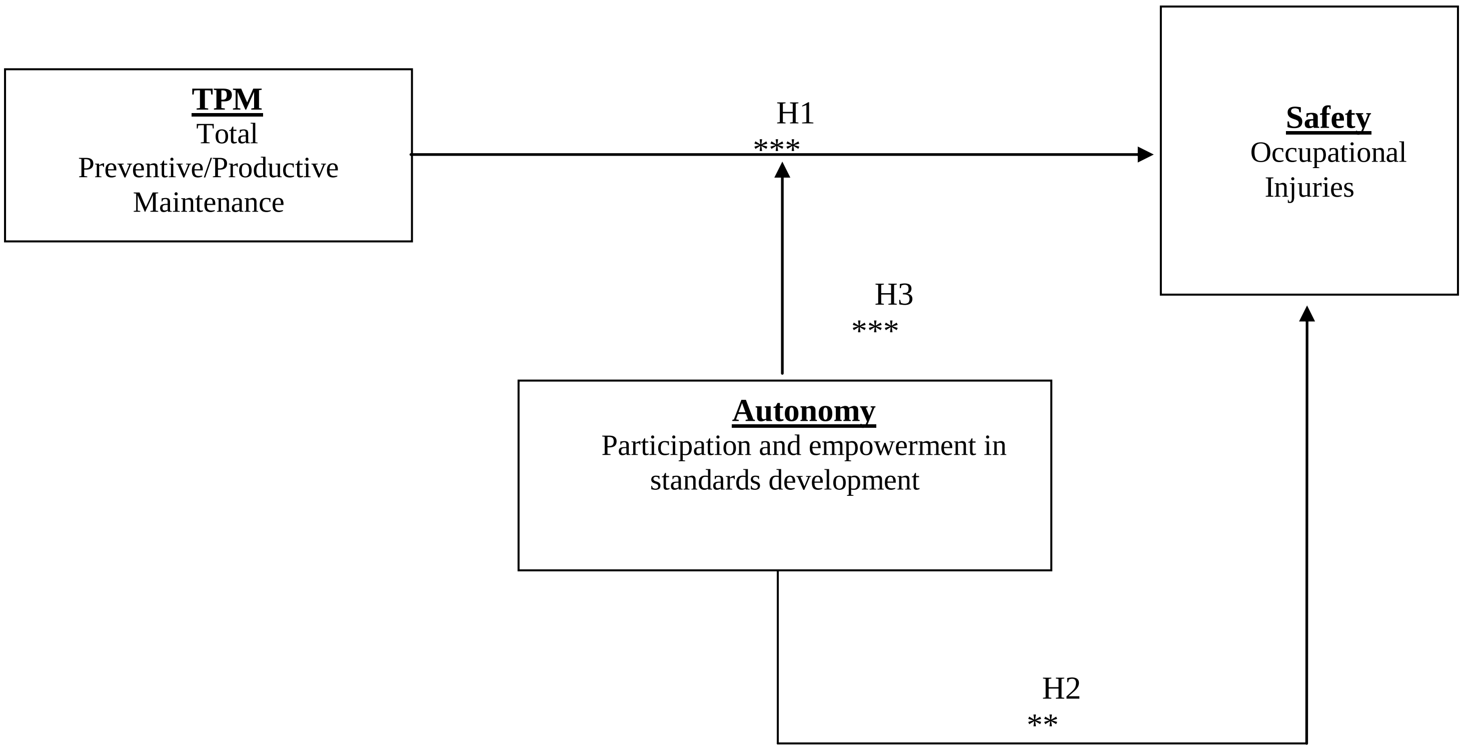

TABLE 1

Independent Variables

Variable Name	Questionnaire Items, Scales, and Reliability Analysis	Description
TPM	N = 4 (α = 0.96) 1-5 scale: “1= no implementation and 5= complete implementation”	TPM (total productive/preventive maintenance): address equipment downtime through total productive maintenance and thus achieve a high level of equipment availability. 4 Items: “ people dedicate a portion of everyday to planned equipment maintenance related activities”; “people maintain all equipment regularly”; “people post equipment maintenance records on shop floor for active sharing with employees”; “people maintain excellent records of all equipment maintenance related activities”.
Autonomy and Participation	N = 1 1-5 scale: “1= no implementation and 5= complete implementation”	“Team leaders help workers develop their own standards, sometimes requesting assistance from staff personnel (e.g. industrial engineering, quality)”.

TABLE 2

Control Variables

Variable Name	Questionnaire Items, Scales, and Reliability Analysis	Description
Banbury	N=1 Binary Variable: 1=”Banbury” and 0=”Otherwise”	Mini-Factory Type. Finishing is used as the base variable.
Semi-finishing	N=1 Binary Variable: 1=”Semi-finishing” and 0=”Otherwise”	Mini-Factory Type. Finishing is used as the base variable.
Building	N=1 Binary Variable: 1=”Building” and 0=”Otherwise”	Mini-Factory Type. Finishing is used as the base variable.
Curing	N=1 Binary Variable: 1=”Curing” and 0=”Otherwise”	Mini-Factory Type. Finishing is used as the base variable.
Plant Age	N=1 1-5 scale: 1=”Early Age Plant” and 5=”Very Old Plant”	5-point scale. Plants are ordered according to the age of machinery and equipment.
Product Mix	N=1 Binary Variable: 1=”Multi-Product Plant” and 0=”Otherwise”	1 = the plant serves both the consumer and the industrial segment, 0 = just one segment is served.

TABLE 3

Poisson Regression Model

Variables	(1) Safety (t)	(2) Safety (t)	(3) Safety (t)	(4) Safety (t)
Safety (t-1)	0.038***	0.050***	0.051***	0.052***
	(0.005)	(0.004)	(0.004)	(0.004)
Banbury	-0.126	-0.069	0.120	0.390
	(0.189)	(0.188)	(0.231)	(0.252)
Semi-finishing	0.062	-0.272	-0.201	-0.015
	(0.260)	(0.179)	(0.187)	(0.221)
Building	-0.198	-0.070	0.192	0.407*
	(0.234)	(0.138)	(0.168)	(0.234)
Curing	0.114	-0.614**	-0.547**	-0.458
	(0.308)	(0.309)	(0.274)	(0.280)
Product Mix	0.183	-0.204	-0.237	-0.084
	(0.197)	(0.140)	(0.145)	(0.140)
Plant Age	0.192	-0.178	-0.227**	-0.253**
	(0.125)	(0.108)	(0.099)	(0.109)
TPM		-0.119***	-0.075**	-0.153***
		(0.024)	(0.033)	(0.032)
Autonomy and Participation			-0.340*	-0.412**
			(0.177)	(0.170)
TPM X Autonomy				-0.139***
				(0.041)
Constant	0.597	2.162***	2.106***	2.190***
	(0.568)	(0.463)	(0.444)	(0.443)
Observations	50	32	32	32

Robust Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1