Exploring the Impact of Environmental and Human Factors on Operational Performance of a Logistics Hub

Abstract This work aims to explore environmental and human factors affecting productivity of warehouse operators in material handling activities. The study was carried out in a semi-automated logistic hub and the data collection has been conducted using wearable sensors able to detect human-related variables such as heart rate and human interactions, based on a smartwatch combined with a mobile application developed by the MIT Center for Collective Intelligence.
Preliminary analysis has shown that the interaction among the warehouse operators and the team leader significantly affect productivity.

1 Introduction

The importance of warehousing as a key activity for manufacturing companies is widely recognized by scholars and practitioners. Although in recent years a more pervasive automation under the label "Industry 4.0" is emerging, a large number of warehouses still strongly relies on human workers, such as forklift drivers, especially in picking activities. Indeed, the picking process is considered among the most laborious and expensive activities in warehouses, and estimates suggest that around 80% of the order picking is still carried out manually [1].

In such a context, where individuals are predominantly involved in material handling activities, individual and team dynamics are among the fundamental drivers of workplace motivation, wellness and system productivity [2]. As a result, there is a growing interest in taking into consideration human factors such as stress, health and collaboration dynamics in the logistic operations. Nevertheless, while such factors promise to achieve better business performance and high levels of safety and well-being of workers there is still a lack of studies [3] that consider both human and working environment factors in such a context. Indeed, studying these variables quantitatively can lead to a clearer insight on which are the factors that affect productivity in such logistics operations.

The recent advent of wearable sensors, and other sensor-based measurement tools (e.g. sociometric badges and smartwatches), is offering researchers the opportunity of collecting and analyzing human factors through data-driven methodologies [4]. For instance, smartwatches are particularly suitable to measure acceleration and heart rate, useful as predictors for physical fatigue of workers [5], and they can efficiently collect a big amount of data in real time, avoiding the main bias linked to common approaches in behavioral studies and increasing the data richness, quality, and reliability. On the other hand, more conventional instruments such as the thermo-hygrometer and lux-meter can be used to measure data about the quality of the environment (e.g. temperature, humidity and luminosity).

Research objective and methodology

This research aims to empirically explore environmental and human factors that may affect productivity and more generally performance of operators in material handling activities. Towards this goal, an exploratory case study was conducted in a semi-automated logistics hub, located in Tuscany - Italy.

The research methodology includes the following steps:

1) *Context analysis.* A context analysis of the logistics hub has been done for setting the case up and to test preliminarily the innovative measurement tools in the specific application context (e.g., smartwatches, thermo-hygrometer and lux-meter with datalogger function).
2) *Data collection.* Data have been collected from employees through the smartwatches (e.g., body movement, acceleration, proximity, speaking, heart rate), while we used thermo-hygrometer and lux-meter for working environmental measures. Finally, productivity data are provided by the Warehouse Management Systems (WMS).
3) *Data pre-processing.* Data from different sources have been properly pre-processed and homogenized to obtain comparable data useful for the analysis phase. Moreover, in order to avoid bias due to the physiological differences among workers (i.e. different heartrate baseline), smartwatch data have been normalized for each operator. Then, additional features were created through the combination of the measured variables, e.g. the mood variables, based on Russell's Circumplex Model [6].
4) *Data analysis.* Correlation and regression analyses have been conducted to propose an explanatory model that can provide guidelines for management with directions for possibly improving workers' productivity, safety and well-being.

Case Study

The experiment has been carried out in a semi-automated logistics hub, located in Tuscany - Italy. The hub is owned by a 450+ million revenue company that produces and sells paper-tissue products all over Europe. The warehouse covers an area of 24 000 square meters with a height of 7 meters and it is open 24 hours a day from Monday to Saturday afternoon. Operators work in 3 shifts.

Operational activities carried out in the warehouse consist of the stocking of inbound pallets and the picking of ordered pallets that must be delivered. Each pallet is 80 cm x 120 cm and the weight is not considered critical due to the lightness of the paper. About 10 operators are employed for each shift, 5 operators for picking, 4 for stocking, 1 team leader, and people from administrative staff.

The layout of the warehouse is shown in figure 1. It is divided in 6 areas. Each of the zones numbered from 1 to 5 has one pallet shuttle while zone 6 is managed using stacks, without any automation. The use of pallet shuttles provides more density of shelves in the warehouse, as well as a greater safety for the operators. We note that although the pallet shuttle partially supports warehouse automation the presence of workers is still very necessary.

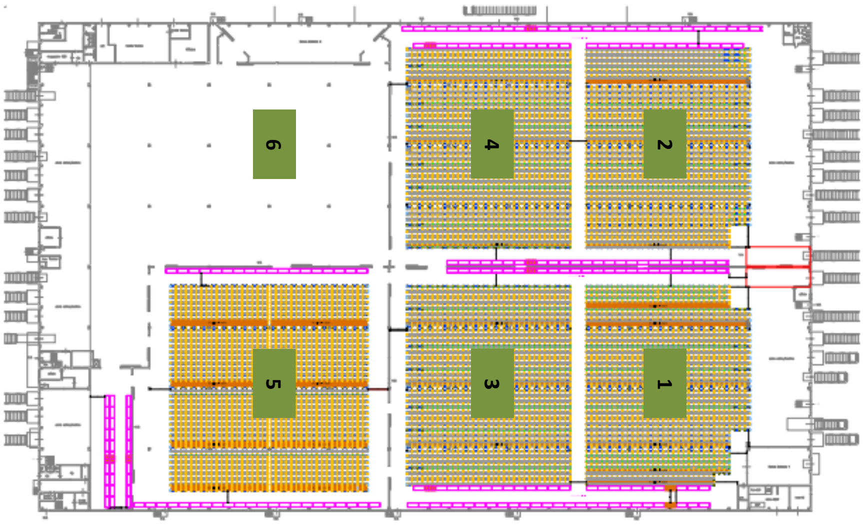

Figure 1 Logistics Hub Layout

Data collection

Human and environmental data have been collected from the warehouse 8 hours a day, 5 days a week, 8 weeks from March to May 2019, for a total of 320 hours monitored for each operator. Figure 3 provides an overview of the hardware and software used for data collection.

As for human factors, a group of 5 picking workers including the team leader, has been equipped with smartwatches and monitored during working activities for the whole duration of the experiment. The tool allows researchers to conduct more in-depth quantitative analysis of interactions inside organizations leading to high level descriptions of human behavior in terms of (i) physical activity/human movement, (ii) speech features (rather than raw audio), (iii) indoor localization, (iv) proximity to other individuals.

As concerning environmental variables, a thermo-hygrometer and a lux-meter, both with datalogger function, have been positioned near to the outbound area of the warehouse for collecting environmental data.

Finally, productivity is evaluated through the hourly number of processed orders (data were extracted by the WMS.

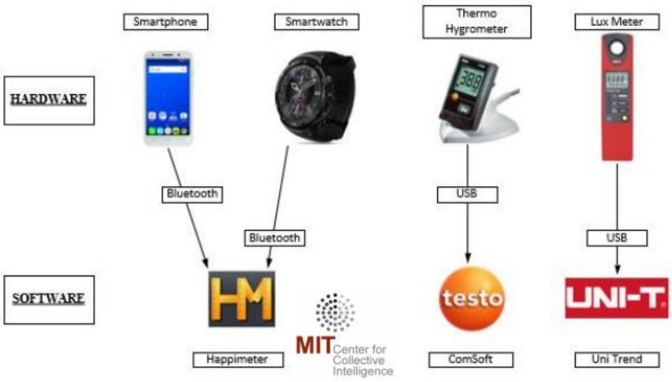

Figure 2 Hardware and Software for data collection

Results

The most significant correlations and p-values are presented in Table 1. Results show that there is a negative correlation with “worked_hours”, i.e. the number of hours worked by an operator, while the correlation with “team leader connection”, i.e. the measurement of how much an operator gets in touch with the team leader, is positive. As an addition, as concerning the features based on Russell’s Circumplex Model [6], the variable “nervous” seems to have a negative correlation with productivity. The last variable “tired” also shows a significant positive correlation with productivity.

Table 1 Correlations with Productivity

Variables	Correlations	p-value
Worked_hours	-0.143	3.00 E-04
Team_leader_connection	0.179	6.50 E-05
Nervous	-0.123	5.00 E-04
Tired	0.091	4.90 E-02

The regression model, that best explains productivity, is shown in Table 2.

Table 2 Regression model with Productivity as dependent variables

Variables	Coefficient	p-value		Statistical index	Value
Worked_hours	-0.0578	3.93 E-03		Multiple R-squared	0.0787
Team_leader_connection	0.1169	2.95 E-07		Adjusted R-squared	0.0667
Stressed	-0.1079	1.92 E-03		Overall p-value	2.77 E-08
Nervous	-0.2504	3.39 E-03			
Week_day	-0.0381	0.333			
Team_leader_presence	0.1095	0.2843			
Luminosity	-0.088	0.0798			
Hours	8.31 E-04	0.9325			

The regression model has an R-squared of 0.079 and an Adjusted R-squared of 0.067 (p-value is 2.772E-08). Considering that orders assigned to the employees are not always homogeneous, e.g. they may differ regarding the difficulty degree, the personal factors influencing individual productivity and other possible confounding effects, a result of less than 10% is acceptable.

Findings show that the only positive coefficient is “team leader connection”, while the other coefficients negatively affect productivity. Performance seems to improve with the increase of connections between the operators and the team leader and if people work in an environment that allows them to be less nervous.

We controlled for the “week day” because the day of the week can characterize the type and complexity of work and intensity of operations; “team leader presence” because it helps to verify that the variable "team leader connection" is not connected to the physical availability (presence or absence) of the team leader in the warehouse; “luminosity” because usually lighting can contribute to improving workplace condition and overall operation performance; “hour” to double check the “worked_hours” variable. We note that "worked_hours" has a greater coefficient than "hour", therefore it can be assumed that it is intended as a measure of the tiredness of an operator.

Discussion and conclusions

This work explores human and environmental factors affecting the productivity of employees in a semi-automated warehouse by using wearable sensors. As an addition, it methodologically contributes to empirically testing the innovative hardware and software for data collection in this specific setting.

Preliminary results show that, as expected, individual productivity depends on the worked hours, and hence is affected by the fatigue of operators, but it also seems to be influenced by coordination mechanisms and by individual variables such as nervousness and stress of employees. Specifically, an increase in the connection of operators with the team leader, which seems to act as a facilitator of operations, increases the productivity. Also, a high level of stress and nervousness leads to a decrease in individual productivity. Finally, no clear evidence about the role of environmental factors emerges in the experiment.

Some managerial implications can be derived, such as the adoption of part-time workers to reduce the amount of worked hours and avoid high fatigue of employees, as well as incentivizing effective collaboration and interactions of operators with the team leader. While it is difficult to confirm a direct causal relationship between human and environmental factors and operators' productivity, we emphasize the opportunity for managers to care for operators' needs and working environmental conditions in order to improve performance.

Further works should improve this study by extending the time window for data collection in order to cover more variability in the handling activities, by increasing the number of observed workers and by extending the investigation to different warehouses with different type of goods, automation level, etc. Also, a greater number of environmental sensors could be adopted to cover the areas of a warehouse to provide more detailed insight on the role of environmental factors.

Acknowledgement

This research project is co-funded by Regione Toscana POR CREO 2014-2020 (CUP 7165.24052017.11200012) and by MISTI MIT-UNIPI program.

Main references

1. M. Napolitano, "2012 warehouse/DC operations survey: mixed signals," Modern Materials Handling, vol. 51, no. 11, pp. 48-56, 2012.
2. E. Grosse, C. Glock, M. Jaber and W. Neumann, "Incorporating human factors in order picking planning models: framework and research opportunities," International Journal of Production Research, vol. 53, no. 3, pp. 695-717, 2015.
3. E. Grosse, Glock, H., & Neumann, P. (2017). Human factors in order picking: a content analysis of the literature. International Journal of Production Research, 55(5), 1260–1276.
4. Gloor, P.A., Fronzetti Colladon, A., Grippa, F., Budner, P., Eirich, J., Aristotle Said "Happiness is a State of Activity" — Predicting Mood Through Body Sensing with Smartwatches, (2018) Journal of Systems Science and Systems Engineering, 27 (5)
5. Z. S. Maman, M. A. A. Yazdi, L. A.Cavuoto and F. M. Megahed, "A data-driven approach to modeling physical fatigue in the workplace using wearable sensors," in Applied Ergonomics, 2017, pp. 515-529.
6. J. A. Russell, "A Circumplex Model of Affect," Journal of personality and social psychology, vol. 39, no. 6, pp. 1161-1178, 1980.