



## Automating Production Process Data Acquisition Towards Spaghetti Chart 4.0

S. Q. D. Al-Zubaidi<sup>a,\*</sup>, E. Coli<sup>b</sup>, G. Fantoni<sup>a</sup>

<sup>a</sup> Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy;

<sup>b</sup> Department of Smart Industry, University of Pisa, Pisa, Italy

### References

- [1] K. Hys, A. Domagała, “Application of spaghetti chart for production process streamlining, Case study”, Archives of Materials Science and Engineering, vol. 89, no. 2, pp. 64-71, 2018, doi: 10.5604/01.3001.0011.7173.
- [2] A. Cantini, F. De Carlo, and M. Tucci, “Towards Forklift Safety in a Warehouse: An Approach Based on the Automatic Analysis of Resource Flows,” Sustainability, vol. 12, no. 21, p. 8949, Oct. 2020, doi: 10.3390/su12218949.
- [3] J. Zhou and P. He, “Research on Data Acquisition System of Flow Workshop Based on IIoT,” 2020 IEEE 3rd International Conference of Safe Production and Informatization (IICSPI), 2020, pp. 1-6, doi: 10.1109/IICSPI51290.2020.9332338.
- [4] E. Trunzer, A. Wullenweber, and B. Vogel-Heuser, “Graphical modeling notation for data collection and analysis architectures in cyber-physical systems of systems”, Journal of Industrial Information Integration, vol. 19, p. 100155, 2020, doi: 10.1016/j.jii.2020.100155.
- [5] G. Fantoni, S.Q. Al-Zubaidi, E. Coli, and D. Mazzei, “Automating the process of method-time-measurement,” International Journal of Productivity and Performance Management, vol. 70, no. 4, pp. 958-982, 2021, doi: <https://doi.org/10.1108/IJPPM-08-2019-0404>.
- [6] S.Q. Al-Zubaidi, G. Fantoni, F. Failli, and M. Frosolini, “Automated Method Time Measurement System for Redesigning Dynamic Facility Layout”, International Journal of Industrial and Manufacturing Engineering, vol. 15, no. 1, pp. 46-51, 2021.
- [7] S. Q. Al-Zubaidi, G. Fantoni, and F. Failli, “Analysis of Drivers for Solving Facility Layout Problems: A Literature Review”, Journal of Industrial Information Integration, vol. 21, p. 100187, 2021, doi: 10.1016/j.jii.2020.100187.
- [8] T. Ruppert, J. Abonyi, “Integration of real-time locating systems into digital twins,” Journal of Industrial Information Integration, vol. 20, p. 100174, 2020, doi: 10.1016/j.jii.2020.100174.
- [9] D. Nahavandi, and M. Hossny, “Skeleton-free RULA Ergonomic Assessment Using Kinect Sensor”, Intelligent Decision Technologies, vol. 11, no. 3, pp. 275-284, 2017, doi: 10.3233/IDT-170292.
- [10] A. Górný, “Ergonomic requirements for the operation of machines and technical equipment”, Modern Technologies in Manufacturing, vol. 137, p. 03005, 2017, doi: 10.1051/mateconf/201713703005.
- [11] M. Doshi, H. Shah, H. Gada, and M. Shah, “Wearable DAQ (Data Acquisition System) for measurement of R.U.L.A.(Rapid Upper Limb Assessment) rating of vehicles”, in Proceedings of the Second International Conference on Intelligent Computing and Control Systems (ICICCS 2018), Madurai, India, 2018, pp. 545-550.
- [12] C. Nnaji, I. Awolusi, J. Park, and A. Albert, “Wearable Sensing Devices: Towards the Development of a Personalized System for Construction Safety and Health Risk Mitigation,” Sensors, vol. 21, no. 3, p. 682, Jan. 2021, doi: 10.3390/s21030682.
- [13] C. Belletier, M. Charkhabi, G. Pires de Andrade Silva, et al., “Wearable cognitive assistants in a factory setting: a critical review of a promising way of enhancing cognitive performance and well-being,” Cogn Tech Work, vol. 23, pp. 103-116, 2021, doi: 10.1007/s10111-019-00610-2.
- [14] E. Stefana, F. Marciano, D. Rossi, P. Cocca, G. Tomasoni, “Wearable Devices for Ergonomics: A Systematic Literature Review,” Sensors, vol. 21, no. 3, p. 777, 2021, doi: 10.3390/s21030777.
- [15] A. Chiarini, “Waste savings in patient transportation inside large hospitals using lean thinking tools and logistic solutions,” Leadership in Health Services, vol. 26 no. 4, pp. 356-367, 2013, doi: 10.1108/LHS-05-2012-0013.
- [16] W. Laurig, F.M. Kühn, K.C. Schoo, “An approach to assessing motor workload in assembly tasks by the use of predetermined-motion-time systems,” Applied Ergonomics, vol. 16, no. 2, pp. 119-125, 1985, doi: 10.1016/0003-6870(85)90214-5.
- [17] D. Verma, A. Shukla and P. Jain, “COVID19: Impact on Indian Power Sector,” in 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE), Jaipur, India, 2020, pp. 1-6, doi: 10.1109/ICRAIE51050.2020.9358342.
- [18] F. Beck and M. Bader, “Map Based Human Motion Prediction for People Tracking,” in IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Macau, China, 2019, pp. 1-7, doi: 10.1109/IROS40897.2019.8967742.

- [19] J. Chen, H. Wang, R. Y. Zhong, "A supply chain disruption recovery strategy considering product change under COVID-19," *Journal of Manufacturing Systems*, vol. 60, pp. 920-927, 2021, doi: 10.1016/j.jmsy.2021.04.004.
- [20] S. Farivar, M. Abouzahra, and M. Ghasemaghaei, "Wearable device adoption among older adults: A mixed-methods study," *International Journal of Information Management*, vol. 55, p.102209, 2020, doi: 10.1016/j.ijinfomgt.2020.102209.
- [21] H. I. Patel, S. A. Senanayake, and J. Triloka, "Human-System Interaction Interface Utilizing 3D Gesture Recognition Techniques based on Wearable Technology," in 5th International Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA), Sydney, Australia, 2020, pp. 1-9, doi: 10.1109/CITISIA.50690.2020.9371806.
- [22] Q. Qi, F. Tao, T. Hu, N. Anwer, A. Liu, Y. Wei, L. Wang, and A.Y.C. Nee, "Enabling technologies and tools for digital twin," *Journal of Manufacturing Systems*, vol. 58, pp. 3-21, 2021, doi: 10.1016/j.jmsy.2019.10.001.
- [23] M. Uddin, A. Gupta, K. Maly, T. Nadeem, S. Godambe, and A. Zaritsky, "Smart Spaghetti: Use of smart devices to solve health care problems," in Proceedings of the 2013 IEEE International Conference on Bioinformatics and Biomedicine, Shanghai, China, 2013, pp. 40-45.
- [24] M. Uddin, A. Gupta, K. Maly, T. Nadeem, S. Godambe, and A. Zaritsky, "Smart Spaghetti: Accurate and robust tracking of Human's location," in Proceedings of the IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI), Valencia, Spain, 2014, pp. 129-132.
- [25] D. Bhushan, and R. Agrawal, R., "Security Challenges for Designing Wearable and IoT Solutions," in A Handbook of Internet of Things in Biomedical and Cyber Physical System, Balas, V., Solanki, V., Kumar, R., Ahad, M. Eds., Cham, Germany: Springer, 2020, pp. 109-138, doi: 10.1007/978-3-030-23983-1\_5.
- [26] G. Chan, S. Mak, K. Tsang and C. Lee, "Safety and EMC compliance with fabrication equipment in semiconductor industry: challenges and solutions," 2019 IEEE Symposium on Product Compliance Engineering (SPCE Austin), 2019, pp. 1-6, doi: 10.1109/SPCE47297.2019.8950802.
- [27] K. Senderska, A. Mareš, and Š. Václav, "Spaghetti Diagram Application for Workers' movement Analysis", *UPB Sci. Bull. Ser. D*, vol. 79, pp. 139-150, 2017.
- [28] M. Periša, T. M. Kuljanić, I. Cvitić, and P. Kolarovszki, P. "Conceptual model for informing user with innovative smart wearable device in industry 4.0," *Wireless Networks*, vol. 27, no. 3, pp. 1615-1626, 2021.
- [29] J. Baalsrud Hauge et al., "Digital Twin Testbed and Practical Applications in Production Logistics with Real-Time Location Data," *Int. J. Ind. Eng. Manag.*, vol. 12, no. 2, pp. 129-140, 2021, doi: 10.24867/IJIEEM-2021-2-282.
- [30] B. Bajić, N. Suzic, N. Simeunovic, S. Moraca, and A. Rikalovic, "Real-time Data Analytics Edge Computing Application for Industry 4.0: The Mahalanobis-Taguchi Approach," *Int. J. Ind. Eng. Manag.*, vol. 11, no. 3, pp. 146-156, 2020, doi: 10.24867/IJIEEM-2020-3-260.
- [31] A. P. Lista, G. L. Tortorella, M. Bouzoua, S. Mostafad, and D. Romeroe, "Lean layout design: a case study applied to the textile industry," *Production*, vol. 31, p. e20210090, 2021, doi: 10.1590/0103-6513.20210090.