Smart manufacturing and opportunities for Official statistics, a focus on Small and Medium enterprises (SMEs)

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1. Current trends of ISTAT business direct surveys

The conduction of official direct surveys on businesses poses growing issues of acceptability by respondents and sustainability of costs by statistical agencies, given the requirements on quality standards of outputs produced. These difficulties lead producers of official statistics to progressively increase the use of alternative sources, mainly in the form of administrative data and big data and, at the same time, evaluate the possibilities of implementing direct M2M (Machine to Machine) acquisition tools [1,2]. In this context, the diffusion of technologies relating to Smart Manufacturing opens up new perspectives.

The framework of official business surveys carried out by Istat, almost all included in the National Statistical Program and consequently characterized by obligation to respond and in many cases by administrative pecuniary penalties in case of non-compliance, requires a considerable commitment from the respondents, which varies in relation to the size class and sector to which they belongs. The system currently includes 44 direct surveys involving approximately 452,322 companies[1]

Population of Italian businesses is highly asymmetric as it is mainly made up of micro and small units. This asymmetry implies that medium-large sized units tend to be involved in a very high number of surveys but, on the other hand, that small and medium-sized enterprises (SMEs) also play a fundamental role in official surveys.

Out of 44 surveys, 20 are short-term, with a weekly, monthly or quarterly frequency, for a set of 127,482 companies involved, 16 are structural with annual frequency and 8 are equally structural but with a multi-year or occasional frequency, for an involvement of approximately 395,453 companies (Table 1). The same table show that 99 percent of companies involved in business official direct surveys are SMEs (97 per cent for short-term surveys). In economic terms the weight of large companies is much higher as they absorb about 23 percent of employment and create 35 percent of the added value.

Table 1. Businesses involved in ISTAT surveys, by size range and type of direct survey.

	Type of direct survey					
Size range	All	%	Structural	%	Short-term	%
Micro and small businesses	430,449	95	373,900	95	111,420	87
Medium-sized businesses	18,425	4	18,135	4	13,036	10
Large businesses	3,448	1	3,418	1	3,026	2
Total	**452,322**	**100**	**395,453**	**100**	**127,482**	**100**

[1] The reference is to the last completed edition of each direct survey.

The involvement of businesses varies from a minimum of one survey to a maximum of 21, many of which are repeated several times during the year, in particular in cases of weekly, monthly and quarterly periodicity. The average involvement is influenced by the size range: from 1.4 surveys on average for the "less than 20 employees" range (micro businesses and small businesses) up to the average of 12.7 surveys for the larger businesses "500" range employees and beyond". Even in the range of medium-small sized companies, with 50-100 employees, the involvement is relatively high and equal to about 6.2 surveys (Table 2).

Table 2. Average involvement of companies in direct Istat surveys, by size range and type of survey.

Size range	Type of direct survey		
	All	Structural	Short-term
Micro and small businesses	1.53	1.45	1.09
Medium-sized businesses	6.21	4.87	1.94
Large businesses	11.81	8.83	3.08
Totale	**1.80**	**1.67**	**1.23**

Participation in surveys is assessed by the ratio between number of surveys in which each company participates and number of surveys in which it is involved. The analysis of the quartiles Q1 and Q4 of participation rates shows a direct relation between partitipation and number of surveys. In fact, for companies involved in a single survey the first quartile is approximately 0.6, while for businesses involved in more than 10 surveys it is lower than 0.1 (Figure1). The result is certainly influenced by a size effect, as larger companies tend to be involved in a greater number of surveys.

Figure 1. Participation rates of businesses in Istat surveys, by number of surveys, Q1 and Q4 quartiles.

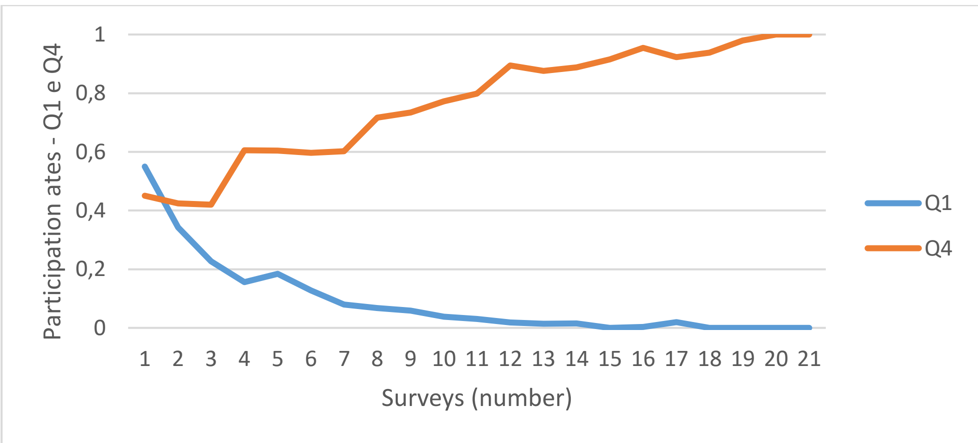


Figure 2. Participation rates of businesses in ISTAT surveys, by size range and number of surveys, Quartile Q4.

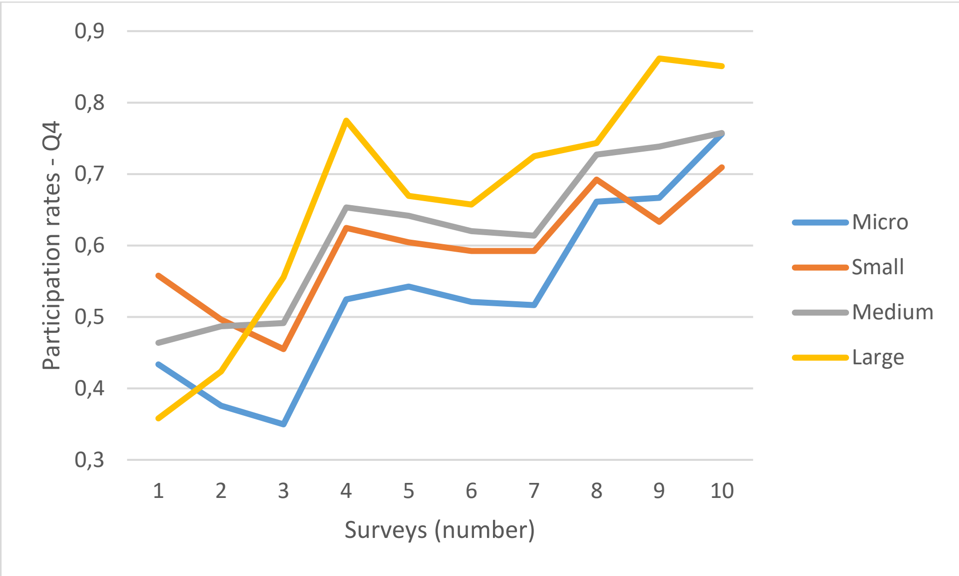


Figure 2 reports trend of participation rates (quartile Q4), by size range and number of surveys, showing participation rates noticeably higher for large businesses than micro and small ones. Therefore, smaller companies experience specific difficulties in responding to the large amount of information required by official statistics.

In reaction to the issues briefly described above, the trends underway in official statistical systems show a progressive shift from single source approach (direct survey) to a multiplicity of alternative sources ("multisource") approach [3,4]. In particular, the transition initially mainly concerned administrative sources [5] and subsequently was extended to new data sources generically defined as big-data. The digital transformation of industrial processes currently underway multiplies the availability of alternative sources, providing further opportunities for official statistics [2]. Therefore, the prevailing strategy is to favor secondary sources wherever it is possible to apply them, reducing direct surveys only to cases in which they are strictly necessary.

For quality evaluation of data collected in business surveys, the main reference paradigm, Total Survey Error (TSE), which states different types of errors that go along with statistical survey processes, extended to the "multisource" approach for the management of statistical processes [6, 7].

2. Digitalisation degree of Italian companies

Results of annual survey on diffusion of information and communication technologies in businesses (in short ICT survey), carried out within the scope of EC Regulations no. 808/2004 and EC n. 1006/2009 following criteria and methodologies shared by all European Union countries [8] and aimed at companies with at least 10 employees, offer significant information on degree of digitalisation of Italian companies, also concerning SMEs. The degree of digitalisation is a proxy of the "readiness" for the adoption of smart manufacturing technologies in different segments of the Italian business, notably industrial.

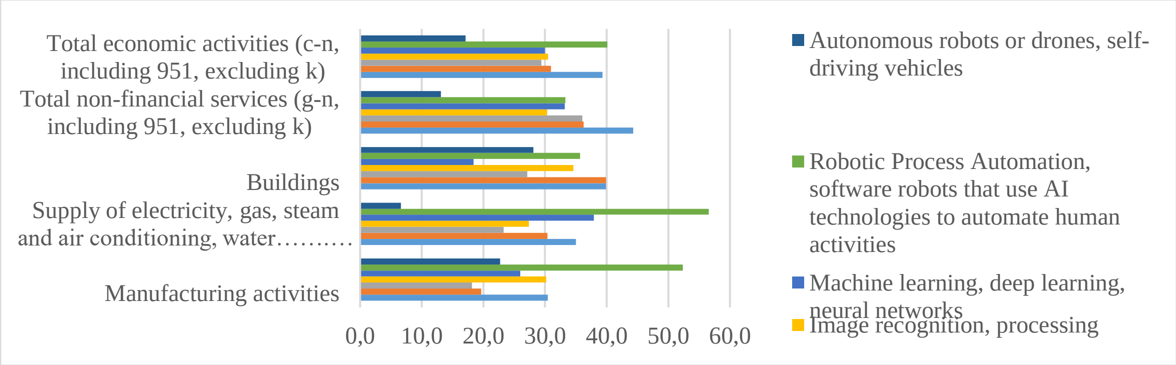
In summary, the results of the 2023 survey show that companies with a high or very high level of digitalisation are 22.2 percent. This share rises to 68.2 percent for businesses having 250 employees or more and is highly variable depending on the sector of economic activity. The percentage share stands at 19.3 percent for small businesses and 47.0 percent for medium-sized businesses having 100-249 employees.

42.7 percent of companies use ERP (Enterprise Resource Planning) software and 17.6 percent use Business Intelligence. These percent shares rise respectively to 85.0 and 68.1 percent for larger businesses, stands at 38.6 and 14.2 percent for small businesses, and at 72.3 and 46.1 percent for medium-sized businesses having 100-249 employees. As regards data analysis, 24.9 percent of companies (73.1 for large companies) analyze data internally through their own employees or those of other companies in the group, of which 6.2 percent (the share rises to 10.7 percent for manufacturing companies and 34.0 percent for all large businesses) are companies that process data produced by intelligent devices or sensors. 61.4 percent of companies purchase cloud computing services (basic, intermediate or advanced) of which 10.9 concern advanced ERP services (13.1 percent for manufacturing companies).

Businesses that use Artificial Intelligence (AI) are 5.0 percent, a share that rises to 24.1 for large companies. Of these, 39.0 percent use AI techniques for production processes, a share that rises to 52.5 percent in manufacturing sector. The adoption of AI techniques does not exclusively concern large companies (46.1 percent) but also smaller ones (38.3 percent in the size class of 10-49 employees). The main cause of the failure to use AI techniques concerns the lack of adequate skills, for 55.1 percent of companies, this share rises to 58.1 percent in the manufacturing sector. Generally speaking, adoption of AI refers to systems that use technologies for the processing of information taken from unstructured text (text mining), image recognition (computer vision), voice recognition, natural language generation (natural language generation), improvement of performance through automatic data learning (machine learning, deep learning, neural networks), collection and use of data to predict, recommend, decide with different degrees of autonomy, the adoption of best action to achieve specific objectives for the company. Concerning the purposes for using AI, Figure 3 below shows that for manufacturing the prevalent use relates to robotic process automation, and software to automate human activities.

AI systems can be based exclusively on software (chatbots and business virtual assistants based on natural language processing, facial recognition systems, machine translation software, data analysis based on machine learning) or embedded in devices (autonomous robots for the automated management of warehouses or assembly work or autonomous drones for production surveillance or package handling, etc.).

Figure 3. Businesses using AI software or systems by purposes and macro-sector of economic activity (percentage values).



Source: Istat – ICT survey, year 2023.

Overall, a picture of advanced digitalisation emerges for larger companies, albeit with gaps and delays in some areas (e.g. AI), while the situation is decidedly more varied for SMEs, where strong differences emerge at sectoral level and by type of technology, purposes and corporate areas of application. Data from ICT survey confirm that businesses with a high degree of digitalisation represent a significant share of Italian SMEs showing a high "readiness" for the implementation of new technologies notably in manufacturing sector. The diffusion of ERP management systems, even of an advanced nature, is significant even among small-sized companies.

Further impulse to the development of these activities may derive from the incentive policies for the 4.0 and 5.0 transition promoted by national Governments.

3. Smart Manufacturing, Industry 4.0 and Industry 5.0 paradigms and new availability of statistical data

Development of paradigms called Industry 4.0, Industry 5.0 (hereinafter I4.0 and I5.0), and of "Smart Manufacturing" has characterized the evolution of industrial processes in recent years. The main difference between Smart Manufacturing and Industry 4.0 is geographical and economic. Project called Industry 4.0, in fact, is of European origin, has Germany among the leaders and has a particular impact in Europe. Definition of Smart Manufacturing has greater traction in the United States, thanks to an initiative called Smart Manufacturing Leadership Coalition (SMLC), a non-profit organization made up of representatives of the manufacturing supply chain, universities and research centers [9].

The two projects have many assumptions in common: interoperability between systems within the entire supply chain, creation of standards and the use of increasingly advanced technical solutions to make processes more efficient, economical, flexible and scalable.

Smart Manufacturing consists of creating a highly automated and interconnected production environment where devices, machines, people and systems can communicate with each other and make decisions based on data in real time. NIST (National Institute of Standards and Technology) defines smart manufacturing as: “fully integrated and collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, supply network, and customer needs.” It is based on cloud connectivity and it is a combination of human creativity, digitally connected machines and assets, and artificial intelligence-based systems and analytics. The goal is to achieve faster, precise and personalized production, reducing waste and increasing flexibility to adapt to changing market needs. Smart factories are characterized by a set of basic technologies that make them more efficient [10]:

- IoT (Internet of Things), devices and machines are equipped to send and receive digital data. Data sent from the device reports its status and activity, while data sent to the device controls and automates actions and workflows. An Industrial IoT (IIoT) network is at the heart of smart manufacturing as it encompasses not only connected assets, but also the intelligent systems and automated processes;
- Artificial intelligence (AI) and machine learning, which automate actions and, in addition, help to predict possible faults, as well as schedule preventive maintenance;
- Analytics and machine learning tools for big data analysis.
- Additive Manufacturing/Hybrid Manufacturing: better known as 3D printing, additive manufacturing increases resilience and agility;

- Cloud Computing: Offers manufacturers the on-demand availability of system resources such as IIoT data, analytics and process automations. Large clouds can be centrally managed, but distributed across regional or global locations;
- Digital simulation/representation: A digital representation or simulation is created to be an identical virtual copy of a machine or process existing in the real world. It allows production teams to test new ways of producing.

I4.0 paradigm has a mainly technological characterization and continues to represent a relevant trend for the automation, efficiency and integration of production processes, especially industrial ones. It transformed the concept of Cyber Physical Systems (CPS) into that of Cyber Physical Production Systems (CPPS). In the era of Industry 4.0, production systems, in the form of CPPS, can make intelligent decisions through real-time communication and cooperation between “manufacturing things” [11]. In particular, I4.0 describes concepts and definitions for the intelligent manufacturing domain. Relevant in the paradigm is the concept of "asset", understood as any "object that has value for an organization" [12]. According to this definition, assets in I4.0 can take any form, for example being a production system, a product, a software installation, intellectual property or even a human resource.

The Boston Consulting Group identified the key enabling technologies of I4.0, which essentially follow those indicated in smart manufacturing, i.e. Big Data and analytics, autonomous robots, simulation, integration of horizontal and vertical systems, IoT, IT security, Cloud, Additive Manufacturing and Augmented Reality [13].

These technologies underlie the five central research themes of I4.0:

- Horizontal integration through value networks;
- “End-to-end” engineering along the entire value chain;
- Vertical integration and networked production systems;
- Cyber-physical systems technology;
- New social infrastructure in the workplace.

In more recent years, the concept of I4.0 has been expanded with that of I5.0, which includes, in addition to the technological component, also the human, environmental and resilience components [14].

The human-centered approach places basic human needs and interests at the center of the production process, moving from technology-driven progress to a fully human- and society-centered approach. “As a result, workers develop new roles moving from “cost” to “investment”. Technology is to serve people and societies, which means that the technology used in the manufacturing sector adapts to the needs and diversity of workers in the sector. You need to create a safe and inclusive work environment to prioritize physical health, mental health and wellbeing” [15].

Furthermore, for the industry to respect planetary boundaries, it must be sustainable. There is a need to develop circular processes that reuse and recycle natural resources, reduce waste and environmental impact and ultimately lead to a circular economy with improved resource efficiency and effectiveness.

Resilience refers to the need to develop a high degree of robustness in industrial production, equipping it against disruptions and ensuring it can supply and support critical infrastructure in times of crisis. The industry of the future will have to be resilient enough to quickly deal with geopolitical changes and natural emergencies.

Industry 5.0 has enriched the main enabling technologies:

1 Individualized human-machine interaction technologies that interconnect and combine the strengths of humans and machines;

2 Biologically inspired technologies and smart materials that enable materials with embedded sensors and advanced functionality while being recyclable;

3 Digital Twin and simulation to model systems;

4 Data transmission, storage and analysis technologies capable of managing data and system interoperability;

5 Artificial intelligence to detect, for example, causality in complex, dynamic systems, resulting in actionable intelligence;

6 Technologies for energy efficiency, renewable sources, storage and autonomy.

In all paradigms considered, the development of new technologies promotes a data-driven approach that considers data management as a strategic element of the business. Adopting a data-driven approach means using the availability of big data in businesses and effectively using them in the decision-making process. Every element of the production chain, including products, is connected thanks to the contribution of sensors, measurement and monitoring instruments (e.g. RFID chips). Every element of the supply chain exists simultaneously in both the physical and virtual worlds. Another common concept is decentralization of control. At each step of the production chain, intelligent control systems allow optimization of the specific phase and communication with the chain in order to make the process more efficient in real time. That is possible by exchanging data and monitoring processes through advanced analysis platforms.

4. The second generation management platforms

Most advanced, second generation and integrated management platforms produce volumes of data that can be used, potentially, to satisfy some needs of official statistics. They mainly take the form of integrated ERP (Enterprise Resource Planning) [10], which include MES (Manufacturing Execution System) functions and AAS (Asset Administration Shell) models [12].

A relevant functionality for an advanced ERP consists in establishing a real-time dialogue with industrial production plants. The connection concerns in particular the MES (Manufacturing Execution System) module for real-time control of production, through the monitoring and management of electrical signals coming from the various industrial systems: piece counters, meters, sensors, etc. The ERP can therefore interact with the information arriving from the systems, consequently performing pre-established functions and possibly activating other devices. It also allows real-time control of the status and use of resources (machines, systems, personnel), detection of production times, self-learning of work cycles, detection of staff attendance, dashboards for immediate control of the performance of each assets, maintenance of machines and systems, qualitative process surveys (characteristics, conformity, measurement, visual inspection). A specific example concerns the integration of ERP system with CMMS (Computerized Maintenance Management System) software, which offers further solutions from an I4.0 perspective. It allows to manage the maintenance of systems and equipment by proposing revision, replacement or repair interventions before any operational irregularities appear. A further advantage of an advanced ERP concerns the possibilities of analyzing the available data, through business intelligence modules, with the possibility of fast and automatic distribution to the correct recipients, regardless of their physical and geographical location [7].

A possible synergy concerns the integration between ERP and electronic data interchange (EDI). It consists of the automatic exchange of predefined and structured data for business purposes between two or more organization information systems. Already in 1996 the National Institute of Standards and Technology (Nist) had defined Electronic Data Interchange as "the exchange from computer to computer of a standardized format for exchanging data”. It is a consolidated technology that is taking on importance again. Each EDI transaction requires a precise message standard (Indicod-Ecr, Edifact, Ansi X.12, Tradacoms, PEPPOL). This can generate critical issues, especially for SMEs partners as a B2B network distinguishes itself for a number of specific requirements.

5. Objectives of the Istat initiative to engineer the use of new sources

The initiative has the primary objective of carrying out a detailed analysis on operating opportunities offered by 5.0 technologies for official statistics in terms of reducing the burden required on respondents, costs and improve quality of the outputs produced, developing operational experimental solutions that can be extended to broader contexts. The SMEs segment takes on specific importance, given the consistent dimensional asymmetry of the Italian production system, in the context of official Italian statistical surveys.

6. The steps of the activity

The activity involves the implementation of the following phases:

- Analysis of the basic characteristics of the current official business survey system, with specific regard to burden of respondents and costs;

- Analysis of the degree of diffusion, also through the use of proxy variables, of the I4.0 and I5.0 technologies in the segments of the Italian business, in order to draw indications on the "coverage" and the possibilities of extending the solutions identified;

- Launch of synergies, information exchange activities and collaboration with the Competence Centers (CS) established by MIMIT (Ministero delle imprese e made in Italy) with the aim of providing services and assistance to companies in 5.0 transition;

- Analysis of the categories of data made available by the main advanced and integrated management platforms (second generation ERP) by carrying out structured interviews with suppliers of main platforms;

- Evaluation of acceptability of new approach among a purposive sample of respondents;

- Detailed analysis of information needs satisfied, limited in the first phase to short-term economic variables only.

7. Discussion

"Single-source" direct official surveys present growing issues of burden on respondents and process efficiency. Consequently, data collection of official business statistics is increasingly oriented to use alternative sources, according to a "multisource" approach. The first type of alternative source, now consolidated for several years, concerns the use of administrative sources. This type of source only covers a part of the information needs of business surveys, as an example the electronic invoicing source by revenue agency, being implemented in several countries, with different stages of progress. The need emerges to boost other alternative sources and automation of DC processes.

In business statistics, a promising alternative source may derive from the mass of data produced by smart manufacturing. This data can be stored in very large and unstructured repositories referred to as “data lakes”. A cost-benefit analysis of this approach aimed at exploiting this type of statistical data points out several advantages but also some obstacles.

Advantages can be summarized in reduction of burden of respondents, process efficiency, costs and quality of the data collected, as they are characterized by high timeliness and accuracy.

Obstacles to overcome in view of effective use of these data in statistical production processes concern complexity for NSIs in managing data collection from different sources, e.g. integration of data collected, greater effort and resources controlling production processes and TSE evaluation and control. Another difficulty derive from necessity to design generalized solutions oriented to engineer M2M acquisition procedures useful for wide categories of data suppliers (critical mass) in relation to the still limited diffusion of second generation ERP and coverage of smart manufacturing technologies, especially for SMEs.

The in-depth analysis of these issues requires a specific data collection at main suppliers of management platforms (advanced second generation ERPs) and a feasibility check at a purposive sample of business that adopt technologies 4.0 and 5.0. Istat has planned these activities for next months.

No doubt the approach represents an opportunity both in relation to the growing difficulties linked to the exercise of data collection of official statistics on businesses in traditional form, and to the incentive policies promoted by national Governments (Transition 4.0 and 5.0). In this regard, the Competence centers, established in Italy by the Ministry for Industry and Made in Italy (MIMIT) to facilitate the 5.0 transition, in particular of SMEs, can play a relevant role.

8. Author Contributions

P. Bosso: section 6 – G.G. Di Paolo: section 1 – D. Distefano: section 2 – P. Papa: sections 3,4,5,7

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