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An information-based risk analysis IT tool protecting the European food system(s)

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Contents

Abstract

The Farm to Fork Strategy has recognised the necessity of intensifying efforts to combat fraudulent practices within the agri-food chain while simultaneously enhancing traceability and alert systems to improve coordination in addressing food fraud.

A substantial volume of food chain data is already accessible at European and international levels, enabling a shift towards a digital, risk-based approach to safeguarding the food system. Nevertheless, this data is dispersed across various food businesses, competent authorities in Member States, and Commission services, and data sets are not always interoperable.

The European Commission could harness its in-house resources, as existing databases, intelligence sources, and digital tools, to aggregate relevant food chain information. This aggregation can enhance descriptive analytics for visualizing current food safety and fraud issues, diagnostic analytics for identifying potential underlying causes, and predictive analytics for more effectively targeting risk-based official controls.

The report recommends incentivising food integrity data sharing among Member States' competent authorities and the European Commission, creating a public-private partnership for transitioning the supply chain to digital traceability, and developing an AI-driven predictive analytics system to support targeting control activities to supply chains where fraud is most likely. It also proposes a project to assess supply chain vulnerabilities.

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Executive summary

Policy context

The *Farm to Fork Strategy* acknowledged the need to scale up the fight against fraudulent practices while enhancing the traceability and the use of alerts to improve coordination on food fraud. The *Council Conclusions on the next steps how to better tackle and deter fraudulent practices in the agri-food chain* underline that successful action to tackle food fraud needs to be based on rapid and effective exchange of the relevant information, appropriate reporting and close cooperation and coordination between authorities within Member States as well as between the Member States and the Commission.

Digital technologies and data analytics are best suited to address those demands.

Key conclusions

A vast amount of food chain data is already available at the European level and internationally to enable the transition to a digital, risk-based approach to safeguard the food system(s). However, those data are scattered among food businesses, competent authorities in the Member States and various Commission services. In addition, databases are not always interoperable requiring time-consuming manual manipulations to prepare them for data analysis.

The European Commission could capitalise on the in-house availability of existing databases, intelligence sources and digital tools by aggregating relevant food chain information to improve (a) descriptive analytics to create a visual overview of current food safety and food fraud issues, (b) diagnostic analytics, which could identify potential underlying drivers of those issues, and (c) predictive analytics for better targeting risk-based official controls. Digital tools to support fraud investigations already exist and official control authorities as well as Commission services could profit from the experience law enforcement agencies have in using them.

Main findings

The protection of the European food system(s) requires a holistic approach by addressing suspicions and problems with advanced digital tools. The digital tools proposed in this report would scale-up the fight against food fraud and food safety issues, while providing a better overview of the European food supply chains and their vulnerabilities.

The report recommends:

— to train a machine learning model with a data set of historic fraud cases provided by the EU Food Fraud Network for assessing the feasibility of using predictive analytics for identifying cases being suspicious of food fraud;

— to encourage Member States' competent authorities to notify all food fraud cases detected by application of Article 9(2) of the Official Controls Regulation to the EU Food Fraud Network using the appropriate iRASFF channel;

— to motivate and incentivise food industry to share food fraud data and intelligence insights through an independent data trust that stewards and governs the sharing of data among industry members as well as competent authorities;

— to set up a public-private partnership to encourage and incentivise food businesses to transition to end-to-end digital traceability systems that are interoperable and allow sharing of traceability data if requested by competent authorities;

— to create a well-defined technology roadmap for setting up an Artificial Intelligence (AI)-driven Information Technology (IT) system for food integrity that integrates data aggregation and analysis by big data technologies involving experts from European Commission departments owning relevant datasets, IT professionals (back-end and front-end developers), and data scientists;

— to initiate a project aimed at constructing generic supply chain maps for a selected number of foods/ingredients where historical fraud incidence data indicate an increased risk, assess their vulnerability and identify critical points in the chain (vulnerability analysis critical control points).

Related and future JRC work

The Knowledge Centre for Food Fraud and Quality, operated by the JRC, is a suitable partner for Commission services regulating the food chain in their endeavour to enhance the protection of the European food system(s). The JRC could support the development of the required digital technology and the steering of expert groups for the vulnerability assessment of supply chains.

1 Introduction

1.1 The political and legal context

Food currently lies at the centre of political and societal discussions worldwide. Policy makers have to integrate different and often conflicting perspectives from many interconnected areas: agriculture, fisheries and aquaculture, health, environment and biodiversity, energy and mobility, trade, sustainability and circular economy, research and innovation, internal market, consumer protection.

Following a series of food scandals at the end of the previous millennium, energising the publication of the **White Paper on food safety**[1] by the European Commission, the European Union (EU) established what is globally recognised as among the best food safety legislative frameworks. The overarching **General Food Law**[2] framed the *risk analysis paradigm*[3] (i.e. the separation between risk assessment, risk management and risk communication) and the *precautionary principle*[4] around future laws and policies dedicated to food safety (e.g. crop protection, animal health and welfare, food additives, genetically modified organisms, biological hazards, etc...). The General Food Law also established the **European Food Safety Authority (EFSA)**[5] with the role of providing science-based risk assessment to help risk managers to make their decisions[6].

Although in the last 20 years the EU has established high food safety standards, food fraud had received little attention until the infamous "horsemeat scandal" in 2013, where products supposedly containing only beef were adulterated with horsemeat. Although this fraud did not pose a threat to consumer health, it had ample resonance as in many Member States horse is considered a pet, and not a commodity. Consequently, it prompted the adoption of a dedicated **Resolution from the European Parliament**[7] in 2014. The 2014 European Parliament Resolution highlights that:

- *"there is no framework in place specifically to target food fraud"*
- *"the Commission has only recently identified food fraud as a new area of action"*
- *"national authorities tend to focus their controls on food safety and do not prioritise food fraud, often due to a lack of capacity and resources"*

The 2014 European Parliament Resolution also states that food fraud cases seem to be on the rise and criminal organisations are getting increasingly involved. The European legislative framework also lacks a clear and uniform definition of food fraud.

At the moment, there is no legal definition of "food fraud" within the European legislative framework or within the *Codex Alimentarius* Guidelines. However, the European legislative framework provides clear references to food fraud and consumer protection:

- The **General Food Law**[2] protects consumers' interests, as they shall be able to make informed choices whenever buying any food product. The legislation aims at preventing food adulteration and misleading, fraudulent or deceptive practices. Food labelling and traceability are addressed as well.
- The Information Management System for Official Controls **(IMSOC) Regulation**[8] states that fraud notifications concern any "*suspected intentional action by businesses or individuals for the*

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1 European Commission (1999) White Paper on Food Safety [719 final]

2 Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 031 1.2.2002)

3 Section IV of the Procedural Manual of the Codex Alimentarius Commission 26th edition. ISBN: 978-92-5-130341-2

4 Article 191 of the Treaty on the Functioning of the European Union (OJ C 202 7.6.2016). Article 7 of Regulation (EU) 178/2002. A definition is available here: https://eur-lex.europa.eu/summary/glossary/precautionary_principle.html.

5 https://www.efsa.europa.eu/en

6 The risk management part is under the responsibility of the decision-makers, usually the European Commission and the Member States.

7 European Parliament resolution of 14 January 2014 on "Food crisis, fraud in the food chain and the control thereof" (P7_TA(2014)0011)

8 Commission Implementing Regulation (EU) 2019/1715 of 30 September 2019 laying down rules for the functioning of the information management system for official controls and its system components (the IMSOC Regulation)

purpose of deceiving purchasers and gaining undue advantage therefrom, in violation of the rules referred to in Article 1(2) of Regulation (EU) 2017/625".

— The **Food Information to Consumers Regulation**[9] states that food information shall not be misleading as regards nature, identity, properties, composition, quantity, durability, country of origin or place of provenance, method of manufacture or production, health effects/properties, special/peculiar characteristics (when compared to similar foods), ingredients not included in the final product. Mandatory food information shall be accurate, clear, and easy to understand for consumers. Voluntary food information shall not mislead or confuse consumers, and be based on relevant scientific data.

— The **Official Controls Regulation** (OCR)[10] instructs Member States' competent authorities to perform their official controls on a risk basis and with appropriate frequency, taking into account also the likelihood that consumers might be misled, with a spotlight on nature, identity, properties, composition, quantity, durability, country of origin or place of provenance, method of manufacture or production of food.

The Directorate-General (DG) for Health and food safety (DG SANTE) published a working definition of food fraud on their webpage, which uses four criteria to describe food fraud[11]: (i) violation of EU rules, (ii) deception of consumers, (iii) economic gain, and (iv) intention.

The academic community is also attempting to establish a consensus over the terminology related to food integrity and authenticity, as summarised in peer-reviewed scientific publications[12,13]. The European Committee for Standardization[14] is working as well on an official standard covering food authenticity.

The **OCR**[15] instructs competent authorities to perform official controls on a risk basis, considering not only threats to food safety but also the likelihood that consumers might be misled and the intentional violations perpetrated through fraudulent or deceptive practices. Besides official controls in the area of food and feed safety, the OCR requires competent authorities to identify possible intentional violations of the rules perpetrated through fraudulent or deceptive practices (Article 9(2)). DG SANTE and the Joint Research Centre (JRC) have jointly published a technical report[16] presenting challenges, opportunities and good practice examples in relation to the implementation of Article 9(2) of the OCR. In addition, the Commission has the empowerment to designate EU reference centres that shall support the activities of the Commission and of the Member States to prevent, detect and combat violations of the rules perpetrated through fraudulent or deceptive practices. So far, the Commission has not exercised this mandate.

In December 2019, the **Council of the European Union** adopted its conclusions[17] on food fraud. The Council stressed that food fraud generates financial losses for both consumers and food operators, threatening the internal market, and often leading to public health risks. Food fraud can also be part of organised crime. An effective strategy to tackle the phenomenon includes a rapid exchange of relevant information, and cooperation/coordination between Member States' authorities and the Commission. The Council called for a legal definition of food fraud, and for a strengthened system for exchanging information without an excessive administrative burden, ultimately developing an integrated strategy against food fraud. The Council underlined similar concepts in May 2021[18],

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9 Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers

10 Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products

11 https://food.ec.europa.eu/safety/eu-agri-food-fraud-network/what-does-it-mean_en

12 Spink, J., Bedard, B., Keogh, J., Moyer, D. C., Scimeca, J., & Vasan, A. (2019). International survey of food fraud and related terminology: Preliminary results and discussion. Journal of Food Science, 84(10), 2705-2718

13 Robson, K., Dean, M., Haughey, S., & Elliott, C. (2021). A comprehensive review of food fraud terminologies and food fraud mitigation guides. Food Control, 120, 107516.

14 https://www.cencenelec.eu/about-cen/

15 https://food.ec.europa.eu/horizontal-topics/official-controls-and-enforcement/legislation-official-controls_en#official-controls-regulation-eu-2017625

16 Winkler, B., Maquet, A., Reeves-Way, E., Siegener, E., Cassidy, T., Valinhas De Oliveira, T., Verluyten, J., Jelic, M. and Muznik, A., Fighting fraudulent and deceptive practices in the agri-food chain, EUR 31436 EN, Publications Office of the European Union, Luxembourg, 2023, ISBN 978-92-68-00336-7

17 European Council (2019) Next steps how to better tackle and deter fraudulent practices in the agri-food chain - Council Conclusions 15154/19

18 EU's priorities for the 2021 United Nations Food Systems Summit - Council Conclusions 9335/21 (31 May 2021)

mentioning the necessity to adequately trace food throughout the food chain and to effectively combat food fraud.

The European Commission's **European Green Deal**[19] (2019) is the comprehensive policy package to achieve climate neutrality by 2050, embracing various policy areas under the responsibility and influence of a plethora of actors and stakeholders, often holding diverging views. The **Farm to Fork Strategy**[20] (2020) is *"at the heart of the European Green Deal aiming to make food systems fair, healthy and environmentally-friendly"* [21]. The Strategy clearly mentions food fraud as an element jeopardising the sustainability of the EU food systems, where the European Commission, Member States, Europol and other EU bodies will need to work together to scale-up the fight against fraudulent practices. The Farm to Fork Strategy also integrates food fraud within the EU's fisheries control system and the enhancement of a dedicated traceability system.

Another priority of the European Commission, **A Europe fit for the digital age**[22], established the importance of digitalisation with a clear focus on data, technology, and infrastructure. In its **White Paper on Artificial Intelligence**[23] (2020) the Commission states that "*digital technologies such as Artificial Intelligence (AI) are a critical enabler for attaining the goals of the Green Deal*". In parallel, within the Communication on **A European strategy for data**[24], data-driven innovation is presented as a great opportunity to contribute to the Green Deal. Data are also mentioned as a tool to ensure a more efficient fight against crime. Finally, the Communication announces the creation of a "*Common European agricultural data space*" (e.g. production data, supply chain data, earth observation or meteorological data) and a "*Common European data spaces for public administrations*" (e.g. data use for improving law enforcement in the EU in line with EU law).

The European Commission's **Promoting our European way of life**[25] initiative mentions fighting against organised crime[26] (including counterfeiting, piracy and infringements of intellectual property rights[27]) as a increasing priority.

The **EU Special Eurobarometer 505**[28] highlighted that, regarding food fraud, respondents are concerned of being misled about the true qualities of food (61%) and the related potential of affecting their health (55%). In addition, 40% of respondents consider it important that food with specific characteristics (e.g. labelled as "organic") meets the EU standards.

In March 2021 the European Commission published a Communication[29] related to the action plans to promote **organic food**. In order to prevent food fraud and strengthen consumer trust, the Commission commits to ensure a robust control system and to support the development of organic fraud prevention policies, increase cooperation with the EU Food Fraud Network and Europol, support Member States to reinforce import controls at the EU border, to strengthen traceability and transparency (through e.g. digital passports and new digital technologies), and to develop early warning systems using AI for data mining.

In October 2021 the European Parliament adopted the **Resolution on the Farm to Fork Strategy**[30], highlighting the importance of tackling fraudulent practices. Efficient traceability mechanisms in the seafood sector are pivotal to guarantee food safety, transparency and to tackle illegal, unreported and unregulated (IUU) fishing, calling for a coordinated approach. The Members of the European Parliament stressed that food fraud and counterfeiting mislead consumers and distort competition

19 COMMUNICATION FROM THE COMMISSION - The European Green Deal [COM(2019) 640 final]

20 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system [COM(2020) 381 final]

21 https://ec.europa.eu/food/farm2fork_en

22 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age_en

23 European Commission (2020) White Paper on Artificial Intelligence - A European approach to excellence and trust. COM(2020) 65 final

24 European Commission (2020) A European strategy for data. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2020) 66 final

25 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/promoting-our-european-way-life_en

26 https://home-affairs.ec.europa.eu/policies/internal-security/organised-crime-and-human-trafficking_en

27 https://home-affairs.ec.europa.eu/policies/internal-security/organised-crime-and-human-trafficking/counterfeiting_en

28 European Commission, Directorate-General for Communication, Directorate-General for Health and Food Safety, (2021). Making our food fit for the future – Citizens' expectations.

29 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS ON AN ACTION PLAN FOR THE DEVELOPMENT OF ORGANIC PRODUCTION (COM/2021/141 final)

30 European Parliament resolution of 20 October 2021 on a farm to fork strategy for a fair, healthy and environmentally-friendly food system (2020/2260(INI)

in the internal market. The European Parliament called on the Commission to work on a European force against food fraud to enhance coordination between the different relevant national agencies, and to increase traceability of the supply chain as a whole.

In April 2022, the **European Food Safety Authority** published the document "*Horizon scanning exercise on preparedness for future risk assessment requirements and possible challenges in regulatory science*"[31]. Within Thematic area 5 (*Sustainable food systems and food safety*) food fraud is mentioned as an element of relevance to be monitored, especially when referred to an increase of fraud and food crimes linked to the development of sustainable food marking systems.

In September 2022, the **European Court of Auditors** concluded that "*the control systems in place to combat illegal fishing are partially effective; although they mitigate the risk, their effectiveness is reduced by the uneven application of checks and sanctions by Member States*"[32]. The report recognizes that the EU scheme has the most comprehensive coverage in terms of products (all processed and unprocessed wild-caught marine fish) compared to the USA and Japanese counterparts; the EU and USA schemes also have the broadest information requirements, increasing the overall level of detailed traceability. The report highlights that the catch certification scheme established in 2008 has improved the traceability and reinforced import control, however "the lack of digitalisation of the scheme reduces efficiency and increases the risk of fraud", posing multiple challenges (slower processing time and administrative burden, fraud risk, lack of information sharing, lost opportunity to automate control and cross-checks). Although Member States asked the Commission to develop a dedicated IT tool (the CATCH database), no Member State seems to be using it.

In October 2022, the European Parliament adopted a **Resolution**[33] on EU aquaculture, reiterating the need for a food traceability system in the EU which "*responds to consumer demands by providing information on where, when, how and what fish or aquatic food has been farmed, primarily to improve food safety but also to enable checks throughout the chain of both EU products and imports from outside the EU and to combat fraud;"* furthermore, it *"believes that this system should involve all actors in the value chain, so that they can collaborate with one another using digital systems, artificial intelligence and other technological innovations*". In addition, the European Parliament "*calls on the Commission to use digital systems and artificial intelligence to improve the traceability and sustainability of aquaculture products and to extend traceability to the feed used*".

Food fraud includes the huge financial damage it causes at the expenses of the EU's finances. Therefore, to combat food fraud, it is not enough to consider only the science and policy frameworks (and regulatory science) that underpin current food law, but the broad and expansive areas of e.g. finance, taxation and customs are equally important.

1.2 EU initiatives to fight food fraud

Since 2013, the European Commission joined forces with several EU agencies, Member States and other non-EU countries (i.e. Switzerland, Norway and Iceland) by establishing the **EU Food Fraud Network**[34]. The main goals are collaboration and cooperation by exchanging information and coordinating actions, whenever there is a violation of the European agri-food legislative framework. As an example, since 2015 the members of the EU Food Fraud Network can benefit from the Administrative Assistance and Cooperation (AAC)[35] System, a dedicated IT tool recently integrated within the Rapid Alert System for Food and Feed (iRASFF).

The **Knowledge Centre for Food Fraud and Quality**[36], operated by the JRC, was launched in March 2018 in order to build a bridge between science and policy. By combining laboratory analyses with

31 Paulović, T., Chartier, O., Zingaretti, M. C., Bertolozzi, D., Martino, G., Krüger, T., ... & Libbrecht, S. (2022). Horizon scanning exercise on preparedness for future risk assessment requirements and possible challenges in regulatory science. EFSA Supporting Publications, 19(4), 7297E.

32 European Court of Auditors, (2022). EU action to combat illegal fishing – Control systems in place but weakened by uneven checks and sanctions by Member States. Special report 20, 2022, Publications Office of the European Union

33 European Parliament resolution of 4 October 2022 on striving for a sustainable and competitive EU aquaculture: the way forward (2021/2189(INI))

34 https://ec.europa.eu/food/safety/food-fraud/ffn_en

35 https://ec.europa.eu/food/safety/food-fraud/aas_en

36 https://knowledge4policy.ec.europa.eu/food-fraud-quality/about_en

market surveillance activities, media monitoring and management of commodity-specific databases, it disseminates knowledge within the European Institutions, to competent authorities in the Member States, to industry stakeholders and to the public. In December 2018 and November 2019 the Knowledge Centre for Food Fraud and Quality organised two technical meetings with Member States' competent authorities[37]. Early Warning Systems (EWSs) and compositional databases received special attention; all Member States were of the opinion that EWSs would improve their capability to fight food fraud, although they are not in routine use in most of Member States. Member States agreed that:

a) a standardisation of food fraud definitions is necessary;

b) proactive EWSs should be developed at EU level for common use by authorities and European Commission services, but operated by a dedicated EU Reference Centre;

c) collaboration within and among Member States and with the European Commission needs improvement;

d) centres of competence (i.e. a network of official control laboratories in Member States) should share the workload of detecting fraud in the food chain.

Food 2030[38] is the research and innovation policy developed by DG RTD to transform the European food system(s). As mentioned in *Pathway 8 – Food Safety Systems of the Future*[39], the EU food safety standards would also benefit from new traceability technologies, digital innovation and authenticity systems, being areas that require further investments. *Pathway 10 – Food Systems and Data* clearly highlights that high-quality data is the currency to shape the future data-driven EU food systems, while ensuring that food is safe and not subject to fraud. A substantial number of food traceability/authenticity related research projects were selected and received funding under Horizon Europe and other past research framework programmes.

1.3 Global initiatives to fight food fraud

At the global level, the **FAO/WHO *Codex Alimentarius* Committee**[40] considers the topic of food integrity and authenticity as an emerging global issue. A number of delegations to the Committee on Food Import and Export Inspection and Certification Systems stated to have experienced food fraud in various forms, acknowledging as well a lack of adequate analytical methods to tackle the problem. Besides stating what they consider as Economically Motivated Adulteration[41] (EMA, wrongly utilised as a synonym of food fraud), the Committee states that:

- it is almost impossible for consumers to trace or confirm the integrity of a product;
- EMA is a criminal activity threatening the safety and health of consumers;
- EMA incidents negatively impact on economy, consumer confidence and businesses' reputation;
- most of reported incidents are likely just a fraction of their true number.

Codex members are supporting the development of a horizontal fraud-specific Codex guideline, highlighting the linkages between food fraud and food safety. A Guidance is currently under drafting but should not increase the burden for food manufactures and competent authorities, or cause trade barriers. Many delegations highlight the importance of food traceability and vulnerability assessments. The fight against food fraud faces however many challenges, e.g., limited access to information, lack of proper training, complexity of supply chains, and scarcity of effective detection techniques, protocols and databases.

The **United Kingdom (UK) Food Standards Agency** has commissioned the elaboration of a vision paper for information sharing in the food system to enable secure exchange of information through

37 https://knowledge4policy.ec.europa.eu/food-fraud-quality/technical-meetings-kc-ffq-1_en

38 https://ec.europa.eu/info/research-and-innovation/research-area/environment/bioeconomy/food-systems/food-2030_en

39 European Commission, Directorate-General for Research and Innovation, Fabbri, K., Froidmont-Görtz, I., Faure, U. et al., Food 2030 pathways for action – Research and innovation policy as a driver for sustainable, healthy and inclusive food systems, Fabbri, K.(editor), Ndongosi, I.(editor), Publications Office of the European Union, 2020

40 https://www.fao.org/fao-who-codexalimentarius/home/en/

41 https://www.fda.gov/food/compliance-enforcement-food/economically-motivated-adulteration-food-fraud

digital technology (data trust framework). Exchange of food fraud incidence data could be a use case for such a framework. Data are retained by the owners in their own distributed data stores and mediated by a body that eases the exchange without seeing the data itself[42]. A similar approach is used by the UK Food Industry Intelligence Network[43] to collect, collate, analyse and disseminate food chain information and intelligence among member organisations. Intelligence and authenticity data are aggregated and anonymised by an independent body (a law firm) and periodically shared with the governmental institutions so that they better understand where risks from food fraud may lay in the UK Food Industry. The UK Food Standards Agency, together with a service provider, piloted a study on the use of AI to support hygiene inspection of food establishments by prioritising businesses that are more likely to be at a higher risk of non-compliance with food hygiene regulations. Currently, this process is manual, labour intensive and inconsistent across local authorities. Using this AI-enabled tool is expected to benefit local authorities by helping them to use their limited resources more efficiently[44]. In another exploratory project the Food Standards Agency develops AI models to identify food and feed risks before they become a public health concern[45].

The **Canadian Food Inspection Agency** uses predictive analytics and data collected from the sampling and testing of food by their inspectors and other partners across Canada. Taking into account historical data and trends associated with certain combinations of foods, environmental factors, populations and hazards, the tool will use machine learning to identify trends and patterns and warn officials when food safety issues are likely to occur[46].

The **Singapore Food Agency** leverages data science to ensure that food in Singapore remains safe for consumption. The Agency monitors a wider variety of traditional and non-traditional data sources, ranging from scientific literature and test results from external laboratories, to social media posts and even public feedback to provide early-warning alerts for potential food safety issues[47]. Also the Agency shifted to a targeted data-driven approach for food safety-related inspections of food establishments, doubling the number of non-compliances detected[48].

The **Taiwan Food and Drug Administration** uses an ensemble learning model for risk prediction of imported foods to improve the efficiency and effectiveness of border controls[49].

1.3.1 USA Food Safety Modernization Act

The United States of America (USA) Food and Drug Administration (FDA) launched in 2011 the **Food Safety Modernization Act** (FSMA)[50] in order to shift the focus from responding to non-communicable foodborne diseases to preventing them. The FSMA covers different perspectives of the US food systems; however, two topics are of high relevance for this project: the new traceability requirements (section 204[51]), and the mitigation strategies against intentional food adulteration (section 106[52]). Vulnerability assessments and mitigation plans are required under the FSMA to protect food against intentional adulteration, although the focus of the FSMA *Final Rule for Mitigation Strategies to Protect Food Against Intentional Adulteration* is aimed at preventing acts intended to cause wide-scale harm to public health, including acts of terrorism targeting the food supply (i.e. food defence).

42 https://www.food.gov.uk/research/cutting-edge-regulator/food-data-trust-a-framework-for-information-sharing

43 https://www.fiin.co.uk/

44 https://www.gov.uk/ai-assurance-techniques/fsa-developing-an-ai-based-proof-of-concept-that-prioritises-businesses-for-food-hygiene-inspections-while-ensuring-the-ethical-and-responsible-use-of-ai

45 https://www.digitalmarketplace.service.gov.uk/digital-outcomes-and-specialists/opportunities/16300

46 https://inspection.canada.ca/inspect-and-protect/food-safety/more-sharing-more-safety/eng/1574450091524/1574450091977

47 https://www.sfa.gov.sg/food-for-thought/article/detail/crunching-data-for-food-safety%27s-sake

48 Singapore Food Statistics 2022. https://www.sfa.gov.sg/publications/sgfs

49 Wu, L. Y., Liu, F. M., Weng, S. S., & Lin, W. C. (2023). EL V. 2 Model for Predicting Food Safety Risks at Taiwan Border Using the Voting-Based Ensemble Method. Foods, 12(11), 2118

50 https://www.fda.gov/food/guidance-regulation-food-and-dietary-supplements/food-safety-modernization-act-fsma; https://www.fda.gov/food/food-safety-modernization-act-fsma/background-fda-food-safety-modernization-act-fsma

51 https://www.fda.gov/food/food-safety-modernization-act-fsma/full-text-food-safety-modernization-act-fsma#SEC204

52 https://www.fda.gov/food/food-safety-modernization-act-fsma/full-text-food-safety-modernization-act-fsma#SEC106

Traceability

The FSMA aims, *inter alia*, at improving traceability and requires food business operators (FBOs) to implement mitigation strategies against EMA At the moment, food firms in USA (except farms and restaurants) only need to maintain baseline record keeping covering one-step forward and one-step backward. However, such requirements proved to be insufficient to track efficiently a specific food chain in case of e.g. outbreaks or recalls. The FDA established new **electronic traceability requirements**[53] including:

- Key Data Elements (KDEs): commodity, variety, quantity, location, date, FBO name, reference document type and number, etc.;
- Traceability lot code (TLC): a descriptor, often alphanumeric, used to uniquely identify a traceability lot; once a food has been assigned a TLC, the records required at each CTE must include that TLC;
- Critical Tracking Events (CTEs): harvesting, cooling initial packing, first land-based received, shipping, receiving, and transformation. FBOs could be requested to share such data quickly and easily (i.e. within 24 hours) in case FDA will ask for such information[54]. Although all FBOs are encouraged to utilise the new traceability classification, the traceability records are mandatory for those firms (with some exemptions for e.g. small farms or restaurants) *"manufacturing, processing, packing, or holding (e.g. importing)"* high-risk foods within the Food Traceability List (FTL) established by FDA according to a newly developed risk-ranking model (*"The Model"*). The FTL includes: cheeses, shell eggs, nut butter, fresh vegetables (i.e. herbs, leafy greens, cucumbers, melons, peppers, sprouts, tomatoes, tropical tree fruits, fresh cuts fruits), seafood (finfish, crustaceans, bivalves), and ready-to-eat deli salads[55].

The Model, designed to be flexible, values pairs of commodities VS hazards according to seven parameters: a) frequency of outbreaks and occurrences of illnesses; b) severity of illnesses; c) likelihood of contamination; d) the potential for pathogen growth, with consideration of shelf life; e) manufacturing process contamination probability and industry-wide intervention; f) consumption rate and amount consumed; f) cost of illness.

Traceability records must be provided within 24 hours of a FDA request, usually in case of an outbreak, recall or threat to public health.

Another highlighted benefit from improved electronic end-to-end traceability is the higher standards of data quality automatically gathered and collectively assessed by FDA authorities, with opportunities to perform predictive analytics with AI as well. On 1 June 2021 FDA launched a public call to "*to develop traceability tools that can be implemented in a scalable, cost-effective way for food operations of all sizes*"[56,57]. The challenge covers tech-enabled traceability solutions appropriate for primary producers, manufacturers, industry, importers, distributors, retailers and foodservices.

Intentional food adulteration

The final rule on intentional food adulteration[58] addresses mostly large companies, while exempting feed producers, farms and small food firms. The rule requires companies to create a **food defense plan** that includes vulnerabilities and actionable process steps, mitigation strategies, procedures for food defense monitoring, and corrective actions and verification. The FDA has also published a Food Defense Plan Builder[59] designed to help owners and operators of a food facility in the development of a food defense plan.

Therefore, the FSMA approach to food fraud establishes a direct involvement of food companies in preventing (through risk-reducing mitigation strategies) adulteration activities taking place within

53 https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-proposed-rule-food-traceability

54 https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-requirements-additional-traceability-records-certain-foods

55 https://www.fda.gov/food/food-safety-modernization-act-fsma/food-traceability-list

56 https://www.fda.gov/news-events/fda-voices/fda-seeks-innovative-food-traceability-tools-and-opens-dialogue-advancing-food-safety-technology

57 https://precision.fda.gov/challenges/13

58 https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-mitigation-strategies-protect-food-against-intentional-adulteration

59 https://www.fda.gov/food/food-defense-tools/food-defense-plan-builder

their premises, rather than envisioning a public-private collaboration aiming at tackling the food fraud phenomenon (as in the case of the food safety strategy).

New Era of Smarter Food Safety

On 13 July 2020, the FDA released the *Blueprint for the New Era of Smarter Food Safety*[60]. The document represents the collective thinking of "*FDA food safety experts, consumers, the food industry, technology firms, federal and state regulatory partners, our regulatory counterparts in other nations, and academia*". The blueprint frames the USA strategy for the next ten years, with the final objective of creating a risk-based prevention-oriented regulatory framework. The core elements are:

— **Tech-enabled traceability**: the document highlights the importance of e.g. digitalisation, AI, Internet of Things (IoT), blockchain, sensor technologies, whole genome sequencing and enhanced analytics. Standardisation and interoperability of data is key for successful and swift tracebacks and traceforwards along the affected food chain.

— **Smarter tools and approaches for prevention and outbreak response**: FDA is planning to utilise big-data predictive analytics to assess the information gathered through the new traceability system, in order to e.g. foresee/mitigate the next vulnerabilities, strengthen root cause analysis procedures, or more easily recall from the market any contaminated product. Machine learning and AI represent valuable opportunities to be explored in this context.

— **New business models and retail modernization**: because restaurants and other retail establishments remain the most usual source of foodborne illness outbreaks, FDA is looking at new ways to protect consumers by changing behaviours and practices, with a special attention on the emerging e-commerce, new delivery models, and new food ingredients and production technologies.

— **Food safety culture**: only by promoting education, training and intervention strategies all along the USA food chain it shall be possible to reduce dramatically the burden of foodborne diseases, especially with the help of dedicated tools and user-friendly technologies (e.g. smartphone apps).

As the USA import 94% of its seafood supply, the FDA has run a pilot of its *Artificial Intelligence (AI) Imported Seafood Pilot program*[61,62] in order to react quickly to imported seafood potentially posing a threat to public health. The pilot utilised Machine Learning to target seafood shipments.

Next to the *Artificial Intelligence Imported Seafood Pilot Program* of FDA, PREDICT (*Predictive Risk-based Evaluation for Dynamic Import Compliance Targeting*) is a risk-based analytics tool FDA uses to electronically screen all regulated shipments imported or offered for import into the USA. It uses data mining, pattern discovery, and automated queries of FDA databases to determine the potential risk of a shipment[63].

60 https://www.fda.gov/food/new-era-smarter-food-safety/new-era-smarter-food-safety-blueprint

61 https://www.fda.gov/food/cfsan-constituent-updates/fda-moves-second-phase-ai-imported-seafood-pilot-program?utm_medium=email&utm_source=govdelivery

62 https://www.fda.gov/news-events/fda-voices/import-screening-pilot-unleashes-power-data-and-leverages-artificial-intelligence

63 https://www.fda.gov/industry/fda-import-process/entry-screening-systems-and-tools

1.4 The Food Risk Matrix

The EU legislative framework does not provide a legal definition of "food fraud", although the topic is indirectly addressed in several laws and the academic community has already provided an overview of the terminology available on the topic. The Food Risk Matrix[64] (Figure 1) describes the artificial boundaries between the four domains and the associated risks affecting the food system(s):

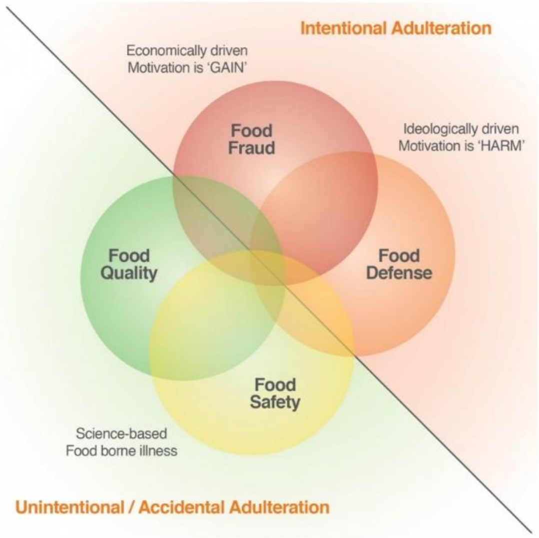
— Food quality risk: an unintentional act resulting in food not meeting the stated or required attributes or standards;

— Food safety risk: an unintentional act that results in a food product that poses a health concern;

— Food fraud risk: an intentional act on a food product motivated economically and not intended to harm consumer health;

— Food defense risk: an intentional act on a food product with the intention to harm the public health (e.g. terrorism).

Figure 1: The Food Risk Matrix.



Source: Food Microbiology Academy.

Providing assurance to consumers and other stakeholders about the safety, authenticity and quality of European food is pivotal to safeguard consumer health and guarantee the correct functioning of the internal market. Incidents related to food safety, quality, fraud, or food defense often can be hardly categorised precisely when signalled. Therefore, the lack of clarity should lead to the precautionary assumption that a non-compliance may potentially be a food fraud with intrinsic food safety risks, unless proven otherwise. As a clear categorisation of non-compliances is a rather theoretical exercise, it is essential to address any non-compliance applying a holistic and standardised approach, regardless of the category/categories eventually assigned to (sometimes after a lengthy investigation). For example:

- A non-compliance without food safety risks may affect food quality or be a food fraud, but the intention of the food business operators (FBOs) may not be so easily proven. A bottle of virgin olive oil mislabelled as extra-virgin olive oil could be the result of an involuntary loss of organoleptic properties over time (e.g. because of storage conditions) or it could happen because the FBO has intentionally sold low-quality olive oil as a more expensive one for financial gain;
- A food fraud may be ultimately uncovered because of the food safety risks initially identified by food safety authorities. Only later national enforcement authorities are able to demonstrate the intention and the financial gain of the fraudulent FBO. Replacing nuts with cheaper peanuts (a known allergenic food) without correctly labelling the product may have severe health consequences for consumers allergic to peanuts, but the enforcement authorities may uncover the fraud only in a second stage of the investigation, sometimes after many consumers have been already impacted by the fraud (initially regarded only as a food safety problem);
- A non-compliance with food safety standards may relate to food safety or food defense, but proving the intention requires an internal investigation by the FBO. Glass pieces found in meatballs may be the result of an unintentional lack of attention by the operators within the production plant, or the intentional sabotage performed by an employer for personal reasons or on behalf of third parties (e.g. retaliation or terrorism).

64 Spink J, Embarek PB, Savelli CJ et al. (2019) Global perspectives on food fraud: results from a WHO survey of members of the International Food Safety Authorities Network (INFOSAN) npj SciFood 3,12

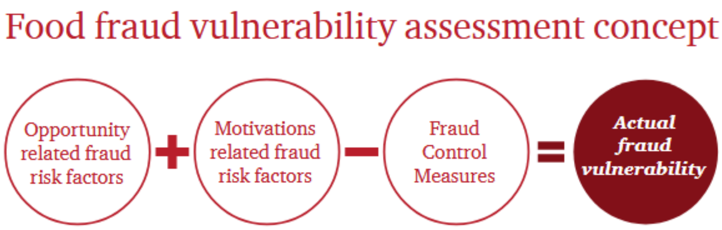
In summary, because the classification of the food risks cannot be always precise and straightforward, **the same approach, methodology and process should be applied to every non-compliance affecting the food system(s), not to ignore or underestimate potential threats to consumer health**.

1.5 Tools to fight food fraud and root causes ("drivers")

Strategies to detect and prevent food fraud broadly fall into two categories: scientific analysis to test the authenticity of foods, and broader mitigation strategies including (i) intelligence gathering, (ii) vulnerability assessments and (iii) economic analysis strategies.

A widely accepted criminology theory, the "**routine activity theory**", sees crime as the outcome of the convergence in time and place of (1) motivated offenders and (2) suitable targets in (3) the absence of capable guardians, which, translated into a food context, represents a triangle defined by (i) opportunities (suitable targets), (ii) motivation (motivated offenders) and (iii) control measures (guardianship)[65]. **Food fraud vulnerability assessments** (FFVAs) identify weaknesses or flaws that create opportunities for food fraud (Figure 2).

Figure 2: Food fraud vulnerability assessment concept.



Source: Food fraud vulnerability assessment (PwC, SSAFE).

A report[66] commissioned by the UK Department of Environment, Food and Rural Affairs considered as root causes of food fraud either macro-economic factors (e.g. drivers of commodity price movements, which provide an opportunity and profit incentive) or micro-economic factors that influence the individual decision of a fraudster. Main drivers of food fraud are[67]:

- Scarcity of raw ingredients can drive prices up and increase the use of alternative ingredients in food production. The concentration of retailers into global chains can cause pressure on food prices, meaning suppliers may cut corners to compete for contracts;
- Consumer demand for foods with special characteristics, such as provenance and ethics which are both expensive to source and easy to imitate;
- The length and complexity of global food supply chains can lead to a lack of traceability, making food fraud harder to detect;
- Criminals may use the internet to carry out illegal trade or pose as a legitimate business in order to infiltrate supply chains;
- Penalties for food-related crimes are generally lower than for other criminal activities.

A comprehensive strategy to combat food fraud would not only try to detect product fraud and identify and prosecute the perpetrator(s) but would also focus on preventive measures. Situational crime prevention theory seeks to minimise the opportunities and increases the risks to deter

65 van Ruth, S. M., Huisman, W., & Luning, P. A. (2017). Food fraud vulnerability and its key factors. Trends in Food Science & Technology, 67, 70-75.

66 https://randd.defra.gov.uk/ProjectDetails?ProjectId=20179

67 https://post.parliament.uk/research-briefings/post-pn-0624/

potential offenders[68]. Until recently, public policymaking in the food domain has concentrated on protecting public health, with great success. However, the current risk analysis approach for food safety has to be overhauled to deliver the evidence and guidance for developing policies to minimise food fraud incidents[69].

Several food safety management systems, which are widely applied to ensure compliance with EU food law, recognised the importance of food fraud as a risk factor and included FFVAs and mitigation plans in pre-requisite programmes for certification (Table 1).

Table 1: Benchmarking requirements for Global Food Safety Initiative recognised certification of food safety management systems.

Food fraud vulnerability assessment	The standard shall require that the organisation has a documented food fraud vulnerability assessment procedure in place to identify potential vulnerability and prioritise food fraud mitigation measures
Food fraud mitigation plan	The standard shall require that the organisation has a documented plan in place that specifies the measures the organisation has implemented to mitigate the public health risks from the identified food fraud vulnerabilities

Source: Global Food Safety Initiative, 2018.

EU food hygiene legislation[70] requires FBOs to have a Hazard Analysis and Critical Control Points (HACCP) programme in place but does not prescribe a risk assessment targeting potential fraud opportunities.

The **EU General Food Law** (Regulation 178/2002) defines traceability as the ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all stages of production, processing and distribution. Although the main use of food traceability is to minimize the potential health risks associated with unsafe food by identifying and locating the contamination source, it can provide transparency to supply chains. Documented traceability in turn can help establishing the authenticity of ingredients by tracking their origin and monitoring their handling and processing. Records typically include information about the origin of the ingredients, production processes, packaging, and distribution. They provide transparency to supply chains and enable stakeholders to identify and resolve issues efficiently.

According to Article 18 of the General Food Law, traceability shall cover all stages of the food chain, from production to distribution (i.e. from farm to fork). FBOs should apply the "one step forward – one step backward" principle, i.e. being able to provide on demand any information related to the suppliers and customers of a specific suspected product.

In order to satisfy the legal traceability requirements, FBOs should keep at least the following information:

— Name, address of supplier, and identification of products supplied

— Name, address of customer, and identification of products delivered

— Date and, where necessary, time of transaction/delivery

— Volume, where appropriate, or quantity

Major FBOs usually have in place traceability systems of various forms, linking their supplies with the final products, for internal purposes and to quickly recall finished products in case of need.

68 Lord, N., Spencer, J., Albanese, J., & Flores Elizondo, C. (2017). In pursuit of food system integrity: The situational prevention of food fraud enterprise. European Journal on Criminal Policy and Research, 23, 483-501.

69 Spink, J., Hegarty, P. V., Fortin, N. D., Elliott, C. T., & Moyer, D. C. (2019). The application of public policy theory to the emerging food fraud risk: Next steps. Trends in Food Science & Technology, 85, 116-128.

70 Regulation (EC) No 852/2004 of the european parliament and of the council of 29 April 2004 on the hygiene of foodstuffs

However, traceability data are scattered across private actors along the food supply chain in a non-harmonised and fragmented manner, neither immediately available to one single operator within the supply chain nor to the authorities. In case of need, EU and national authorities have to contact each individual FBO to track problematic lots along the food supply chain. Such practice delays the identification of the non-compliant lot. It requires considerable efforts to manually cross-check various data sources to create a coherent picture of the flow of the ingredients, the actors involved, and the relationship(s) among them.

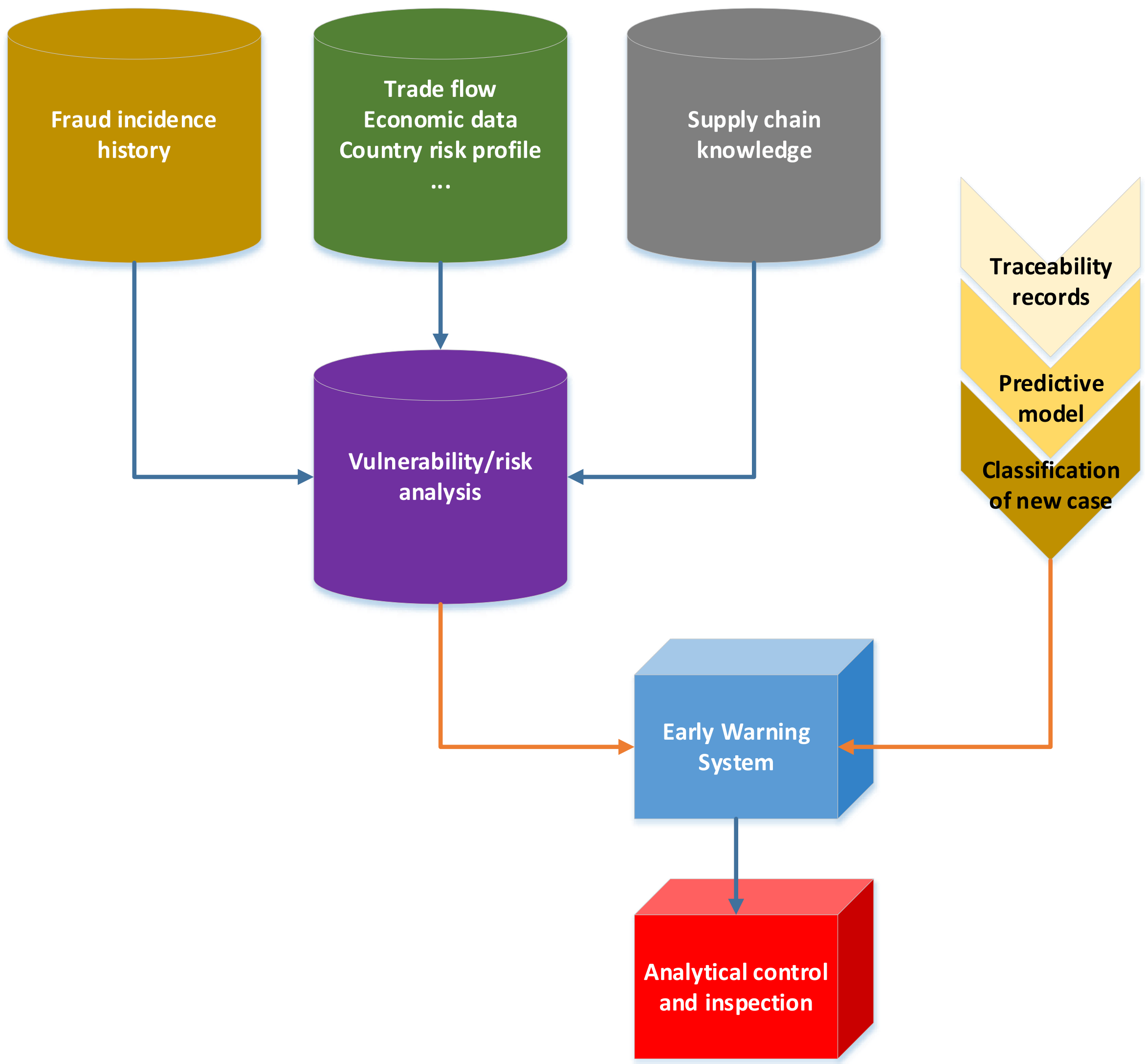
One of the limitations of the current EU traceability systems is the "one step forward – one step backward" principle, which does not provide end-to-end transparency of a supply chain. Another weakness is the lack of a technology platform to aggregate data from diverse (manual or electronic) record keeping systems, which could be interrogated by operators and authorities in situations requiring product tracing in response to a food safety or fraud issue. Today's food supply chains might be complex and rarely transparent. Together with the clandestine nature of fraud, it makes it difficult to detect illegal manipulations of food, let alone to predict where fraud incidents may occur.

Only the integration of various knowledge and intelligence sources can provide an indication of what is happening undetected or what might happen in the future. Intelligence gathering involves collecting and analysing information from various sources to identify and understand the methods, patterns, and actors involved in fraudulent activities within the food industry. Advanced data analytics, machine learning (ML), and AI can be employed to process and analyse large volumes of data, helping to recognise irregularities in the data, detect potential fraud indicators, and highlight areas that require further investigation. Intelligence can be collected from open sources (e.g. Internet and media reports), in specialised databases reporting food fraud cases (e.g. iRASFF) or databases that can be used to derive indicators related to geopolitical risks.

For example, Bayesian network models have been used to compute probabilities of frauds in the food system. Among the drivers included in the Bayesian networks were price of the product, trade volume, country of origin, indices for perceived corruption, and price spikes. Another screening tool uses import statistics and time-series analysis tool to identify statistically relevant changes in commodity flows and prices, with subsequent analysis of the flagged cases by subject matter experts.

Authenticity testing using a broad range of detection methods is considered as the ultimate proof that a product is in its original, genuine, verifiable and intended form as declared and represented ("true to the name"). As food testing is a resource intensive process, an information system that directs testing activities into areas where fraud incidences are more likely to occur would be beneficial to control authorities as well as honest FBOs and their service providers. Targeted surveillance optimises usage of resources, economise testing and increase the probability of uncovering illegal activities. Figure 3 visualises the interplay of different knowledge sources and strands of activities that informs an EWS, which in turn enhances the efficiency and efficacy of authenticity testing.

Figure 3: Elements of an integrated system for detection and mitigation of food fraud.



Source: JRC.

2 Scope and objectives

A comprehensive strategy to combat agri-food fraud not only attempts to detect product fraud and identify and prosecute the perpetrators, but should also focus on preventive measures. Horizon scanning to collect weak signals of irregularities, validating and synthesising them into actionable intelligence can play an important role in this respect. The knowledge outcomes can inform agri-food fraud risk assessments and vulnerability analysis of supply chains, and help targeting control activities of competent authorities. It will help to increase the resilience of the agri-food system to fraudulent manipulations and create hurdles to deter fraudsters. Deployment of modern information and communication technology that can combine different existing data streams and create a "big data" pool is a prerequisite for data-driven discovery of irregularities, indicative of possible non-compliance with the EU food law.

An IT platform for integrating, synthesising and analysing information collected from different data sources is a key element for generating warning signals and trends of fraudulent manipulations along food value chains to support the fight against agri-food fraud. Furthermore, the platform would not only be used as an EWS but boost the ability of services to trace and connect relevant information of actual fraud cases in a more efficient way.

Objectives

The main study objective was the exploration of design options for an **IT platform to integrate and analyse agri-food fraud related information** for creating early warning signals of fraud and to support handling of suspicious cases.

To achieve the objectives, a scoping study for the design of an IT tool to integrate and analyse food integrity related information was undertaken, comprising of the following tasks:

- Investigate which relevant IT systems already exist for collecting and analysing relevant information related to food integrity, and for detecting fraud in the wider sense, taking account of the price of commodities, trends of imports from third countries and administrative measures put in place by EU Member States (e.g. border closures, redirection of trade flows);
- Identify relevant data sources curated by various Commission services that can be used for data driven discovery of hidden connections;
- Collect the needs of Commission services for AI analytics for managing agri-food fraud cases and predictive modelling to detect irregularities in the food supply chains they regulate;
- Formulate use cases in close cooperation with the concerned services and map out the desired functionalities of the IT tool to identify commonalities and potential synergies for optimal use of resources during software deployment/development;
- Evaluate conditions (e.g. the need for a legal basis) to enable data sharing and its use for the creation of the IT system for food integrity;
- Assess the option of integrating the existing IT systems for exchanging food safety relevant information to benefit from synergistic effects of a comprehensive system to safeguard food integrity;
- Synthesise the gathered information into basic design requirements for the development/deployment of the desired IT tool.

Producing the IT tool is outside the scope of the project.

3 Methodological approach

The report collects and summarizes the needs shared by experts in the fields of food fraud, food safety, customs, trade, information technology and criminology, describing the functionalities of an ideal IT tool which could theoretically support the experts in their daily activities to scale up the protection of the EU food systems. Interviews were carried out separately with experts from the public and, in one case, from the private sector.

Further interviews were carried out with colleagues across several European Commission services to understand which databases, IT tools and intelligence sources are already available at EU level to be exploited in order to address the needs shared during the interviews. In most of the cases the information shared were confidential or EU-sensitive, therefore they have been recorded for future use but not referenced within this document.

Desk research was carried out to identify other databases, IT tools and intelligence sources from public or international organisations, or developed by the private sector. Resources from private companies were recorded for internal use but not shared within this document in order not to give an undue advantage and visibility to some companies over others.

Grey literature and academic papers were analysed to provide solid scientific bases to the report, to identify the relevant food fraud drivers to be addressed and to provide concrete recommendations on how to proceed with the next steps. Such desk research cannot be considered a comprehensive review or meta-analysis for reasons of time constrains and limited resources.

The European legislation and the *Codex Alimentarius* documentation has been scanned and investigated in order to show the perspective of the international community and to provide legal bases to some recommendations within the text.

4 The needs of the different Commission Services

Several interviews were carried out within Commission DGs and EU Agencies in order to understand the needs that the data-driven IT tool should cover, and the functionalities that would support the daily activities in each DG. An overview of keywords extracted from the interview transcripts is given in Figure 4.

Figure 4: Word cloud created from the interviews.

Source: JRC.

Considering all the needs expressed so far, an information-based risk analysis IT tool for protecting and monitoring the European food systems should be framed around three different work streams: **data collection**, **data analysis**, and **data deployment**. In simple terms, it should analyse data by ML tools and/or AI to discover and flag irregularities ("warnings") that require subsequent interventions by subject matter experts.

The system should provide three main functionalities:

1. an **insight capacity** giving an overview of non-compliances in real-time ("*what is happening*"), scaling up the existing food traceability system in the EU, and mapping supply chains. The use of ML/AI shall support EU and Member States officials to discover hidden data connections in the existing databases that are difficult to uncover manually, given the vast amount of data, especially in case of non-compliances notified by national food fraud and food safety authorities. For example, at the moment national authorities and EU institutions have to invest a considerable amount of time to manually reconstruct the traceability chain of non-compliant product(s) by contacting individually FBOs, whereas improved interoperability of existing databases could dramatically cut the time needed to create a comprehensive traceability record of a product, which is key for successful and swift trace-backs and trace-forwards along the affected food chain.

2. an **investigative capacity** at EU and global level. Too often fraudulent companies or individuals evade detection and deceive investigators by e.g. changing names, subcontracting third companies, or simply by selecting specific entry points in the supply chains more vulnerable than others. The system shall provide capabilities for:

- matching satellite images with the company address to reveal unauthorised/illegal premises or fake addresses, clearly not suitable to store food products according to the quantities declared;
- matching scanned documentation with templates of Certificate of Analysis in order to reveal part of the documents manually removed or amended, thus hiding non-compliant values for specific contaminants (i.e. document forgery);
- matching harvesting areas, claimed on e.g. seafood documentation, against their opening seasons and location;
- matching logos and third-party certificates in the submitted documentation against authentic labels, photos and company websites and official registries, revealing non-conformities and misalignments;
- identifying excessive earnings or profit increases, matching outliers between annual profit and company size;
- an automatic warning in case national authorities mark a consignment erroneously as "valid" even if e.g. the documentary check is not satisfactory;
- hidden connections and suspicious patterns among buyers and suppliers, revealing the identity of often the same individual/company (the "bad players") behind recurrent food crimes;
- wrong declaration for CN codes in order to pay less taxes or avoid detection.

3. an **anticipatory capacity** (i.e. predictive analytics) in order to re-direct risk-based official controls in the Member States to specific food supply chains more vulnerable to frauds and safety threats ("*what will happen*?"). The use of digital tools shall support EU and Member States officials to not only train the IT system with data from selected databases and results from real-world investigations (i.e. supervised learning), but also with potential for self-learning without being explicitly programmed via training (i.e. unsupervised learning), ultimately improving its predictive analytics capabilities. Model validation by subject matter experts is needed only the first time a new pattern is uncovered, thus resulting in an automatic signal in case a similar anomaly is registered. Relevant parameters to model a supply chain vulnerability and predict future non-compliances should include at least the three main categories: a) prices of commodities; b) trends of EU imports; and c) administrative measures between countries.

The system shall be a public-public partnership, since the data are too sensitive to be shared with business operators.

Relevant food integrity databases managed by the EU Institutions are not always user-friendly and lack important functionalities (e.g. query functions, data visualisation) and interoperability. They need to be modernised before integration into a future IT system that should be more agile, efficient, frequently updated, aligned with the users' needs, and interconnected to other IT systems of relevance. In addition to EU Institutions and Member States, also the competent authorities in third countries should be able to feed (but not necessarily access) the future IT system, being considered an important source of information and intelligence.

The design of the new system should be flexible enough to cover the whole Food Risk Matrix (food fraud, food safety, food quality and food defense) in case of need and future interest. The methodological approach and the architecture of the future IT system may contribute to the development of similar approaches in areas unrelated to food.

Data quality has to be ensured following the FAIR principle (Findable-Accessible-Interoperable-Reusable) even if the data is only available to authorised users. Multilingualism and standardised text (e.g. pre-generated lists) should be implemented as much as possible, in order to avoid free text.

The system should improve and ease information sharing. All actors potentially interested in non-compliances, signals and trends should be informed, while clearly indicating which legislative framework has been infringed (e.g. general food safety legislation or the organic one). At the moment, the same non-compliance notification may be of relevance for more than one IT system, but such information is often not shared (e.g. a non-compliance on organic food notified in TRACES that should be notified in OFIS as well). Notifications should be sent automatically by the system but validated/confirmed manually later by Member States' officials. Fraudulent operators may potentially be beneficiaries of EU funding; therefore funding bodies should be informed automatically whenever funded entities have infringed the law (e.g. frauds in the organic sector performed by companies funded under the Common Agricultural Policy). Similarly, external auditors (e.g. in case of third party certifications) should be informed whenever there is a non-compliance detected in a company certified by their accredited auditing firm.

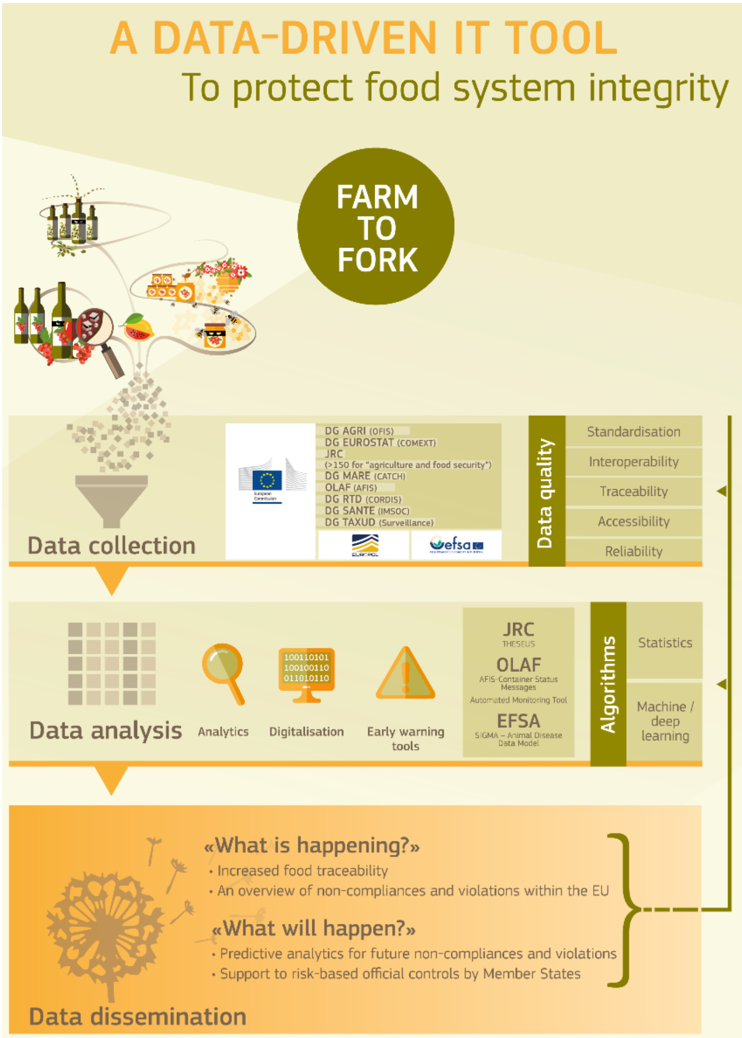
A clear advantage of the development of such an IT tool would be a better understanding of EU and global markets. Prices, quantities, trends, trade flows, are all of clear interest for many actors within the EU Institutions who perform market analysis.

5 The tripartite structure of the project

Addressing the needs expressed by the stakeholders will require the creation of an integrated IT infrastructure managed at EU level and supporting the competent and enforcement authorities in the Member States. There are a number of tools and data source for building the IT system currently available. In addition, suggestions for improving the functioning of current systems, which would need further developmental work and/or require amendments to the existing legislation, are also offered. The suggestions are intended to trigger the discussion and attract resources to expand the current IT systems and to align it better with the needs of the user community.

The core of the report is divided into three sections: **data collection**, **data analysis**, and **data (model) deployment** (Figure 5). Each of the three sections encompasses various perspectives (e.g. legal, scientific, political, financial, technical, societal), all relevant to be considered holistically for the success and acceptance of the future IT system.

Figure 5: Conceptual overview of the tripartite structure of the IT system.



Source: JRC.

In summary, the ideal IT system should connect all relevant data sources via an EU/supranational data warehouse (managed at EU level), analyse the data by deploying approaches/functions aligned with the needs described previously, and ultimately delivering the results to personnel of the EU and Member States' (a) food safety authorities; b) police/enforcement authorities; c) and customs authorities. Data quality is pivotal for the success of the exercise (Annex 1).

5.1 Existing data and intelligence collection tools

Food systems generate different types of data: finance (prices), customs (container, export and import destination, origin), traceability (lot number) and safety checks (official controls), to name a few. Many food products may bear Geographical Indications or certification scheme logos (e.g. organic) in addition to labelling requirements mandated by the EU legal framework. Member States' control authorities perform regular checks at the EU borders and within the internal market, but their database are mostly not interconnected and inter-operable, meaning that data cannot be shared between the different Member States or between different competent authorities in a same Member State.

Many databases are not freely accessible because their access is restricted to some public authorities or they may be available after paying an annual fee. However, the amount of data collectively available in some databases and intelligence sources is enough to build an effective and fully functional system in order to fulfil most of the needs expressed by end users.

Examples of existing databases, intelligence tools and IT systems, which can be useful sources for creating a dedicated food integrity information system are summarised in Table 2 (databases/tools may serve more than one sector). The databases managed by the private sector were not included in this report, although these have been taken into consideration for the overall analysis.

Table 2: Summary of existing relevant databases, intelligence sources and IT systems.

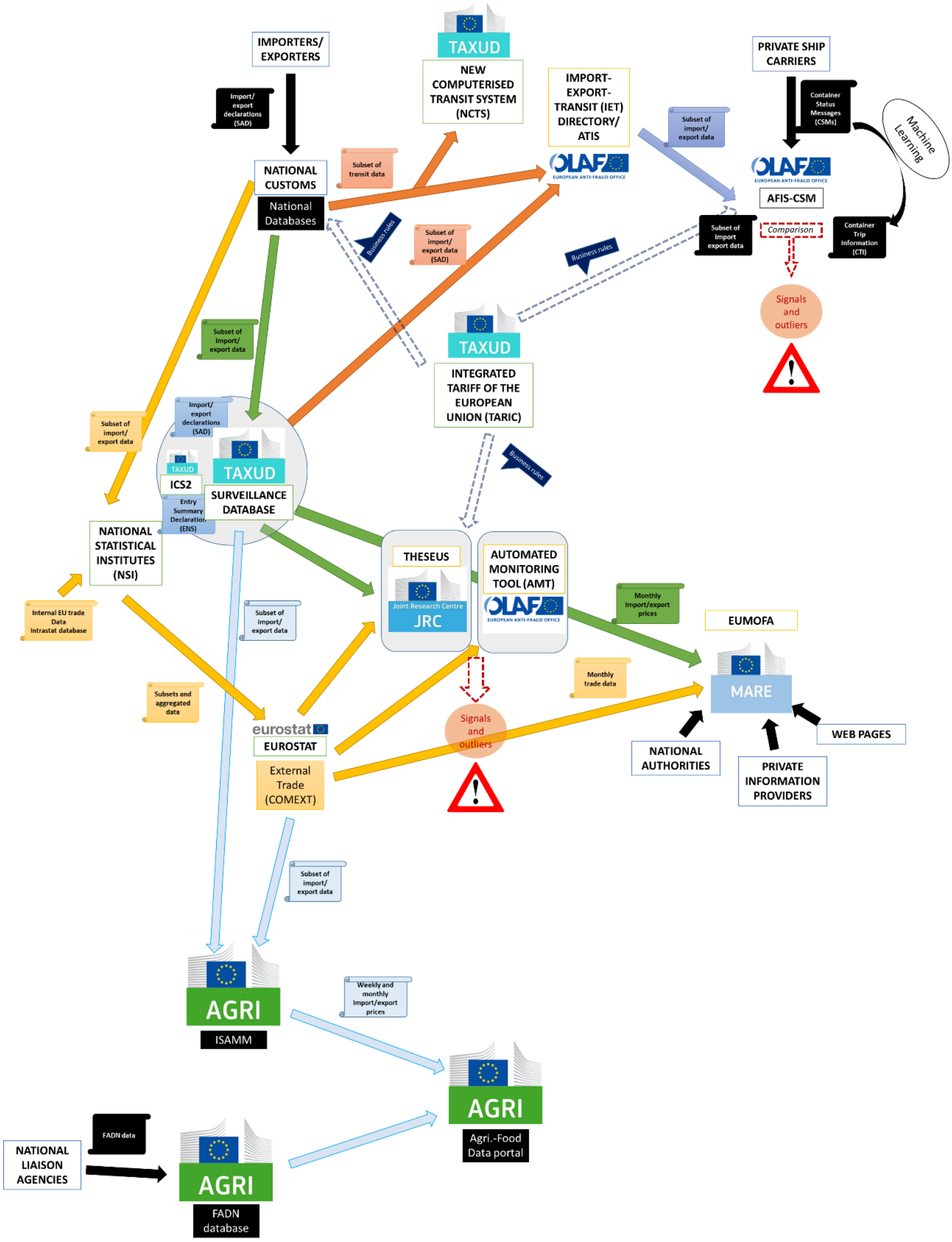
Sector	Acronym	Name	Owner
Trade	AFIS	Anti-Fraud Information System	OLAF
		Crisis Impact Analysis	DG TAXUD
		JRC Dashboard - Trade Flow Analysis for Structural Breaks	JRC
	AMT/THESEUS	Automated Monitoring Tool/THESEUS	OLAF/JRC
	COMEXT		DG Eurostat
	Comtrade		United Nations
Customs and imports	AFIS-CSM	Container Status Messages	OLAF
	ICS2	Import Control System 2	DG TAXUD
	NCTS	New computerised transit system	DG TAXUD
	SURV3	Surveillance 3	DG TAXUD
	TARIC	Integrated Tariff of the European Union	DG TAXUD
Agri-Food markets	AGRIDATA	Agri-food Data Portal	DG AGRI
	AMIS	Agricultural Market Information System	DG AGRI
	ASAP	Anomaly Hotspots in Agricultural Production	JRC
	EFSCM	European Food Security Crisis preparedness and response Mechanism	DG AGRI
	EUMOFA	European Market Observatory for Fisheries and Aquaculture	DG MARE
	ISAMM	Information System for Agricultural Market Management	DG AGRI
	MARS Bulletin	— Monitoring Agricultural Resources Bulletin	JRC
		OECD-FAO Agricultural Outlook	OECD-FAO
Alert and cooperation networks	ADIS	Animal Disease Information System	DG SANTE
	CATCH		DG MARE
	EUROPHYT		DG SANTE
	OFIS	Organic Farming Information System	DG AGRI
	iRASFF	Rapid Alert System for Food and Feed	DG SANTE
	TRACES	TRAde Control and Expert System	DG SANTE

Food Fraud	iRASFF-FF	Administrative Assistance and Cooperation – Food Fraud	DG SANTE
Investigations	EIS	Europol Information System	Europol
	GetI		OLAF

Source: JRC.

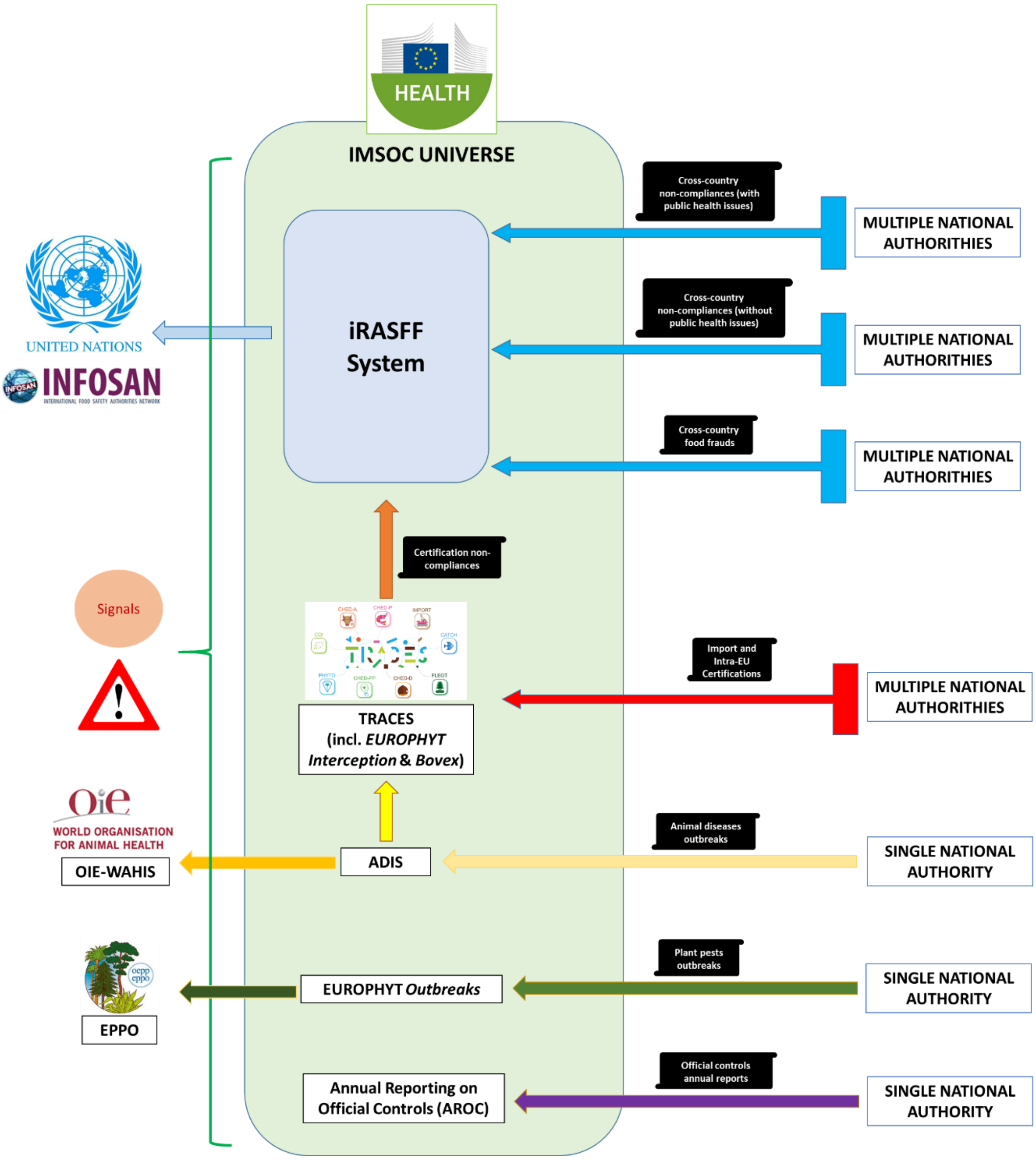
Some databases are already partially interconnected and they communicate with each other at some extent. An overview of connection between some EU and global databases is provided in Figure 6 and Figure 7.

Figure 6: Data flows between some of the EU and national databases.



Source: JRC.

Figure 7: Data flows between some of the EU, national and international databases.

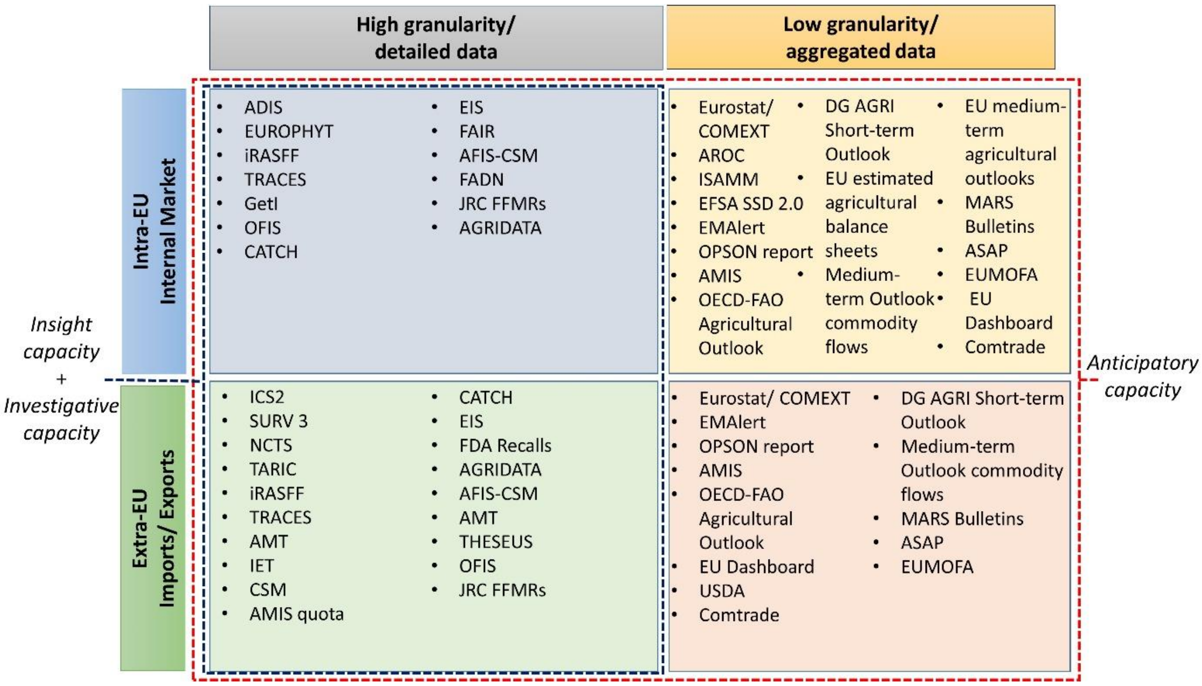


Source: JRC.

Whereas the databases and IT tools with a high data granularity may potentially feed all three capacities fulfilled by the proposed IT system (*insight*, *anticipatory* and *investigative*), most intelligence sources and some databases are useful to build only the *anticipatory capacity*, as they work on trends and big numbers.

Figure 8 classifies the various databases (excluding private databases), intelligence sources and IT tools in four categories according to two parameters: **internal market *vs* imports**; and **high data granularity *vs* low data granularity**. The same database, IT tool or intelligence source may fall into more categories.

Figure 8: Classification of the databases, IT tools and intelligence sources according to the level of granularity and geographical coverage. While all sources may contribute to the anticipatory capacity of the ideal IT tool, only sources characterised by a high granularity may feed the insight and investigative capacities.



Source: JRC.

Most of the information required to build the *anticipatory capacity* and the *investigative capacity* seem already available (although not immediately accessible) in one or more of the analysed databases, IT tools and intelligence sources. The *insight capacity* is fully developed in terms of imports of products entering the EU, which are possible to monitor with high granularity. However, the *insight capacity* in the internal market is compromised by the lack of three sets of crucial data:

1. **Traceability data** of the food supply chain. While the EU possesses highly granular data for products of animal origin imported through a Border Control Post, whatever happens in the internal market is not directly accessible to public authorities. FBOs have the legal obligation to record only their suppliers and their customers; the authorities may request such data in the context of an investigation, but the process can be inefficient and data are not always available in time and in sufficient quality. As a consequence, public authorities are oblivious to the connection between FBOs (the "*food supply maze*") and, if needed, they do not have a clear overview of the full traceability, affecting as well part of the *investigative capacity*.

2. **Laboratory analyses and authenticity tests** performed by the food industry. Collectively, the amount of analysis performed by the food industry dwarfs those performed by competent authorities in the Member States. In line with several food defence guidelines, the food industry (especially companies with a high turnover) usually invests large resources to build trustworthy supply chains, especially when a new supplier is assessed at the beginning of a contract. Those data are not shared with governmental authorities, therefore frauds affecting the food industry are taken care of internally by the food industry (between supplier and buyer), with the consequence that a criminal operator may affect simultaneously several other FBOs because those affected do not communicate between themselves nor to a third neutral knowledge-broker. For reasons of preserving its commercial strategy, the food industry is reluctant to share information about its suppliers.

3. Data from **official inspections** performed by competent authorities in the Member States. Although many Member States' competent authorities publish annual reports or news on their websites, Member States are obliged to share only cross-country (i.e. affecting several

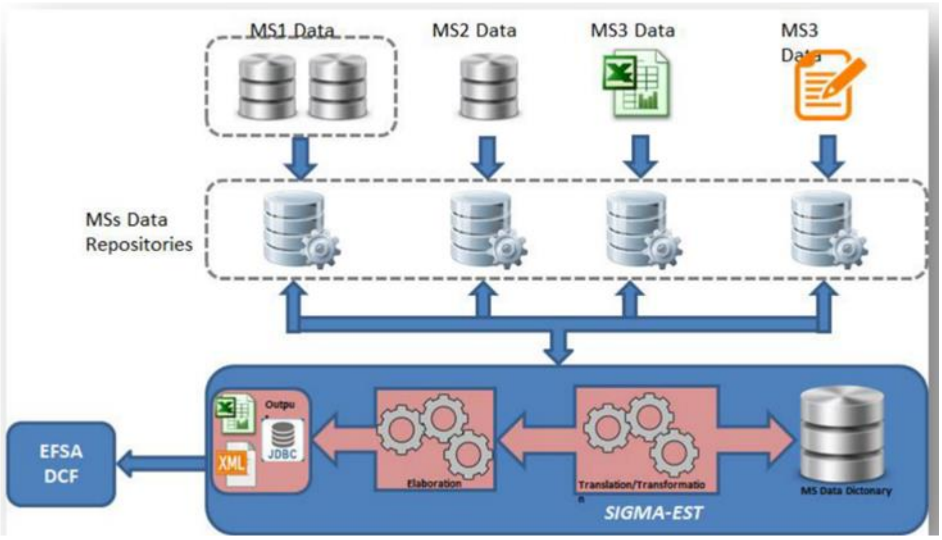
Member States) non-compliances, in terms of food fraud (iRASFF, OFIS). There is a lack of overview of the full range of national non-compliances and the related data, which may range from authenticity tests to criminal investigations. In addition, the same non-compliance may be dealt with differently according to the authority who is in charge of the case: customs, food safety agencies and the police approach the same case differently and do not necessarily communicate with each other, compromising potentially the success of the investigation. In addition, a tighter coordination between the three different national authorities (customs, food safety, and police) is necessary.

5.2 Possibilities to improve the existing data and intelligence collection tools

5.2.1 EU wide registry of food fraud cases

Whereas it seems unrealistic to access in the near future the data held by the food industry, Member States may more easily agree to share records of national non-compliances (without compromising police investigations) via the existing iRASFF system. The relevant data scattered across various national databases, IT tools and intelligence sources could be integrated in a supranational EU data warehouse by utilising data mapping tools and application programme interfaces (APIs) without reshaping and disrupting the national databases. The process developed by the SIGMA project, where several Member States' competent authorities send national data to a dedicated database via APIs (Figure 9) managed by the European Food Safety Authority, is a good example for automated data mapping and integration.

Figure 9: Data submission from European countries to the European Food Safety Authority: the SIGMA project approach.



Source: SIGMA Consortium, 2022. Data submission from European countries to EFSA: the SIGMA project approach. Source: EFSA supporting publication 2022:EN-7254. https://www.efsa.europa.eu/en/supporting/pub/en-7254

Recommendation 1

A comprehensive overview of past fraud cases is an indispensable resource for conducting vulnerability assessments of supply chains. By analysing them, patterns related to e.g. commodity, geography, means of transportation, etc., and potential risk areas within the supply chain can be identified. Machine learning algorithms can be used to enhance the capability of detecting anomalies associated with food fraud and to train models to recognise risk factors where fraudulent activities are likely to happen.

The developed models can then be applied to real-time cases to detect sudden deviations, anomalies, or suspicious activities that may indicate potential fraud. These models are 'self-learning' as they use new cases to fine tune the model parameters to improve their predictive ability.

(Pseudo)anonymised dataset of historic fraud cases may be used to train a machine learning model for assessing the feasibility of using predictive analytics for identifying cases being suspicious of food fraud. The JRC could be entrusted to carry out this feasibility study as it has proven expertise in data analytics and food fraud, both operating within the European Commission IT environment.

Recommendation 2

Having enough data ('big data') is a fundamental prerequisite for data-driven analytics because it enhances the accuracy, reliability, and depth of insights derived from data. It is especially crucial in fields like machine learning, where data is the primary driver of model performance and predictive power. A larger dataset helps machine learning models to better understand the underlying patterns and relationships in the data to make more accurate predictions or classifications.

Current EU legislation provides that Member States can share cross-border violations of the agri-food chain legislation via the Alert and Cooperation Network. However, notification of (potential) food fraud cases transmitted to the EU Food Fraud Network have primarily a cross-border dimension, which means that a comprehensive overview of food fraud cases in the EU is not available.

Therefore, Member States' competent authorities could be encouraged to notify all food fraud cases detected by application of Article 9(2) of the OCR to the EU Food Fraud Network using the appropriate iRASFF channel, including those having only a national dimension (at the moment there is only the legal obligation to notify cross-country cases). This, together with data analytics, will result in a better understanding of fraud risks in the EU food supply.

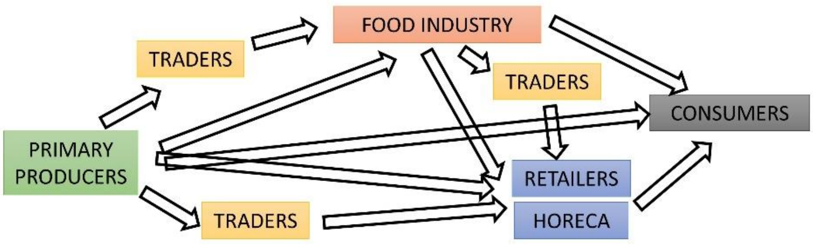
Likewise, the food industry shall be motivated and incentivised to share food fraud data and intelligence insights through an independent data trust that stewards and governs the sharing of data among industry members as well as competent authorities. Access to food fraud data held by industry would greatly enlarge the available data set that can be used for descriptive, diagnostic and predictive analytics.

5.2.2 Modernised and enhanced food traceability

Regulation (EC) No 178/2002 mandates FBOs to adopt a "one step back—one step forward" approach. However, it does not contain requirements regarding the form and structure of traceability systems and procedures. Consequently, the EU lacks a centralised traceability system, instead relying on the commitment of the FBOs to share data in case of need.

Although the concept of a linear food supply chain[71] is usually used to describe the actors along a food supply chain, the connections between food and ingredients, individuals and companies is much more complex, non-linear and intertwined, resembling a network difficult to represent and visualize (Figure 10).

Figure 10: a simplified structure of the food supply chain.



Source: JRC.

Competent authorities have to identify where a non-compliance started, regardless if it concerns a food safety or food fraud incident. Currently, the authorities' officers must manually draw the food network under investigation, trying to gather all relevant information in a timely manner, and aiming at identifying which "node" of the network may be the problematic one. Obviously, a digitalised traceability system has the potential to ease the burden of trace-back investigations to a large extent by automatically linking stakeholders in a supply chain.

Blockchain technology has emerged as a promising solution for enhancing food traceability, improving the flow of information and providing transparency of supply chains. The immutable records allow stakeholders, including consumers (via QR codes), to verify the records associated with the food they purchase. However, as also highlighted by FAO[72], blockchain does not seem to be the best candidate to build a solid governmental traceability system. In particular, it cannot prevent unscrupulous actors from changing or manipulating lots prior to or after data being recorded on the blockchain because the lot is traced through a marker on the product packaging (e.g. a barcode or QR code) and not the physical product itself. Blockchain participants are usually anonymous, therefore impeding any further action by authorities in case of need. For this reason, public databases and IT systems are seen as more aligned with the needs of EU and national services, without taking into account blockchain technology.

The European Parliament Research Service has published a comprehensive report[73] addressing blockchain with eight case studies, including blockchain applications in the food industry. As blockchain technologies provide benefits when "*reliance on a single authority able to operate this infrastructure is not feasible or not desired*", the future traceability system may better profit from a managed database operated and owned by the European Institutions and the EU Member States, as highlighted by Chart 1[74] of the FAO document[72]. By using any blockchain technology, no single actor has full control of the system, but also the different technologies are often not interoperable, and no clear standards have been agreed so far. Several of the 20 policy options proposed in the report pertain to supply chains where the European Commission is encouraged to provide funding for technology adoption and implementation by the concerned sectors. Notwithstanding the recommendations, the report also states that the expected benefits are not unique to blockchain technology but rather derive from the digitalisation of supply chain logistics processes.

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71 https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/food-supply-chain_en.pdf

72 Sylvester, G. (2019). E-agriculture in action: Blockchain for agriculture. Opportunities and Challenges. ISBN 978-92-5-131227-8 (FAO)

73 European Parliament, Directorate-General for Parliamentary Research Services, Tcholtchev, N., Lämmel, P., Frazzani, S. (2021). Blockchain for supply chains and international trade – , European Parliament

74 Adapted from the original flowchart created by National Institute of Standards and Technology (NIST). Page 42 of: Yaga D, Mell P, Roby N, Scarfone K (2018) Blockchain Technology Overview. NISTIR 8202

As part of the EU Strategy to create a blockchain ecosystem, the European Commission and the European Union Intellectual Property Office (EUIPO) have co-organised the EU Blockathon 2018 competition, resulting in the establishment of the Anti-Counterfeiting Blockathon Forum[75], "a network of people and organisations working together to shape and deliver the future anti-counterfeiting infrastructure. The Forum and the future infrastructure will interconnect organisations, enforcement authorities and citizens to help the transport and proof of authentic goods and address the challenges of counterfeiting". The winner of a following contest developed the best proposal of a blockchain-based digital infrastructure for authenticating products and exchanging data between the EU intellectual property offices, governments, customs authorities, manufacturers, retailers, logistics operators and customers[76], focusing on Intellectual Property Rights (IPR) infringements. The final goal was the creation of a product authentication system almost impossible to breach of corrupt. As highlighted in the "Blockchain Use Case" document[77], the creation of blockchain systems can benefit enforcement authorities and customs as well. For example, tokenised goods (with proven authenticity) may have a swift passage through customs checks, or enforcement authorities may be alerted in case the good integrity is at risk, e.g. through permissioned applications sending automatic notifications to rights holders and authorities, potentially recording even customs actions. This future blockchain architecture should be complementary and compatible with existing systems/databases managed by the governmental authorities, without being an additional burden for customs, enforcement authorities and rights holders. Especially the customs authorities would be capable of comparing the information stored within the tokenised goods (e.g. shipping routes) and the documents provided by carriers and importers, identifying misalignments and irregularities and focusing controls on specific consignments, containers and/or goods. Food safety authorities may be alerted if e.g. the recorded temperature during transportation were not compliant with the hygiene requirements, or if the product has been opened illegally and potentially adulterated while on route. The new traceability system may benefit from the "tokenisation" in the authenticity layer, i.e. the process of producing a token. Tokens are assets that allow information and value to be transferred, stored, and verified efficiently and safely, usually produced by the rights holders in the first place. Other actors of the food value chain (e.g. transport, enforcement and provenance) add optional and supplementary features and information linked with the tokenised goods. As highlighted in the Blockathon Report[78], "blockchain has clear potential […], as it is a technology that can track and trace a product throughout its supply chain".

A lesson learned from blockchain technologies to be imported into the future traceability system is the possibility for companies to disclose voluntarily some information to consumers (e.g. origin, production methods, etc…), in order to build trust and confidence as currently allowed by many blockchain applications. Some FBOs already allow their consumers to obtain extra non-mandatory information (e.g. origin, production method) by simply scanning a QR code. By giving such opportunity within the future institutional traceability system, consumers would reward the most transparent operators across the food supply chain, potentially spreading such practices without any legal imposition.

75 https://euipo.europa.eu/ohimportal/en/web/observatory/blockathon

76 https://euipo.europa.eu/ohimportal/en/web/observatory/blockathon/acbi

77 https://euipo.europa.eu/tunnel-web/secure/webdav/guest/document_library/observatory/documents/Blockathon/Blockathon-Forum_Blockchain-Use-Case.pdf

78 https://euipo.europa.eu/tunnel-web/secure/webdav/guest/document_library/observatory/documents/Blockathon/Blockathon_Report.pdf

Box 1: examples of studies on blockchain performed in third countries.

A report produced by researchers from the Deakin University mentions that "*blockchain tends to be oversold as a 'guarantee' of product authenticity and anti-counterfeiting in general, but it is not the ultimate solution to the problem of product fraud because there is no guarantee as to the integrity of the data that a blockchain contains.*"[79]

The UK Food Standards Agency also investigated[80] the potential impact of blockchain technologies on food chains. The participants of the two projects highlighted "real potential benefits to improvements in safety standards and quality of food throughout many value chains" (e.g. provide data only once and re-use) when applying blockchain technologies. However, they also expressed concerns about initial financial investments, sharing confidential and/or commercially sensitive data with competitors, and the fear of a single entity dominating the governance of such distributed systems. The Food Standards Agency report highlights that "*it should not be the responsibility of a regulator such as Food Standards Agency to set up and define and manage such a chain as the scope could increase to beyond regulation*", thus reducing the expectations that blockchain technologies (considered anyway still immature) could replace or support governmental and regulatory systems or databases.

Recommendation 3

Leveraging the digital transformation for improving product traceability is not only beneficial for resolving food safety crises; it makes supply chains also more transparent, accountable, less susceptible to fraud, and enables more effective identification of vulnerabilities. On top, digital traceability can enhance consumer trust in the food they buy. International standards outlining the principles and basic requirements for the design and implementation of traceability systems are already in place, among them ISO 22005 and the GS1 Global Traceability Standard, including the GS1 Electronic Product Code Information Services (EPCIS), providing transparency as products move physically along an entire supply chain ("what, when, where, why and how" of products). A wide range of IT systems built on internationally accepted principles are available on the market to aid traceability implementations.

It is recommended to set up a Public-Private Partnership to encourage and incentivise FBOs to transition to end-to-end digital traceability systems by facilitating traceability research and development expenditure. The initiative should be primarily directed towards small hold farmers and small-medium enterprises to increase their capacity to participate in digital traceability solutions. Funding should be provided for the adoption of already existing digital technology to ensure that requirements for certain previously agreed key data elements are met, systems are interoperable, and traceability data can be provided on request to competent authorities via an API. This can substantially reduce the authorities' lag time to respond to food chain incidents by providing them a transparent view of the affected supply chain.

A dedicated Working Group representing food public and private chain stakeholders should be set up to elaborate and agree the required key data elements as well as the necessary IT infrastructure at national as well as at supranational level.

79 Smith M, Ashraf M, Austin C, and Lester R (2021) Product fraud: Impacts on Australian agriculture, fisheries and forestry industries. ISBN 978-1-76053-169-0

80 Insights and Learnings from exploring the use of Blockchains (2021) https://www.food.gov.uk/research/research-projects/food-data-trust-a-framework-for-information-sharing

5.3 Data analysis

As the complexity of the worldwide food supply chain grows, the food sector needs to incorporate data-driven solutions by expanding the usage of information technologies that facilitate the gathering, sharing, and analysis of data.

The European Commission and competent authorities collect, collate and store an impressive amount of food chain data in their repositories. Those data can be mined by powerful cloud computing AI tools to extract insights that can be used effectively to visualise connections and patterns not recognisable with traditional statistical methods.

Data science is today considered a separate science embracing competencies belonging to different traditional academic sectors, not being simply a branch of mathematics. There are two goals in analysing data[81]:

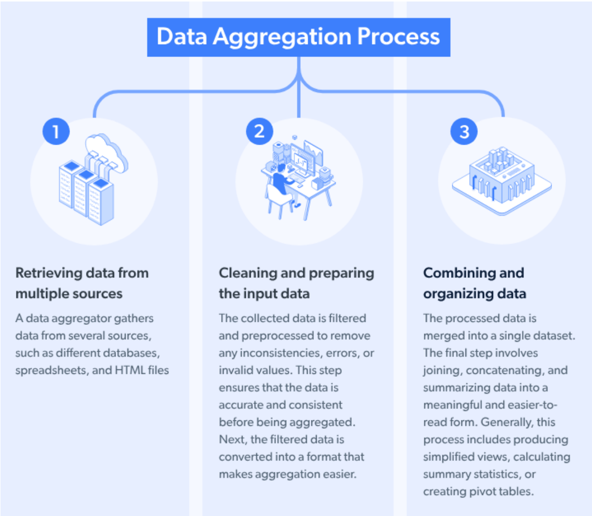
— **Inferring** how the response variables are associated to the input variables (*generative modelling*), where data and signals are analysed with methodologies to visualise them and detect patterns, groups, trends and outliers or to confirm hypotheses with appropriate testing methods;

— **Predicting** what the responses are going to be to future input variables (*predictive modelling*), where the algorithm also self-learns how to recognise complex non-linear correlations.

Building the ***insight capacity*** into the state of food integrity in the EU requires (1) data integration, (2) visualisation, (3) analytical tools and (4) real-time collaboration[82].

Data aggregation/integration across relevant data sources and informatics tools must combine all relevant data elements into a single shared view to create a more complete picture of an emerging or ongoing event (Figure 11). This will allow a faster recognition of existing problems and generate new knowledge that will contribute to latency reductions. The SIGMA–Animal Disease Data Model of the European Food Safety Authority is an example for aggregating data known to be already collected by several Member States, which can serve as a blueprint.

Figure 11: Data aggregation process.



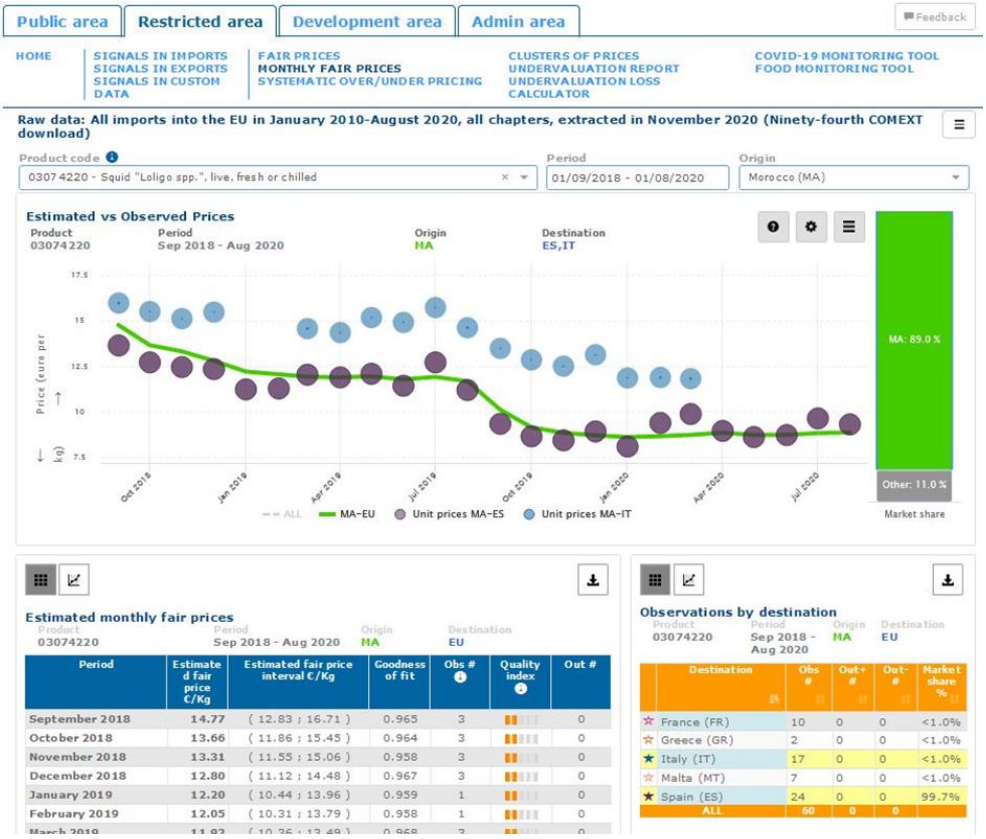
Source: https://brightdata.com/blog/web-data/data-aggregation

81 Donoho, D. (2017). 50 years of data science. Journal of Computational and Graphical Statistics, 26(4), 745-766

82 Greis, N. P., & Nogueira, M. L. (2017). A data-driven approach to food safety surveillance and response. In *Food protection and security* (pp. 75-99). Woodhead Publishing

A **visualization tool** not only provides a graphical representation of data that is more easily interpreted, but can also be used as a problem-solving tool. For example, dashboards, charts, graphs, tables, and other graphical elements to visually represent data in (near) real-time. This allows users to understand patterns, trends, and anomalies at a glance (Figure 12).

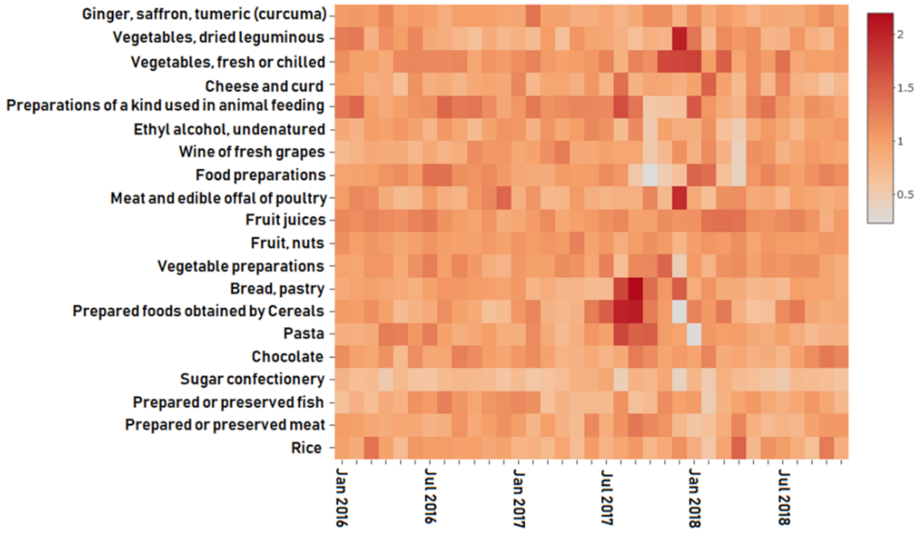
Figure 12: an example of a visualisation tool. Monthly Fair Prices of the THESEUS repository of the JRC, which is in support of the anti-fraud work of the EU Customs and other relevant services in the European Institutions.



Source: JRC.

Analytical Tools can be used to assess the likelihood of a food integrity incident from fused data in order to guide response actions (e.g. inspection) followed by sampling and analysis of high risk products (Figure 13).

Figure 13: Heat map depicting intrinsic risk and its dynamics for certain agri-food commodities based on trade flow data.



Source: Fera ltd.

AI-enabled data analytics for food safety has been used for example to detect pathogens in food, model food spoilage due to microbial growth and activity, flag the presence of contaminants, and grade the freshness of certain foods. In addition, data-driven algorithms have not only the ability to detect but also to predict general food safety hazards as well as identify the most important influential factors and the relationships between these factors and the presence of food safety hazards[83],[84],[85]. iRASFF data were frequently used as input for data-driven food safety risk prediction[86,87,88]. Consequently, regulatory authorities and food safety risk assessment bodies such as the European Food Safety Authority are becoming increasingly interested in using AI based analytics to make and keep the food supply safe[89].

By contrast to data-driven tools for food safety, only a few AI based initiatives offer predictive analytics for food fraud, which are either based on a combination of various data sources, such as historic iRASFF data, meteorological data, certain World Bank Indices, or trade flow data. Researches from Wageningen University and Research (WUR) pioneered the use of Bayesian Network modelling and historical RASFF data combined with indicators taken from EUROSTAT, European Food Safety Authority, FDA, World Bank, etc., as input for predicting the type of food fraud[90,91]. The gained insights can assist competent authorities in formulating surveillance strategies

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83 Wang, X., Bouzembrak, Y., Lansink, A. O., & van der Fels.Klerx, H. J. (2022). Application of machine learning to the monitoring and prediction of food safety: A review. *Comprehensive Reviews in Food Science and Food Safety*, *21*(1), 416-434

84 Qian, C., Murphy, S. I., Orsi, R. H., & Wiedmann, M. (2023). How can AI help improve food safety?. Annual Review of Food Science and Technology, 14, 517-538

85 Benefo, E. O., Karanth, S., & Pradhan, A. K. (2022). Applications of advanced data analytic techniques in food safety and risk assessment. Current Opinion in Food Science, 100937

86 Nogales, A., Díaz-Morón, R., & García-Tejedor, Á. J. (2022). A comparison of neural and non-neural machine learning models for food safety risk prediction with European Union RASFF data. Food Control, 134, 108697.

87 Bouzembrak, Y., & Marvin, H. J. (2019). Impact of drivers of change, including climatic factors, on the occurrence of chemical food safety hazards in fruits and vegetables: A Bayesian Network approach. Food control, 97, 67-76

88 Liu, N., Bouzembrak, Y., Van den Bulk, L. M., Gavai, A., van den Heuvel, L. J., & Marvin, H. J. (2022). Automated food safety early warning system in the dairy supply chain using machine learning. Food Control, 136, 108872

89 PwC EU Services & Intellera Consulting (2022) Roadmap for action on Artificial Intelligence for evidence management in risk assessment. EFSA supporting publication 2022:EN-7339. 120pp.

90 Marvin, H. J., Bouzembrak, Y., Janssen, E. M., van der Fels-Klerx, H. V., van Asselt, E. D., & Kleter, G. A. (2016). A holistic approach to food safety risks: Food fraud as an example. Food research international, 89, 463-470

91 Bouzembrak, Y., & Marvin, H. J. (2016). Prediction of food fraud type using data from Rapid Alert System for Food and Feed (RASFF) and Bayesian network modelling. Food Control, 61, 180-187

focused on specific products that might be more susceptible to fraud based on the nature and source of the product, pricing, shifts in product demand, etc.

The Bavarian State Office for Health and Food Safety (LGL Bayern) developed ISAR (Import Screening for the Anticipation of Food Risks), meanwhile used by other German State ('Länder') food authorities, to improve hazard identification and to implement more targeted food control measures. Input data are captured from the German Foreign Trade Statistic. For each commodity, monthly information on the import volume and the related commodity price is available for each country exporting to Germany. Time series analysis is then applied to obtain predictions of expected commodity prices and import volumes in future months. Unexpected changes in the series create signals and shifts that, after confirmation by subject matter experts, can trigger measures to mitigate a food safety or food fraud issue. The proprietors of the system identified a couple of opportunities to improve the performance of the system, e.g. by including notifications of the iRASFF databases together with other relevant indices pertaining to the geopolitical and social environment of exporting countries.

Media observations collected by a specific application of the European Media Monitor (MedISys) is used by the European Food Safety Authority for the detection of emerging risks in the food chain[92] and in combination with text mining it can also serve as an early warning tool to show global trends and developments in food fraud activities[93,94]. The JRC produces the freely available Food Fraud Monthly Reports, based on screening of relevant media reports collected via MedISys[95].

Next to MedISys-FF and the Food Fraud Monthly Reports, other EU IT tools are of relevance for predictive food integrity analytics:

— **AFIS-CSM**: the software a) compares import-export information from maritime shipping companies with single administrative documents (SADs) provided by exporters, b) it reconstructs the itinerary of containers and c) checks for discrepancies in information flows. For example, an exporter may declare a different origin to pay less import duties or to evade sanitary controls targeting specific third countries. For some cases information is available even when monitoring road or train transport until the container is unloaded in the EU territory.

— **AMT/THESEUS**: the algorithm a) identifies imports with a price too low compared to the average market value (even considering the origin and the destination), b) it uncovers systemic underpricing/overpricing, c) it estimates the fair price and fair weight, and d) it visualizes spikes, trends and levels for commodities of interest. For example, a fraudster based in a third country may export to the EU sugar syrup mislabelled as honey with an import price much cheaper than standard honey; as a consequence, the system may spot the outlier because of the price "too good to be true".

— **JRC Dashboard** - Trade Flow Analysis for Structural Breaks: the dashboard highlights structural changes in trade flows (specifically imports) by utilising data from the Surveillance database. For example, if a specific commodity from a specific country is subject to increased sanitary controls because of past non-compliances in terms of food safety, the trade of that commodity may be redirected to neighbouring countries to be exported to the EU while avoiding the more stringent sanitary scrutiny (i.e. by changing export location). As another example, the dashboard may identify the replacement of a specific product with a cheaper (but functionally similar) one by monitoring the quantities of the latter imported in higher amounts.

— **Monitoring Agricultural Resources Bulletin (MARS)**: Since 2011 the Bulletin is published monthly and provides: a) crop yield forecasts for the ongoing season; and b) information on the condition of crops and on weather conditions affecting crop growth and development. Two series of MARS Bulletins are published: "JRC MARS Bulletin – Crop monitoring in Europe" (every month, focused on EU Member States and neighbouring countries) and "JRC MARS Bulletin - Global outlook"

92 European Food Safety Authority; Development of web monitoring systems for the detection of emerging risks. EFSA Journal 2009; 7(10):1355. [50 pp.].

93 Bouzembrak, Y., Steen, B., Neslo, R., Linge, J., Mojtahed, V., & Marvin, H. J. P. (2018). Development of food fraud media monitoring system based on text mining. Food Control, 93, 283-296

94 Marvin, H. J., Hoenderdaal, W., Gavai, A. K., Mu, W., van den Bulk, L. M., Liu, N., ... & Bouzembrak, Y. (2022). Global media as an early warning tool for food fraud; an assessment of MedISys-FF. Food Control, 137, 108961

95 https://knowledge4policy.ec.europa.eu/food-fraud-quality/monthly-food-fraud-summary-reports_en

(twice during the growing season, on Turkey, Ukraine, Kazakhstan, Russia and North Africa). Detailed Information on the MARS crop yield forecasting system, as well as relevant datasets, are publicly accessible via the Agri4Cast Toolbox.

— **DG TAXUD Crisis Impact Analysis**: The dashboard focuses on exports (values and quantities), monitoring the impact of sanctions and conflicts while analysing market elasticity. It uses data within the Surveillance database and it provides circumvention analysis by modelling trade flows of exported goods from the EU to selected destination countries. For example: some goods are prohibited to be exported from the EU to a specific country under embargo, but companies may utilise third countries as transit intermediaries to ultimately ship the goods to the sanctioned country.

Commercial softwares used by law enforcement agencies could be deployed for data mining, traceability, analysis of unstructured data, unveiling of hidden connections, and forecasting.

Based on the outcomes of the technology mapping exercise and a cost-benefit analysis, senior management can decide whether the system should be implemented to improve the integrity of the EU food supply chain.

Recommendation 4

Data-driven analytics to support informed decision making offers new opportunities to enhance food integrity by analysing 'big data' to identify potential risks, patterns, trends, and areas for improvement. Creating big data involves the accumulation and processing of large volumes of information from various sources. Machine learning can identify subtle patterns and correlations in large datasets that might not be apparent through traditional analysis. This can help authorities to identify emerging risks more effectively and to support the design of appropriate risk-based monitoring schemes.

Creating and managing big data requires careful planning, resources, and expertise in data management, analysis, and relevant technologies. It is also important to have a clear objective for collecting and analysing big data to ensure that the efforts contribute meaningfully to the objective of the exercise.

The European Commission is mandated to collect large volumes of food chain data; other data sets held by Commission services could be of use as well. However, the data sets are often dispersed and lack interoperability. Aggregating these data sets has the potential to generate the required 'big data' to facilitate data-driven decision support processes.

The JRC recommends to create a well-defined technology roadmap for setting up an AI-driven IT system for food integrity that integrates data aggregation and analysis by big data technologies involving experts from European Commission departments owning relevant datasets, IT professionals (back-end and front-end developers), and data scientist. The roadmap should consider the need for:

- computing infrastructure (cloud computing, high performance computing) for computationally intensive tasks;
- building and implementing APIs for data aggregation from diverse sources and tools for data cleaning, transformation, and standardisation before storage;
- appropriate data storage solutions to accommodate large data sets;
- a collaborative environment where data scientists, IT professionals and food chain experts collaborate on machine learning models and analytics pipelines;
- compliance with data protection regulations, particularly when handling personal or sensitive information.
- training for IT professionals and data scientists to proficiently manage cloud resources and big data technologies.

Predictive modelling can be utilised to cover food fraud as well as food safety risks. However, it is sensible to assume all food fraud may be a potential risk to public health unless proven otherwise[96]. Specific models trained on different data sources have to be built if both aspects of food integrity shall be covered.

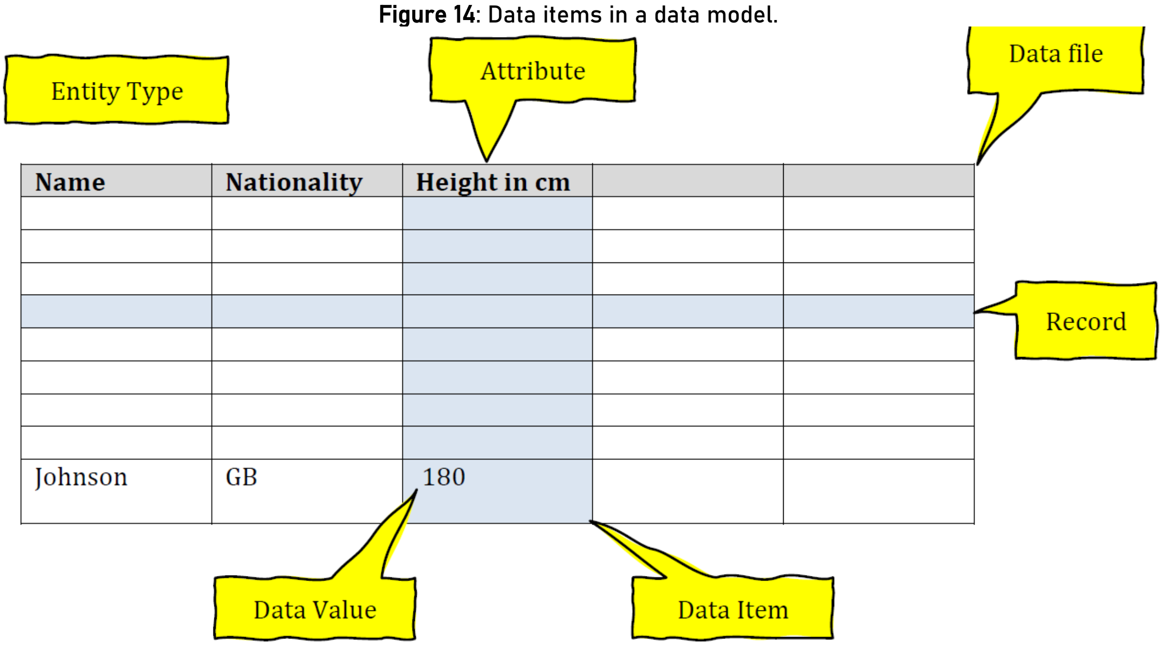
For example, with the values already available a product coming from a country with a high corruption index and low food safety index would already be marked as vulnerable in terms of both food fraud and food safety. However, after the finalisation of dedicated food risk vulnerability assessments (FRVA, see below), the proposed system may also be able to mark a product in powder form, which is generally more vulnerable to food fraud (as adulterants can be more easily mixed with the authentic product), but maybe less to food safety risks (because microorganisms cannot reproduce easily in a dry environment).

The previous step should deliver information to an EU database already harmonised and structured, inter-operable and comparable, and legally available and accessible to staff (EU and/or Member States). The digital IT tool should be able to identify and correct irregularities, gaps or errors in the input data, with suggestions to be validated by experts before proceeding with the data analysis.

Data are expected to be delivered continuously to the digital IT tool. Member States' operators and inspectors, the EU Institutions, and possibly the food industry should be able to insert input data in a semi-automated, multilingual and standardised format. The (food) product shall be characterised by a number of information entries (an "ID Card") to be provided by public and private actors along the food chain, and later collected by the new EU database.

Developing a user-friendly data collection system across the EU (*top-down*), co-developed together with all stakeholders (*bottom-up*), but still complete and informative, will be key for the success of such information-based risk analysis IT system.

Figure 14: Data items in a data model.



Source: Black A., Nederpelt P. van. (2020) Dictionary of dimensions of data quality (3DQ) Dictionary of 60 Standardised Definitions. DAMA-NL.

Figure 14 shows the most common terminology associated with databases. "**Records**" may be considered as one of the "ID cards" of a food product. Each record will include a series of **data items** (filled with **data values**) gathered from the individual databases and associated with the general **attributes** co-developed with bottom-up and top-down approaches.

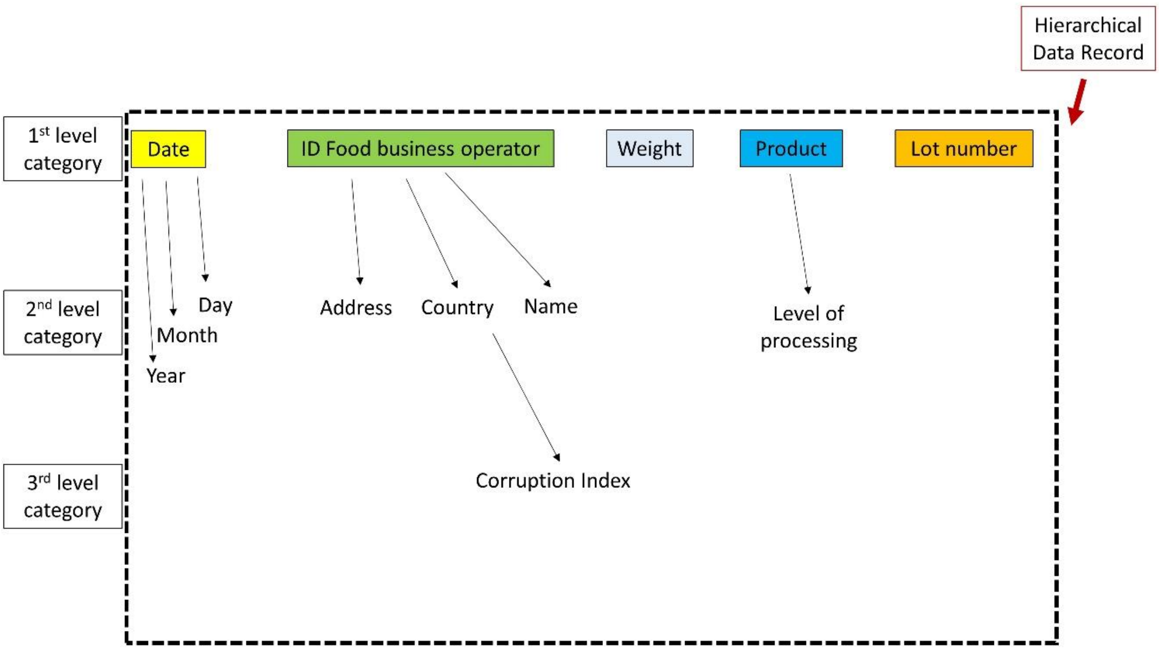
96 Elliott, C. (2014). Elliott Review into the integrity and assurance of food supply networks-Final report: A national food crime prevention framework. PB 14192

The new EU database should include several attributes organised in hierarchical levels. Although data items are shown as sequential cells in Figure 14, not necessarily all data items should be treated equally from a hierarchical perspective, and therefore a **multi-layered record** may provide additional benefits in the context of the new EU database (Figure 15).

— Data values inserted/chosen manually by the users/operators (e.g. food inspectors, national and EU authorities, FBOs) are considered the **1st level category**. The objective is to minimize the number of inputs falling into this category to reduce manual mistakes, limiting in parallel the administrative burden for the operators. In order to collect inputs harmonised and interoperable across all Member States, a suitable solution would be a series of options to choose from (i.e. several lists) whenever possible, in the native language of the user (i.e. multilingual - available in all 24 EU languages, and possibly additional ones from third countries). Inputs falling within this category may also include non-compliances uncovered through official controls or internal audits from the private sector.

— Each data value in the 1st level category would be automatically associated with a **2nd level category** of data values, pre-compiled by national and European authorities and linked unequivocally only to a single 1st level data value. Similarly, even **lower level categories** may be envisioned according to the needs. For example (Figure 15): the identity of a FBO (1st level category) is automatically associated with pre-compiled data as e.g. the country of origin (2nd level category), that implies some parameters as corruption index, etc… (3rd level category). In other words: when users introduce (directly or indirectly) a specific data value, all data values hierarchically inferior and associated with it (the associated "package") never change and are introduced automatically into the data record.

Figure 15: A simplified example of hierarchical data record, with the different levels of categories for each data item. Each text box represents one data item.



Source: JRC.

The project may profit from the creation of a **dedicated Working Group** in order to establish:

— The data attributes within each data record. Not all data items should be filled, however there should be the possibility to utilise such data model independently from the source of information (i.e. database), thus being flexible, versatile and coherent with the requests and needs of each actor of the food supply chain;

— The nomenclature to be utilised for each data item;

— The categorisation and hierarchy of data items, according to the principles of speed, minimalism, multilingualism and automatism.

The Working Group should include especially those actors who will provide and will use/analyse the data records. Overall, the data model established should be easy to be filled, multilingual, informative, interoperable, and complete.

However, an effective and valuable data record would be more complex than what is described above. This report frames the architecture of two "ID Cards":

— The "**Transaction ID Card**" is a collection of information related to a specific transaction between two actors of the food chain.

— The "**Food ID Card**" is the collection of all Transaction ID Cards connected to a specific product and related ingredients.

The possibility of having a harmonised set of data values within an EU database will provide the foundation for further analysis. In summary, each data value provides useful information not only utilised to describe an individual transaction of a specific food product, but also to be further processed by a digital IT tool to calculate the probability that the concrete food lot/consignment may be subject to non-compliances.

5.3.1 "Transaction ID Card" data elements

The "Transaction ID Card" is a collection of data items related to a specific transaction between two actors of the food chain. Similarly to a line connecting two dots within a network, such record would provide selective data on a specific event that took place in a specific time (and place, possibly). It contains several data items hierarchically organised as shown in Table 3. As previously mentioned, the operator shall insert only the information within then 1st level category, while the rest of the Transaction ID Card (i.e. lower hierarchical levels) will automatically be filled by the digital IT tool. In addition, there are some data items that are not just simply referred to a single data item of higher hierarchical level, but that stem from the interconnection of different data items (of various hierarchical levels) contained in the Transaction ID Card itself. As a consequence, such "**derived data items**" (Figure 16) do not need to be inserted manually by the operator but are provided and calculated by the IT system automatically. The data items in Table 3 provides in *[square brackets]* the proposal on which classification, list, options or format to use for the data values.

Table 3: Data items of the Transaction ID Card.

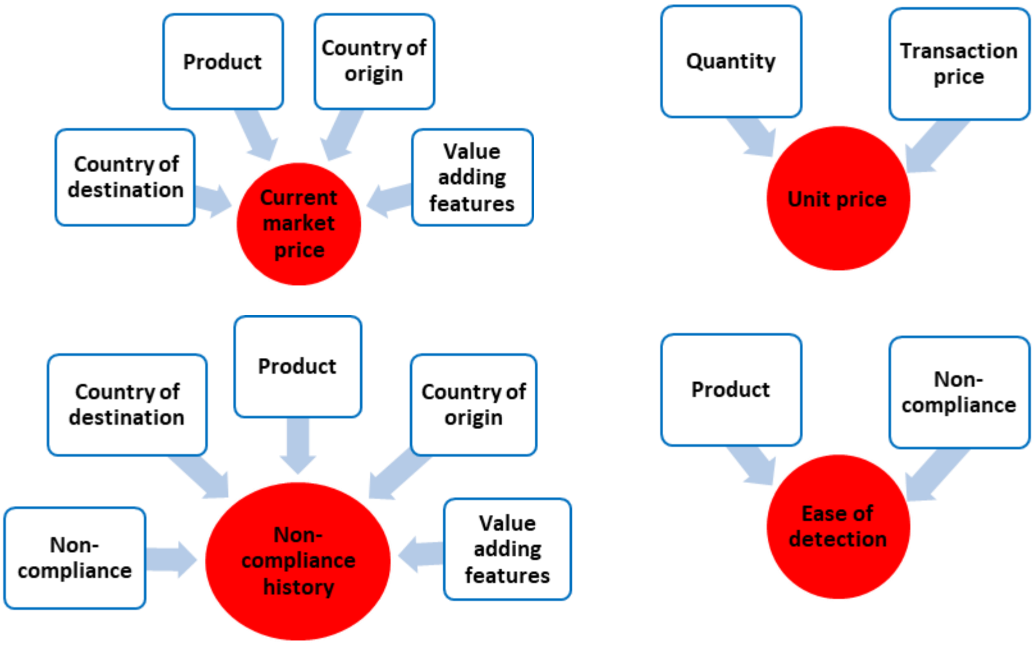
1st level category *(to be filled manually by human personnel)*	**2nd level category** *[automatically linked to a specific 1st level category]*	**3rd level category** *[automatically linked to a specific 2nd level category]*
Date *[DD/MM/YY]*		
Product *[TARIC]*	Physical qualities and processing level *[whole, pieces, powder, liquid]*	
	Refrigeration *[Y/N]*	
	Supply situation	
Transaction Price *[€]*		
Quantity *[units, kg, l]*		

Value adding features *[organic, halal, kosher, conventional]*		
Identification number *[lot number, tag number]*		
Means of transportation *[air, water, road, train]*		
Seller *[ID number; e.g. LEI number]*	Age *[months]*	
	Economic health	
	Firm size	
	Recidivism	
	Address *[Street address, house number, Zip code, UN/LOCODE Country]*	Poverty and crime [*GDP per capita growth at NUTS3 level]*
		Corruption *[Corruption Perception Index]*
		Country-based geopolitical risk
	Owner	
	Certifications	
	Sector competition level	
	Supply chain position	
Buyer *[ID number; e.g. LEI number]*	Age *[months]*	
	Economic health	
	Firm size	
	Recidivism	
	Address *[Street address, house number, Zip code, UN/LOCODE Country]*	Poverty and crime [*GDP per capita growth at NUTS3 level]*
		Corruption *[Corruption Perception Index]*
		Country-based geopolitical risk

	Owner	
	Certifications	
	Sector competition	
	Supply chain position	
Checkpoint location	Address *[Street address, house number, Zip code, UN/LOCODE Country]*	Poverty and crime [*GDP per capita growth at NUTS3 level]*
		Corruption *[Corruption Perception Index]*
		Country-based geopolitical risk
Non-compliance *[Y/N]*	Typology of non-compliance	
E-commerce *[Y/N]*		
Current Transaction ID (CTI)		
Backward Transaction IDs (BTIs)		
Forward Transaction IDs (FTIs)		
DERIVED DATA ITEMS [automatically inserted by the digital IT tool]		
Current market price *[€/(U/kg/L)]*		
Unit price *[€/(U/kg/L)]*		
Future market price *[€/(U/kg/L)]*		
Non-compliance history *[%]*		
Ease of detection		

Source: JRC.

Figure 16: Derived data items: Current market price; Unit price; Non-compliance history; and Ease of detection.



Source: JRC.

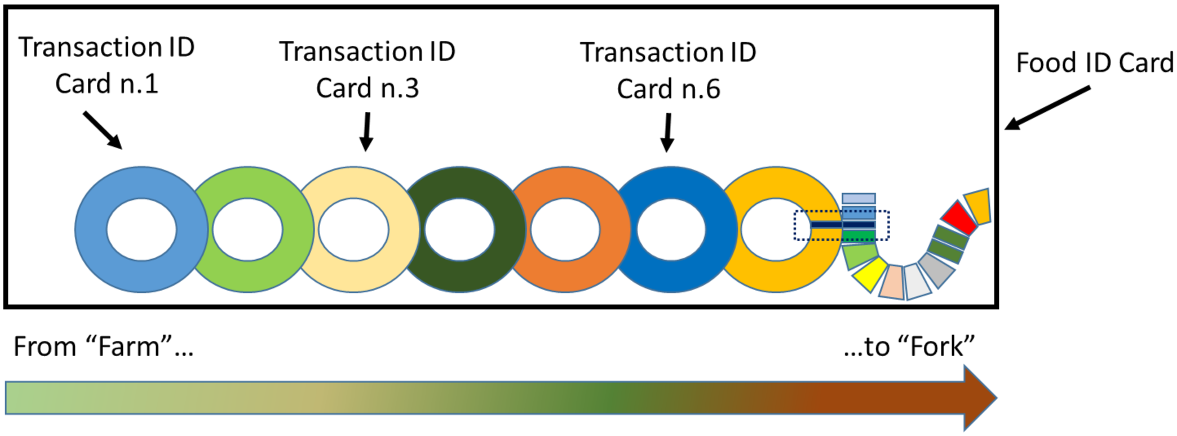
Annex 2 provides a detailed list of all data items of the Transaction ID Card and an analysis of the associated food fraud drivers according to some scientific and economic literature. The data items collected in the Transaction ID Card, given their high granularity, do not only provides a solid base to increase the full traceability of the food supply chain (the "*insight capacity*" and "*investigative capacity*") but also feeds the vulnerability analyses to be performed in relation to the *anticipatory capacity*.

5.3.2 The "Food ID Card", a collection of all "Transaction ID Cards"

The "Food ID Card" is a collection of all Transaction ID Cards related to a specific product in a specific time and place (i.e. a specific point within the supply chain). The Transaction ID Cards can be visualised as "pearls of a necklace" (Figure 17). In reality, more chains would converge into a single Food ID Card.

The Food ID Card should include the vast majority of data items to be used by the digital IT tool, however a minority of derived data items (e.g. supply chain length and supply chain complexity) could be indirectly associated to (and calculated for) each Food ID Card (Figure 16). All previous and following Transaction ID Cards of the ingredients used to produce a specific product would thus be visible to the human operator.

Figure 17: A simplification of the Food ID Card. Each Food ID Card is a collection of Transaction ID Cards linearly linked through specific data items. The last Transaction ID Card is opened, showing the several data items within. The data items highlighted by the blue dotted line provides the same information in both transaction ID Cards, connecting them. In reality, more chains would converge towards a single Food ID Card. As a general rule, the number of Transaction ID Cards contained within a Food ID Card will increase with the level of processing and with the number of actors involved in that specific chain.



Source: JRC.

Supply chain length and supply chain complexity – [Derived data item]

One of the available definitions for "supply chain" is the network of organisations involved in different mechanisms and activities, with links to the previous and subsequent steps that produce value in the form of goods and services conveyed to the consumer[97].

The threat that a long and complex supply chain represents to the authenticity of foodstuff is widely recognised in the literature[98,99,100,101,102,103,104,105,106]. This is because long supply chains decrease transparency, visibility and trust as fraudsters can exploit supply chain vulnerabilities introducing illegitimate goods into the regular market[107]. As a matter of fact, the increasing number of steps before foodstuff reaches the consumer increases the supply chain opacity as it is much harder to monitor the good's composition and provenience[108]. In other words: the more actors have been involved in the production of a certain good, the higher chances of food fraud being committed by some of those actors. Shorter supply chains are thus less vulnerable given the minor number of actors.

A supply chain monitoring system is mostly not in place to control and register each step between the producer and the consumer to ensure the legitimacy of the product. Its implementation may be useful to recollect foodstuff composition and origin, reducing fraud opportunity as the information available would deter adulteration.

97 Christopher, M. (2016). Logistics & supply chain management. Pearson Uk.

98 Roberts, M. T., Viinikainen, T., & Bullon, C. (2022). International and national regulatory strategies to counter food fraud. Food & Agriculture Organization.

99 Codex Alimentarius Commission. (2017). Discussion paper on food integrity and food authenticity. CX/FICS 17/23/5. Prepared by Iran with assistance from Canada and the Netherlands, Codex Committee on Food Import and Export Inspection and Certification Systems (CCFICS) (23rd Session), Mexico City, Mexico, 1-5 May 2017.

100 Lotta, F., & Bogue, J. (2015). Defining food fraud in the modern supply chain. Eur. Food & Feed L. Rev., 10, 114.

101 Manning, L., & Monaghan, J. (2019). Integrity in the fresh produce supply chain: solutions and approaches to an emerging issue. The Journal of Horticultural Science and Biotechnology, 94(4), 413-421.

102 Manning, L. (2016). Food fraud: Policy and food chain. Current Opinion in Food Science, 10, 16-21.

103 Morehouse, J. E., & Cardoso, L. (2011). Consumer product fraud–how to stop the fraud now. Supply Chain Quarterly.

104 Tibola, C. S., da Silva, S. A., Dossa, A. A., & Patrício, D. I. (2018). Economically motivated food fraud and adulteration in Brazil: Incidents and alternatives to minimize occurrence. Journal of Food Science, 83(8), 2028-2038.

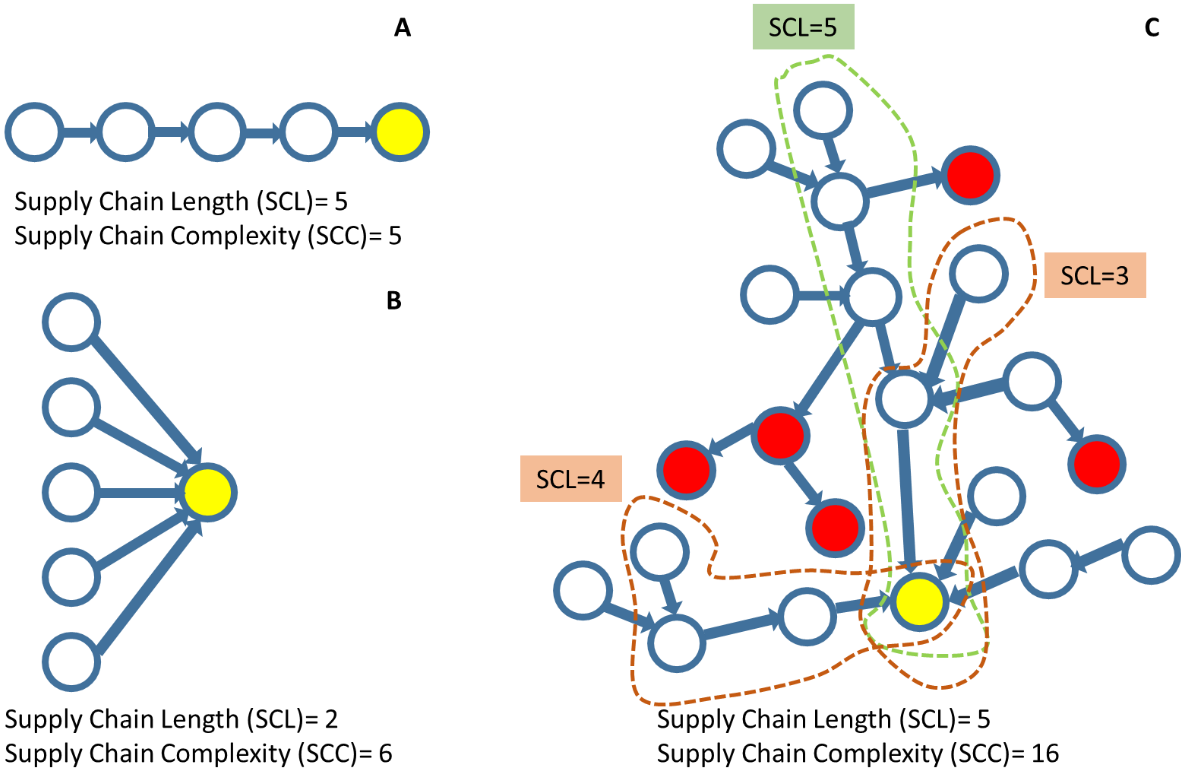
105 Lotta, F., & Bogue, J. (2015). Defining food fraud in the modern supply chain. Eur. Food & Feed L. Rev., 10, 114.

106 Kennedy, S. (2008). Why can't we test our way to absolute food safety?. Science, 322(5908), 1641-1643.

107 Stadler, R. H., Tran, L. A., Cavin, C., Zbinden, P., & Konings, E. J. (2016). Analytical approaches to verify food integrity: Needs and challenges. Journal of AOAC International, 99(5), 1135-1144.

108 Sarpong, S. (2014). Traceability and supply chain complexity: confronting the issues and concerns. European Business Review.

Figure 18: Examples of Supply Chain Length (SCL) and Supply Chain Complexity (SCC) calculated for the node/transaction of interest (yellow circle). A) Section A represents a one-ingredient food product sold from one actor of the food chain to others, without further processing. B) Section B represents a multi-ingredient product, with the ingredients delivered by multiple suppliers to a single processor. C) Section C symbolizes the most common situation, where single ingredients and highly processed ingredients contribute to the final product. The longest supply chain is outlined in green, whereas other two shorter supply chains are outlined in red. Red circles represent nodes/transactions not belonging to the supply chains of the node/transaction of interest (in yellow).



Source: JRC.

The derived data item "**Supply Chain Length (SCL)**" may be defined as the maximum number of consecutive nodes that compose the supply chain of a specific node. In section A of Figure 18 the number of nodes leading to the node of interest is four, plus the node of interest: the SCL is calculated as five. On the other hand, the "**Supply Chain Complexity (SCC)**" may be defined as the total number of nodes contributing to the production. In section B of Figure 18. The SCC is six, whereas the SCL is only two because five suppliers contribute to the node of interest but there is only one step between them and the node of interest. Finally, section C of Figure 18 highlights the difference between SCL and SCC. The maximum number of consecutive contributing nodes is five (as shown in green), but the total number of contributing nodes is sixteen.

Taking into account both variables may be useful to capture two different aspects of a specific food supply chain: SCL represents the exchanges throughout the supply chain, hence opportunities of adulteration by the different economic agents, whereas SCC may capture the number of ingredients that compose the product, hence the opportunities of adulteration of each ingredient. The combination of the two variables may enable the proposed IT tool to understand comprehensively these two aspects of a food supply chain.

5.4 Model deployment

The expected outputs of the IT system fall within two main categories:

- **"What is happening?"**: An overview of non-compliances and trade flows of commodities within the EU, employing dashboards showing geographical maps, heat maps, charts to represent trends, comparisons, patterns, distributions and time-series of data in near-real time to provide a situation report. This functionality is intended to assist users in quickly and effectively making informed decisions about which mitigation measures to implement. To trace back a non-compliant lot, competent authorities could request to access the digital traceability records of the concerned FBOs, via an Application Programming Interface (API), if available. In this case, the system could show the linkages between non-compliant ingredients and the derived processed products, as well as the connections between FBOs. Ideally, all the connected nodes along the food network will become visible, providing a better understanding of the dimension of the non-compliance and speeding up recall or withdrawal of all affected products.
- **"What will happen?"**: An AI algorithm (e.g. machine/deep learning) will be trained to recognise patterns according to a variety of data sources identified by vulnerability analysis of certain supply chains (e.g. market prices, non-compliances, corruption level, etc.) to predict potential non-compliances. The objective will be to support Member States' competent authorities in setting up more effective and efficient surveillance and official control programmes to protect the food supply chain from food safety and food fraud incidences. The results of investigations and official controls should be fed back to the algorithm to improve its predictive power.

  The vulnerability analysis shall rely on the quantitative values associated with the "Food ID card" data items of the product. Such values are either derived from internationally recognised indexes, or alternatively forged by a) an expert group that would translate qualitative judgements into quantitative values, and/or b) the proposed IT tool shall self-learn how much weight to attribute to each input in order to best tailor its predictions. For example, the ML approach may decide to associate a higher weight to the price, rather than the geographical origin, according to the history of that commodity as recorded from past cases. In other words, the digital IT tool may consider the price as a better predictor of vulnerability compared to the geographical origin.

  The objective will be to support Member States' control authorities (the main actors who can perform enforcement actions) to target certain containers/products approaching the EU border, or specific companies/products/individuals within the internal market. However, the outputs will ultimately be checked by a multidisciplinary centre of competence.

5.4.1 Insight capacity

Principles of the future traceability system

The EU lacks a centralised traceability system, relying on the information provided by the FBOs along the food supply chain in case of need. A solid traceability system would highly scale-up the preparedness to safeguard consumer health, and it can easily contribute to fight any food fraud or criminal action within the internal market.

Although the concept of a linear food supply chain[109] is usually utilised to describe the network of FBOs contributing to shape the global food systems, the connections between food and ingredients, individuals and companies is highly more complex, non-linear and intertwined, resembling a chaotic network quite difficult to represent and visualize at once (Figure 10). For example, many operators in the food service industry are small-scale businesses dealing with a large number of products and ingredients, whereas on the contrary e.g. an olive oil producer is usually a medium-sized enterprise dealing with many suppliers delivering a single product.

The new traceability system should immediately provide the authorities with a clear overview of such **food maze**, virtually taking few minutes to trace any source along the food supply chains, and

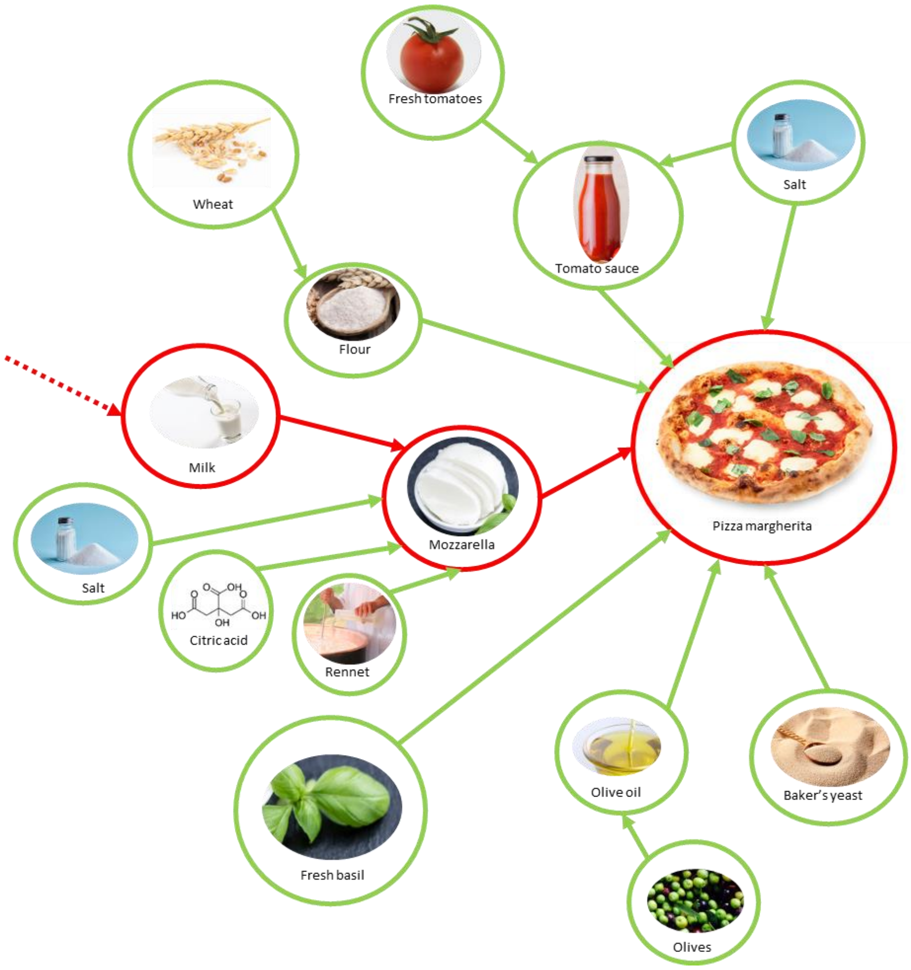
109 https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/food-supply-chain_en.pdf

delivering a fast targeted response before more non-compliant products might affect other consumers. Therefore, some core principles need to be established framing the functionalities of the future IT tool:

— Any non-compliant product/ingredient (e.g. fraudulent, unsafe) transmits the non-compliance to the other derived products/ingredients forward along the chain; however the opposite is not necessarily true, i.e. if a product containing more than one ingredient is non-compliant, not all its ingredient are non-compliant. **The non-compliance status moves forward, and not backward, along the food supply chains**.

— Any information associated with the "Transaction ID Card" is automatically carried along the food supply chain, and associated with the "Food ID Cards" of the derived food products. In other words: **the ID of each product automatically contains also the information of its ingredients**, thus it is not necessary to contact the other actors in the supply chain to retrieve that information. The system should deliver user-friendly visualization tools in this regard.

Figure 19: A simplified food network of the ingredients required to prepare a pizza margherita. Arrows represent connection between supplier and consignee. Circles represent a specific lot of food/ingredient. Red shapes represent non-compliant sections of the food network.



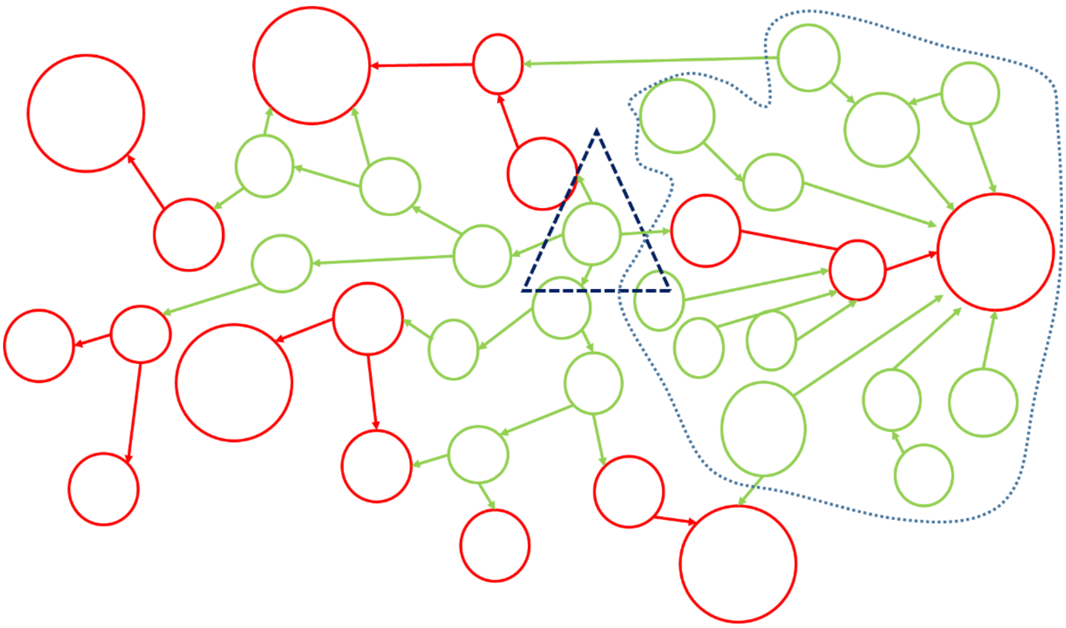
Source: JRC.

As an example, Figure 19 shows the simplified version of the food network related to a pizza margherita. Each circle/node represents a specific lot of ingredient, while arrows show the flow supplier-consignee. During an official control by food safety authorities, a specific lot of the ingredient "mozzarella" is found contaminated with high levels of melamine: with the proposed IT tool, the authorities may ask the FBO to immediately withdraw from the market the non-compliant lots of mozzarella and derived lots of pizzas, because they can swiftly trace which processed food product contains the non-compliant ingredients. Additionally, the authorities have at their disposal all the information covering the lots of ingredients (e.g. milk, salt, citric acid, rennet) used to produce that specific lot of mozzarella, thus they can start investigating if the contamination happened in the factory producing mozzarella, or if the contamination was carried by a non-compliant lot of ingredients.

First advantage: the new traceability system would guarantee higher speed in finding the data needed to investigate any non-compliance, without being subject to the data availability from the supply chain actors upon request. Products suspected of being unsafe or fraudulent could be more easily identified and withdrawn from the market by FBOs.

Following the example from the previous section, the authorities are still unaware if the contamination started in the factory producing mozzarella, or it was a consequence of a non-compliant lot of ingredients. Figure 20 shows the previous food network (from Figure 19) surrounded by the blue dashed line as part of a wider food network. Once again, each circle/node represents one lot of ingredients, whereas the arrows represent the flow supplier-consignee. Each FBO may be responsible for multiple nodes (i.e. producing more than one food product), and each node may contribute to more than one node (i.e. each lot of ingredients may be used in many lots of derived food products), adding complexity to the whole network.

Figure 20: An example of food network. Arrows represent any connection between supplier and consignee. Circles represent a specific lot of food/ingredient. Red shapes represent non-compliant sections of the food network. The dashed purple triangle highlights the node/product in common between the non-compliant sections of this food network. The area surrounded by the blue dashed line represent the food network drawn in the previous Figure 19.



Source: JRC.

The EU and national authorities need to identify where the non-compliance started, regardless if it concerns food safety and/or food fraud. Different sections of the food network (marked in red in Figure 20) show the same non-compliance almost simultaneously in the proposed IT system.

- Nowadays: the authorities' officers must manually draw the food network under investigation, trying to gather all relevant information in a timely manner, and aiming at identifying which "node" of the network may be the problematic one;
- In the future: with the help of the proposed IT tool, the non-compliant lot of ingredients (marked with the dashed purple triangle in Figure 20) which triggered the risk (by "contaminating" other

nodes of the food chain) is automatically signalled to food inspectors. It is the only node in common to all non-compliant sections of the food network already discovered by food inspectors; notably, some of the nodes not coloured in red, although possibly non-compliant, may not yet be uncovered along the food chain by official controls, and therefore are displayed in green.

Identifying the nodes which trigger the non-compliance, disrupting all the food chain, is pivotal to help official authorities to better target investigations and controls on certain lots and FBOs. In real food networks this exercise may be very challenging, given the high level of complexity and number of lots of ingredients. Therefore, human personnel alone may not be able to identify the most vulnerable nodes by simply drawing manually the food network and tracing the movement of goods.

Second advantage*:* the new traceability system would automatically identify hidden connections in the food network, supporting authorities to better uncover which FBOs and/or which food products are responsible for several non-compliances identified along their supplier-buyer chain, without depending on the manual labour of personnel from EU and national authorities.

Previously, the report classified the databases and intelligence sources in four macro-categories (Figure 8) according to data granularity and geographical coverage (internal market VS imports). The insight capacity is fed by those sources with high granularity, required to connect single products/lots and uncover the network of transactions in the internal market and at the EU border.

At the moment, data from FBOs are shared only upon request by Member States' competent authorities (e.g. in case of a food safety/food fraud non-compliance and subsequent opening of an investigation), and data from Member States' competent authorities are not shared with the EU or other Member States' competent authorities unless a non-compliance affects more than one Member State (data shared through iRASFF). As a consequence, not enough granular information are available on the EU food supply chain, limiting the data-mining possibilities of the proposed IT system.

Third advantage: the collection of all traceability-related data in a single centralised database would improve the interoperability and availability of data currently fragmented across different public and private databases, providing granular information for the proposed IT system to better perform its anticipatory capacity.

5.4.2 Investigative capacity

The *investigative capacity* capitalizes on the same approach and IT architecture of the *insight capacity* as described in the previous section. Whereas the *insight capacity* focuses on products and their related non-compliances, the *investigative capacity* exploits the full traceability potential to identify rogue FBOs who could recurrently jeopardise the integrity of the food supply chain. For this reason, also the insight capacity is fed by those databases and intelligence sources with high granularity (Figure 8), required to connect FBOs and uncover the network of transactions in the internal market or at the EU border.

In the ideal scenario (i.e. the availability of the "Transaction ID Cards" and "Food ID Cards"), the proposed IT tool would apply the same methodology on the new EU database to cover both the *insight capacity* and the *investigative capacity*, therefore, no further programmes would be needed. Figure 19 and Figure 20 focused on product traceability, however the same Figures are still relevant for the investigative capacity if, conceptually, "products" are replaced with "FBOs".

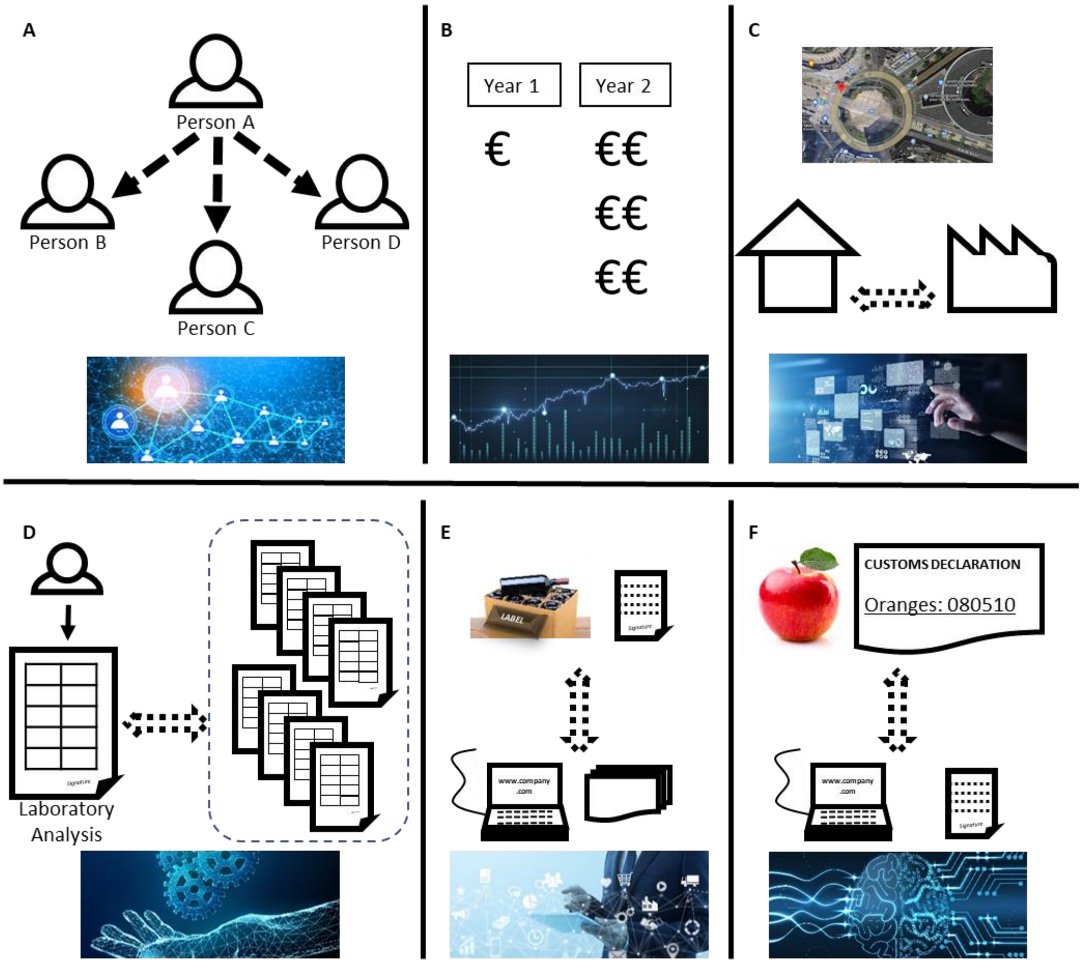
Figure 21 shows how the proposed IT tool would specifically exploit the structured and unstructured data available in the new EU database to investigate fraudulent and criminal activities affecting the food system(s). The most relevant functionalities include:

- **Connecting FBOs** who share common interests and are involved in recurring frauds, especially when group of people responsible for criminal activities are not immediately obvious from the official data. Examples of data sources include mostly social media (e.g. Facebook, Twitter, YouTube).
- **Signalling unrealistic increases in revenues** in short time. If a company has significantly increased its profits as compared to the average of other companies in the same business

sector, the system should identify such outlier and signal it to the authorities. Excessive profits may result from fraudulent operations, thus requiring increased scrutiny.

- **Assessing addresses and geographical locations** according to the suitability of the declared establishment for food business operations. For example, a rogue FBO may misdeclare the address of a private apartment on a certificate, but the system would compare the pictures from e.g. Google Maps with a set of parameters typical of food establishments, thus signalling to the investigators a suspicion on the official documentation.
- **Unveiling forged certificates and documentation** by comparing them with commercial and public templates. A FBO working in the organic sector may receive laboratory analyses for pesticides (using standard kits commercially available) registering some residues levels not compliant with the organic legislations. A fraudster could manually or digitally alter the certificate to remove the non-compliant values, but although a human inspector may have difficulties to recognise a single missing row among tens of lines, the system would automatically identify the missing data items by comparing the submitted documentation with templates stored internally or on online databases.
- **Recognise logos and third party certificates** (e.g. organic, Geographical Indications) on products and documentation, comparing them with the information available on the company website or registries from official authorities (e.g. EUIPO). The system would automatically signal if the submitted documentation declares some products as "organic", even though the company/registration website does not mention at all the possibility to buy organic products, or no organic logos/certification number is publicly available on the website.
- **Scrutinize customs declaration** with other data sources (company website, other documentation) to uncover misdeclaration of country of origin or CN codes in order to avoid risk-based official controls carried out on products coming from specific third countries or products subject to temporary increased scrutiny. A fraudster may alter customs declaration to pay less taxes or to avoid sanitary controls.

Figure 21: Functionalities covered by the *investigative capacity*. A) Connecting individuals through social networks, finding hidden linkages between their companies. B) Monitoring revenues of FBOs, highlighting suspicious increases. C) Comparing addresses of facilities and companies with real pictures from e.g. Google Maps, unveiling facilities not resembling FBOs. D) Comparing laboratory analyses with those provided by testing companies and certification databases, unveiling modified or removed rows from the submitted documentation. E) Comparing logos and certifications on the labels or documents with the company website, revealing inconsistencies between products sold online and products declared. F) Comparing CN codes declared on customs declarations with other documentation and company websites, unveiling misdeclaration of CN codes to pay less duties or to avoid specific sanitary controls.



Source: JRC; Google Maps.

5.4.3 Anticipatory capacity

The *anticipatory capacity* covers those steps before a non-compliance is discovered and the investigation starts. The *anticipatory capacity* supports and optimizes risk-based official controls to highlight suspicions and identify possible non-compliances later investigated through the functionalities covered by the *insight capacity* and the *investigative capacity*. The data accumulated during the inspections and investigations will help to improve the *anticipatory capacity* and better tailor it to real cases through a feedback mechanism. Several functionalities described previously for the *investigative capacity* may be applied in both steps: to start an investigation or during an investigation.

Analytics activities are classified in three macro-categories[110] according to the decision-making goal outcome:

— *Descriptive analytics*, highlighting relationships amongst data. Analysts may discover casual connections not evident or obvious if manually investigated;

— *Predictive analytics*, applying statistics- or ML- based techniques to predict future trends and patterns. It is pivotal that the organisation continues to accumulate data to verify the efficacy of the predictive algorithms;

— *Prescriptive analytics*, based on predictive analytics, and suggesting the best (i.e. resource-efficient) course of actions in order to achieve a specific outcome. In the ideal scenario, responses would be automatic following new inputs.

The proposed IT tool should support EU and national authorities in identifying the most suspicious/vulnerable products in the internal market or imported into the EU territory, tailoring official controls accordingly through an impartial and risk-based approach. Notably, as highlighted in the OPSON IX Report[111], "*Europol and Interpol managed to develop predictive models with indicators of possible shortage of raw materials*". It would be wise to profit from such previous experiences by integrating them in the context of this project. The long-term goal should be the decrease in number and impact of non-compliances in the internal market and at the EU border.

In the previous sections, the report classified databases and intelligence sources according to the level of granularity (Figure 8). The *anticipatory capacity* may feed on all databases, intelligence sources and IT tools already available, but especially on the data items of the "Food ID Card" associated with quantitative values to be assessed and compared (the "Food ID Card" data items in Annex 2 were chosen also because relevant as drivers). Given the vast diversity of data theoretically available, the *anticipatory capacity* should be able to predict vulnerabilities of specific supply chains according to e.g. production levels, natural conditions, FBOs identity, geopolitical crises, sanitary epidemics, market prices, country-specific factors, market trends, administrative barriers, to name a few. Some examples (sometimes inspired by real cases) include:

— The war in Ukraine has created a global shortage of wheat and sunflower oil, but the request from consumers is unchanged. It is reasonable to believe that those two supply chains (wheat and sunflower oil) are now under pressure and more vulnerable, therefore potentially more targeted by fraudsters given the need to fill a market void while prices rise.

— A FBO who has never sold organic olive oil, who has never been certified by an accredited certification body, and who has never advertised organic olive oil on the company websites, suddenly submits official documentation mentioning organic products delivered to a buyer in the olive oil supply chain.

— Sesame seeds from a specific third country were found to be highly contaminated with residue levels not compliant with the EU legislation. As a result, increased risk-based official controls have been redirected towards that commodity imported from that specific third country. The exporter FBO has thus decided to avoid the official controls either by a) changing CN codes or b) shipping the products (with correct CN codes) from a neighbouring country. The proposed IT tool

110 Spink, J., Elliott, C., Dean, M., & Speier-Pero, C. (2019). Food fraud data collection needs survey. npj Science of Food, 3(1), 1-8.

111 https://www.europol.europa.eu/publications-documents/operation-opson-ix-%E2%80%93-analysis-report

would signal such patterns by a) showing changes of market trends in similar products from the same country (e.g. less sesame seeds, more pumpkin seeds) or b) showing decreased imports of sesame seeds from the third country under scrutiny coupled with higher imports of the sesame seeds from neighbouring countries. In other words, the proposed IT tool would signal redirections of trade flows.

— A specific lot is sold at 67% of the average market price because the rogue FBOs has replaced beef with cheaper and unsafe horse meat without declaring it on the label. The ideal digital IT tool would identify such outlier according to the analyses of all transaction prices, thus redirecting official controls towards the suspicious lot "*too good to be true*".

— An animal disease has devastated beef production in third countries, and it could spread to other countries if left unchecked. So far, the EU has managed to contain the disease by nullifying the imports of contaminated lots. The ideal digital IT tool would increase the risk-based official controls on specific beef imports given the global animal health situation, but, as soon as the disease is over, the official controls would decrease accordingly.

— The yearly production of Manuka honey, specifically made in Australia and New Zealand, is estimated at e.g. 2 800 tons. In June the EU has already imported 1 500 tons of Manuka honey, and worldwide 1 300 tons of Manuka honey have already been traded in third countries. While approaching the maximal global production, the IT tool would signal imports of Manuka honey as suspicious, given that the traded quantities may exceed the estimated yearly production. In other words, it would signal if high-value products are traded in unrealistic quantities.

— Products are produced in a country X characterised by high corruption levels, weak control systems, recurrent non-compliances and low gross domestic product (GDP) per capita. Provided the other variables are the same, products produced and exported from country X would be considered more vulnerable to fraud and safety non-compliances compared to products produced in a country Y scoring better for the parameters under examination. Consequently, risk-based official controls would inspect more often products from country X rather than from country Y.

Finally, the results of investigations and official controls (supported by the i*nsight capacity* and *investigative capacity*) should feed inputs back to the IT algorithm in order to align itself to reality and improve the predictive power of the *anticipatory capacity*. Therefore, the IT tool should be capable of:

— Signalling vulnerabilities on a mix of vulnerability factors *a priori* established and inserted by human personnel;

— Suggesting potential vulnerability factors resulting from data meta-analysis, assessed by human personnel (to verify causation besides correlation) and later feeding back on the digital IT tool for further refinement.

In both cases, the most important question remains unsolved: how much weight should be assigned to each specific vulnerability factor? Could the machine-learning algorithm establish the weight of each value independently?

5.5 Vulnerability analysis of supply chains

Food safety management systems based on HACCP principles are widely applied by FBOs to ensure that food is safe to consume and it complies with regulatory requirements. ISO issued the ISO 22000 Food Safety Management series of standards. Together with a number of private standards (e.g. FSSC 22000, IFS Food, BRCGS Global Food Safety), they form the basis for certification of FBOs by third party auditors to document the availability and functioning of a system to ensure the safety and quality of their products. Several of those standards cover food fraud as well and require FBOs to conduct and document a food fraud vulnerability assessment.

Identifying food fraud risks and vulnerable points in a supply chain and the data sources that qualitatively or quantitatively characterise the risks are key elements for a data-driven predictive analytics system.

Vulnerability analysis systematically considers the factors that create vulnerabilities in a supply chain, i.e. where food fraud is more likely to occur[112]. Multiple food fraud vulnerability assessment tools have been developed to support FBOs in their endeavour to safeguard the supply chain (e.g. SSAFE). By adopting criminological theory and using vulnerability assessment tools, companies can assess vulnerability for food fraud on both company and supply chain levels. In addition, vulnerability analyses for certain high risk food supply chains already exist in the scientific literature.

Some examples of vulnerability analyses already performed include:

- Regarding **FBOs**, the industry segment and the tier are better predictors of vulnerability than company size or its geographical location. The influence of the business size varies much more with the company's location. The FBOs a) at the end (e.g. catering, retail) of the animal products supply chains, b) larger sized, and c) in Africa and Asia seem the most vulnerable to fraud[113]. The higher vulnerability of casual dining food services[114] (compared to mass caterers) was also confirmed, although elsewhere manufacturing was identified as the main point of adulteration (as the food becomes indistinguishable from its original form)[115].
- Due to the nature of **milk**, biological hazards (i.e. pathogenic micro-organisms as *Listeria* or *Salmonella*) are the most common threats to the integrity of the dairy supply chain[116]. Chemical (e.g. antibiotics, aflatoxins, heavy metals) and physical contaminants pose much lower threats for dairy products. The most common milk fraud issues include addition of water to milk and addition of illegal (and often unsafe) materials as e.g. milk powder, urea, cane sugar, melamine, formalin, caustic soda and detergents. Cheese and yoghurt are mostly affected by fraudulent documentation.
- The vulnerability to fraud in the **spice** chain is overall perceived as medium vulnerable[117], with higher vulnerability scores for technical opportunities (grinding the spices easily mask adulterants within) and economic drivers (spices being expensive commodities). Key risks include adulteration, detection difficulty, prices, and market competition. Recently the JRC has published the results of an EU wide coordinated control plan to establish the prevalence of fraudulent practices in the market of herbs and spices[118]; the overall rate of suspicious samples was 17%, ranging from 48% in the oregano supply chain to 6% for paprika/chilli.
- The **organic** sector covers credence-based products (similarly to kosher and halal) highly vulnerable to frauds. Some of the most recurrent drivers are the price asymmetry between organic and conventional food products (with consequent economic pressure and motivation to substitute, mislead or deceive) and the ethical culture of the organisation[119], although overall the organic supply chains were perceived slightly less vulnerable than conventional chains[120] due to fewer opportunities for fraud and the presence of more adequate controls.
- A recent study on **seafood**[121] reported the most recurrent frauds based on geographic location or supply chain node. The most prevalent fraud type is species adulteration with illegal or unauthorized veterinary residues (especially from Asia), ruminant DNA in fishmeal and various adulterants. The second most recurrent fraud is the chain of custody abuse, with health marks or certificates being absent, improper, or fraudulent. Aquaculture farming was found to be the most vulnerable supply chain node, followed by import/export, and then processing. The report

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112 Manning, L., & Soon, J. M. (2019). Food fraud vulnerability assessment: Reliable data sources and effective assessment approaches. Trends in Food Science & Technology, 91, 159-168

113 van Ruth, S. M., & Nillesen, O. (2021). Which company characteristics make a food business at risk for food fraud?. Foods, 10(4), 842

114 van Ruth, S. M., van der Veeken, J., Dekker, P., Luning, P. A., & Huisman, W. (2020). Feeding fiction: Fraud vulnerability in the food service industry. Food Research International, 133, 109158

115 Soon, J. M., & Abdul Wahab, I. R. (2022). A Bayesian Approach to Predict Food Fraud Type and Point of Adulteration. Foods, 11(3), 328

116 Montgomery, H., Haughey, S. A., & Elliott, C. T. (2020). Recent food safety and fraud issues within the dairy supply chain (2015–2019). Global Food Security, 26, 100447

117 Silvis, I. C. J., Van Ruth, S. M., Van Der Fels-klerx, H. J., & Luning, P. A. (2017). Assessment of food fraud vulnerability in the spices chain: An explorative study. Food Control, 81, 80-87

118 Maquet, A., Lievens, A., Paracchini, V., Kaklamanos, G., De La Calle Guntinas, M.B., Garlant, L., Papoci, S., Pietretti, D., Ždiniaková, T., Breidbach, A., Omar Onaindia, J., Boix Sanfeliu, A., Dimitrova, T. and Ulberth, F., Results of an EU wide coordinated control plan to establish the prevalence of fraudulent practices in the marketing of herbs and spices, EUR 30877 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42979-1, JRC126785

119 Manning, L., & Kowalska, A. (2021). Considering fraud vulnerability associated with credence-based products such as organic food. Foods, 10(8), 1879

120 van Ruth, S. M., & de Pagter-de Witte, L. (2020). Integrity of organic foods and their suppliers: Fraud vulnerability across chains. Foods, 9(2), 188.

121 Lawrence, S., Elliott, C., Huisman, W., Dean, M., & van Ruth, S. (2022). The 11 sins of seafood: Assessing a decade of food fraud reports in the global supply chain. Comprehensive Reviews in Food Science and Food Safety, 21(4), 3746-3769.

also provides the most recurrent frauds in specific continents; for example species substitution, species adulteration, fishery substitution, illegal processing and undeclared product extension are strongly associated with Europe and North America and with the top end of the supply chain.

- A recent food fraud vulnerability assessment in the Chinese **Baijiu** supply chain[122] came to the conclusion that the main food fraud drivers are numerous technical opportunities (lack of know-how on detection capabilities), strong economic drivers (the raw material price, the specific composition or properties of raw materials, and the competition level in the supply chain), and insufficient control measures (raw material counterfeiting detection systems are mainly used by producers, while most retailers do not test the authenticity of raw materials).

Official controls may already profit from the knowledge available to tailor risk-based official controls, which can later-on be improved once a data driven IT system provides more insight.

The Routine Activities Theory uses three elements to explain crimes: the motivated offender, the suitable target, and the lack of guardianship[123,124], therefore an environment less vulnerable hinders fraudulent activities. Based on this theory FFVAs aim at identifying opportunities for fraud in a supply chain, searching for motivations for supply chain stakeholders to commit fraud and assessing the efficiency and effectiveness of controls put in place (deterrents).

Food chains obviously differ in their specificities and characteristics and the associated risk factors will therefore vary as well. However, certain factors will pertain in general and they have been already described in the literature[124]. Based on this academic insight, PwC together with SSAFE categorised them into three main groups (Table 4), which they have used to compose a self-assessment questionnaire directed primarily at FBOs but a number of elements are also of relevance for competent authorities to identify fraud risk in a particular food chain.

Table 4: Indicators for the three key elements opportunities, motivations, and control measures and their numbering used in the food fraud vulnerability assessment.

Opportunities	Motivations	Control measures
1. Complexity of adulteration raw materials	12. Supply and pricing raw materials	31. Price asymmetries
2. Availability technology and knowledge to adulterate raw materials	13. Valuable components or attributes raw materials	32. Fraud monitoring system raw materials
3. Detectability adulteration raw materials	14. Economic conditions own company	33. Verification of fraud mon. system raw materials
4. Availability technology and knowledge to adulterate final products	15. Organizational strategy own company	34. Fraud monitoring system final products
5. Detectability adulteration final products	16. Ethical business culture own company	35. Verification of fraud monitoring system final products
6. Complexity of counterfeiting	17. Criminal offences own company	36. Information system own company
7. Detectability of counterfeiting	18. Corruption level country own company	37. Tracking and tracing system own company
8. Production lines/processing activities	19. Financial strains supplier	38. Integrity screening own employees
9. Transparency chain network	20. Economic conditions supplier	39. Ethical code of conduct own company
10. Historical evidence fraud raw materials	21. Organizational strategy supplier	40. Whistle blowing own company
11. Historical evidence fraud final products	22. Ethical business culture supplier	41. Contractual requirements supplier
	23. Criminal offences supplier	42. Fraud control system supplier

122 Wang, Y., Liu, J., Xiong, Y., Liu, X., & Wen, X. (2023). Food Fraud Vulnerability Assessment in the Chinese Baijiu Supply Chain. Foods, 12(3), 516.

123 Cohen, L. E., & Felson, M. (1979). Social change and crime rate trends: A routine activity approach. American sociological review, 588-608

124 van Ruth, S. M., Huisman, W., & Luning, P. A. (2017). Food fraud vulnerability and its key factors. Trends in Food Science & Technology, 67, 70-75

	24. Victimization of supplier	43. Mass balance control. supplier
	25. Corruption level country supplier	44. Tracking and tracing system supplier
	26. Economic conditions sector	45. Social control chain network
	27. Criminal offences customer	46. Fraud control industry
	28. Ethical business culture sector	47. National food policy
	29. Historical evidence branch of industry	48. Law enforcement local chain
	30. Level of competition in sector	49. Law enforcement chain network
		50. Fraud contingency plan

Source: SSAFE, PwC (2017).

Many of the key factors/drivers of food fraud can be described in qualitative or quantitative terms, which are accessible via existing data sources. For example, socio-economic and geopolitical data can be provided by Eurostat, FAO, World Bank, Transparency International, UN Development Reports, The Economist, The International Country Risk Guide, etc., which are relevant for assessing the fraud risks at a higher level, e.g. for an exporting country, a particular supply chain, or a combination of both.

Indexes at a country level for augmenting the predictive analytics for food fraud could include:

- The governance index of the country
- Whether there is a legal system regulating the food chain in the country
- The GDP of the country
- The economic growth of the country
- The supply chain index of the country
- The political risk index (PRI) of the country
- The human development index of the country
- Global Innovation Index of the country

A group of experts can help in translating qualitative statements into quantitative metrics, as devised by NSF Safety and Quality UK Limited[125] (Figure 22 and Figure 23).

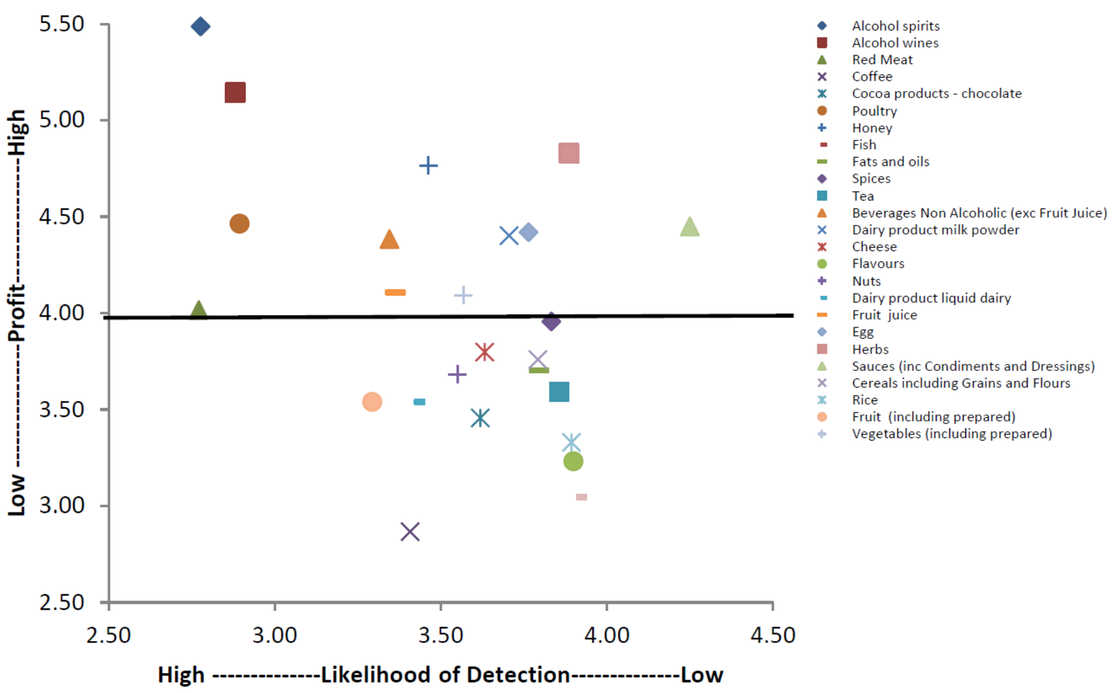
125 Jack, L. (2015). Risk modelling of food fraud motivation:'NSF fraud protection model'intelligent risk model scoping project FS 246004

Figure 22: Profit Metric and criteria.

Profit Indicative criteria		Cost of Commodity	Cost of Adulterant	Profit margin	Sales Volume
High	5	High raw commodity cost greater than£10/kg indicates profits more likely to be high	Low cost of raw commodity adulterant(s) <£0.5/kg indicates profits likely to be higher	Very high profit margin available greater than 50%: high premium product	Large number of potential outlets
	4	Medium-High raw commodity cost between £10/k and £3/kg indicates profits more likely to be high	Medium-low range raw commodity cost between £0.5/kg and £1.50/kg indicates profits more likely to be moderate	High profit margin available between 10%-50%. Premium product.	
	3	Medium range raw commodity cost between£3/kg and £1.50/kg indicates profits more likely to be moderate	Medium range raw commodity cost £1.50/kg and £3/kg indicates profits more likely to be moderate	Moderate profit margin available around 10%: everyday item with some premium but main opportunity is to undercut market price.	
	2	Middle-low raw commodity cost between £1.50/kg and £0.50/kg indicates profits more likely to be high	Medium-High cost between£3/kg and £10/kg indicates that profits are likely to be low	Low profit margin available between 1%-10%. Everyday product with limited opportunity to undercut.	
Low	1	Low cost <£0.50/kg indicates that profits are likely to be low	High cost greater than£10/kg indicates that profits are likely to be low	Very low or no premium available: basic commodity	Few outlets

Source: NSF Fraud Protection Model[125].

Figure 23: The NSF model for ranking food fraud risks.



Source: NSF Fraud Protection Model[125].

Each product category or topic to be covered requires substantial resources to:

— understand the legislation and policies in place;
— identify relevant databases;
— gather scientific evidence and assessments;
— consult stakeholders, especially those who will provide inputs (e.g. data and documents);
— establish the IT resources, both physical (e.g. servers) and digital (e.g. algorithms, programmes);
— assign personnel for monitoring and follow-up.

Recommendation 5

A substantial number of scientific publications describes attempts to identify vulnerability factors and food fraud drivers for specific commodities and tiers of the supply chain. However a more targeted approach is needed, as most of the published literature is primarily directed towards food businesses and not much consideration is given how competent authorities can use it for vulnerability assessment of complete supply chains and trading routes.

To bridge this gap it is recommended to initiate a project aimed at constructing generic supply chain maps for a selected number of foods/ingredients where historical fraud incidence data indicate an increased risk. Next, the project team, including supply chain experts, should asses their vulnerability and identify critical points in the chain (vulnerability analysis critical control points, VACCP). Based on the VACCP, relevant data sources characterising the food integrity risks should be identified, located inside as well as outside of the EC. The project's outcome would serve as a pre-requisite for the successful implementation of Recommendations 1 and 3 as both would profit from the inclusion of socio-economic and geopolitical indicators in the descriptive and predictive models. Conversely, the vulnerability assessment could benefit from the work conducted in Recommendations 1 and 3, because, during the data mining phase, valuable, previously unknown, and potentially actionable patterns of risk factors may surface. Including them together with the associated indicators could, in turn, improve the predictive ability of the model (i.e. self-learning capacity of the model).

Given the plethora of food products available to consumers, the complexity of global supply chains and the multitude of potential hazards compromising food integrity, the generic VACCP of supply chains and the associated predictive risk model can only include food ingredients that have a high risk of being the target for fraudulent manipulations. The Annual Report of the Alert and Cooperation Network, the annual summaries of the JRC Food Fraud Monthly Reports and commercial databases can be used for ranking ingredients on the basis of past food integrity incidences. To further prioritise them for inclusion in the programme risk ranking should be applied. Models for ranking food safety risks quite often use two dimensions where the risk likelihood (probability) is plotted against its impact (severity). The NSF Fraud Protection Model builds on such an approach but uses "Likelihood of Detection" and "Profit" instead as metrics (Figure 23). Ingredients/products situated in the right upper quadrant (highly profitable, less likely to be detected) would constitute the primary targets of fraudsters.

6 Remit and uncertainties of the ideal information-based risk analysis IT tool

A broad dialogue within the European Institutions and with the industry and civil society is needed to address some critical questions, set up boundaries and establish working modalities before consolidating any future IT system.

6.1 Which products should be monitored?

There is a need to frame which commodities/products to be covered and addressed through the ideal digital IT tool. There is no clear definition of food fraud at EU level. However, Article 2(21) of Commission Implementing Regulation (EU) 2019/1715 states that:

'fraud notification' means a non-compliance notification in iRASFF concerning suspected intentional action by businesses or individuals for the purpose of deceiving purchasers and gaining undue advantage therefrom, in violation of the rules referred to in Article 1(2) of Regulation (EU) 2017/625;

The legislative framework covered by Article 1(2) of Regulation (EU) 2017/625 includes food and food safety, genetically modified organisms, feed and feed safety, animal health and welfare, plant health, plant protection products, organic food, and EU quality schemes[126], some not covered by any previous section of this report. In addition to scientific evidences, a political decision is needed to establish up to which limits and topics the functionalities and coverage of the ideal digital IT tool should be enlarged to. A concrete opportunity could be starting with the core "food" commodities (i.e. destined to human consumption), slowly expanding to other topics according to the priorities decided at political level, and by integrating the lessons already acquired along the way.

6.2 Which risks should be addressed?

The ideal digital IT tool described so far may potentially be utilised to cover all aspects of the Food Risk Matrix (food quality, food fraud, food safety, and food defense). Some non-compliances are mostly financial, with no risks for consumer health. On the opposite, some food safety non-compliances do not necessarily bring obvious financial gains to the fraudsters.

By focusing only on financial risks, health (i.e. food safety) risks may be ignored, and vice versa. In case such system would be used by customs authorities, police offices and food safety agencies as well, the relative importance of financial risks VS health risks, and how to integrate the various risk typologies in the same IT system, should be established at political level. However, it seems a shared desire to cover both food fraud and food safety. As stated by Prof. Chris Elliott, "*it is sensible and prudent to assume all food fraud may be a potential risk to public health unless proven otherwise*"[127].

For now, two possibilities could be hypothesized for the predictive analytics algorithm (Figure 24):

— The ideal digital IT tool provides a vulnerability indicator for financial risks, and a separate indicator for health risks. Therefore, each product/transaction will carry at least two indicators, and it will be the responsibility of national authorities' officials to decide if focusing on products vulnerable to high financial risks/low health risks, or vice versa, without any other indication or direction from the ideal digital IT tool.

Or

— *A priori* the programmers establish within the ideal digital IT tool a certain weight for financial risks, and another weight for health risks, according to political choices rather than via ML. Such parameters are weighted and integrated into a single parameter/value, giving the possibility for national authorities' officials to have a clear ranking of most vulnerable products, taking into account all risks (e.g. financial and health).

In case it is established at political level to combine all risk indicators into a single value, it could be still relevant to visualize the single indicators (financial and health) separately, because some agencies and institutions may only be interested in assessing and addressing a specific risk typology

126 https://agriculture.ec.europa.eu/farming/geographical-indications-and-quality-schemes/geographical-indications-and-quality-schemes-explained_en

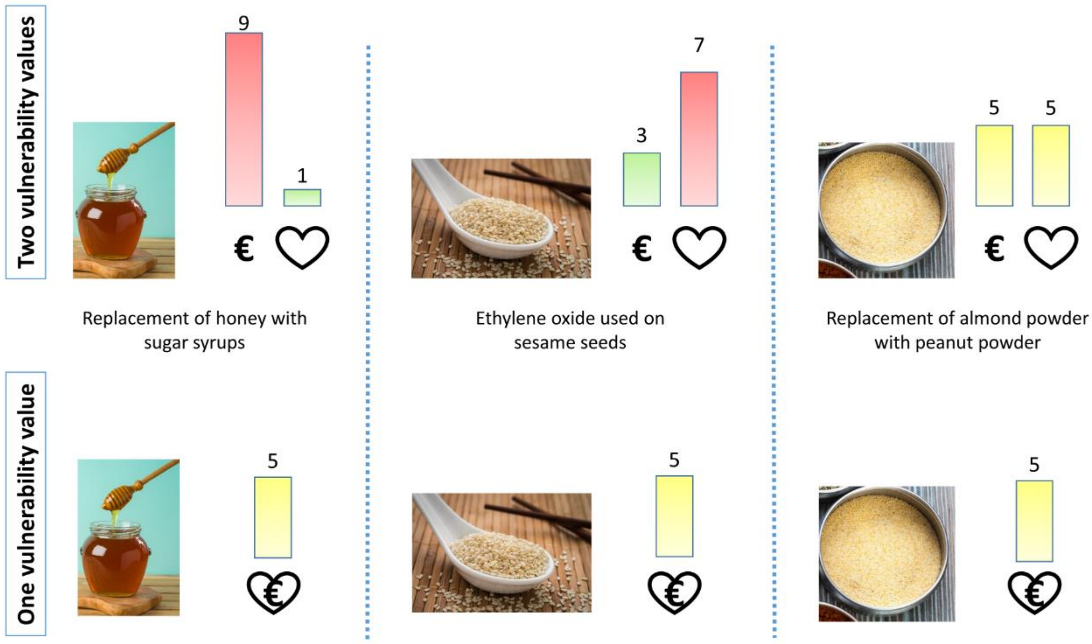
127 Elliott, C. (2014). Elliott Review into the integrity and assurance of food supply networks-Final report: A national food crime prevention framework. PB 14192

(e.g. DG TAXUD is mostly interested in monetary fraud indicators, whereas the European Food Safety Authority mostly in food safety risks).

This report focuses on the ideal digital IT tool required to predict vulnerabilities mostly falling under the financial aspect. In case of a political will to predict and rank health risks according to frauds, products, exposures, etc..., the European Food Safety Authority is the most authoritative choice to assess if health risks may be given priorities, and to provide such ideal ranking (and indicators) of the most relevant drivers for food safety issues.

Finally, it is worth mentioning that the official controls in place in many Member States mostly focus on food safety aspects, rather than fraudulent ones. Therefore, a risk-based official control systems should profit from the already established framework available to deal with food safety threats. As noted by DG SANTE[128], "*EU countries have some arrangements in place to deal with fraud threats in the agri-food chain, but official controls focusing on fraudulent and deceptive practices are not yet systematically in place across all control areas.*"

Figure 24: the two aspects of food integrity, where a non-authorised treatment or ingredient substitution introduces a food safety hazard. The € symbol represents financial risks (i.e. monetary losses), whereas the heart represents health risks (i.e. food safety threats). Risk severity ranks from 1 (very low) to 10 (very high).



Source: JRC.

6.3 Which illegal activities should be targeted?

The European legislative framework and the *Codex Alimentarius* lack a clear definition of food fraud. Therefore, this report drafts the layout of a system covering a subject so far undefined from a legal perspective. Two steps may be necessary to be taken if any future project will follow the present report:

— Establishing the legal definition of food frauds in the EU legislation;

— Deciding which frauds should be covered by the future information-based risk analysis IT tool.

The food fraud scientific community has repeatedly tried to establish and classify food frauds[129]; however, some criminal activities are still lacking clarity and are not considered as fraudulent

128 European Commission, Directorate-General for Health and Food Safety, (2022). Report from the Commission on the overall operation of official controls carried out in Member States (2019-2020) to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products – , Publications Office of the European Union

129 Robson, K., Dean, M., Haughey, S., & Elliott, C. (2021). A comprehensive review of food fraud terminologies and food fraud mitigation guides. Food Control, 120, 107516.

activities in some classifications (e.g. smuggling; black and grey market; low hygiene conditions; IUU fishing).

7 Conclusions

This report provides an overview of European and international databases, intelligence sources and IT tools covering food integrity, namely the safety and authenticity of food, which protects the interests of honest food chain stakeholders, including consumers.

The needs of the different European Commission services have been captured through interviews of staff dealing with the development and implementation of food chain policies. From the interviews three main capacities (*insight*, *investigative*, *anticipatory*) emerged, which a data-driven decision system should possess to scale up the protection of the European food system(s).

Food-related data are collected separately and in a mostly non-standardised manner by various EU and national actors, according to different legal bases. Data interoperability, accessibility, reliability has to be addressed and improved to serve as a solid foundation for further data analytics by AI to flag anomalies in supply chains. This information, together with relevant socio-economic and geopolitical indicators and specific supply chain knowledge, would support regulatory bodies to assess the situation and, if necessary, choose the most appropriate mitigation measures.

Substantial investments in computing infrastructure and human capital are required to modernise the current IT landscape inside and outside the EC.

Centre of competence on food integrity

Member States have already expressed their wishes for the creation of a centre of competence which could scale-up the fight against food fraud and protect the integrity of the European food systems[130]. The creation of a dedicated Interservice Group with representatives of the interested DGs and EU offices (namely JRC, AGRI, SANTE, MARE, TAXUD, OLAF, RTD) could be the starting point for Commission services to share information, needs and contact points. In addition to policy officers, such a centre of competence requires the involvement of technical officers with knowledge on food fraud, food safety, criminology, data analysis, economics, markets, customs, food law, statistics, to name a few. The involvement of other relevant authorities and agencies (e.g. European Food Safety Authority, Europol) would provide a strong added value for the success of the centre of competence, especially from a technical perspective.

The centre of competence will be best placed to assess the food fraud and food safety drivers, trends and vulnerabilities already known, producing food fraud vulnerability assessments and monthly reports by analysing e.g. market prices and trends, geopolitical developments, recent food safety scandals, and ultimately supporting national inspectors to redirect sanitary and customs controls towards specific products in the internal market and at the EU border through a qualitative (but not quantitative) analysis.

Pilot project on seafood

At the beginning, a pilot project may be set up with the seafood sector (Annex 3), given the relevance of the sector and the well-established controls, in particular regarding fishing catches and imports, including the measures to fight against IUU fishing. Seafood commodities are subject to fraudulent practices and food safety risks, and the EU is heavily dependent on imports of fish and fishery products.

As the EU cannot access all the data required to build a full traceability of all supply chains, it is worthy to focus on a specific step of the food supply chain on imports, on which the EU has access to highly valuable and granular data. Several databases and intelligence sources are already focusing on food imported at the EU border: Surveillance 3, COMEXT, AFIS-CSM, AMT, THESEUS, TRACES, iRASFF, CATCH, DG TAXUD Crisis Impact Assessment.

Food ID Card

As the development of a comprehensive "Food ID Card" is hindered by the gaps in the information on all transactions taking place within the internal market, such prototype could focus on collecting the data required to build the "Transaction ID Cards" of imported products. The JRC can access several

130 https://knowledge4policy.ec.europa.eu/food-fraud-quality/technical-meetings-kc-ffq-1_en

databases managed by other Commission services without bringing about any change to the current legislative framework.

The creation of a Food ID Card template, and the related Transaction ID Cards, is an ambitious and resource-demanding exercise. It is however pivotal for the protection of the European food systems for a number of reasons:

- It provides a complete overview of trade data at regional, national and global level, fostering the creation of data-driven policies and unveiling trends for foresight exercises. The Covid-19 crises and the Russian aggression against Ukraine has demonstrated that some of our globally interconnected food supply chains are more vulnerable than expected. Uncovering such vulnerabilities with data-driven tools is the first step to reduce dependencies of the EU for critical/essential products.
- Besides food frauds, and despite of high levels of protection experienced by EU citizens, food safety risks are a constant threat to consumer health. The availability of the complete and digitalised EU food network in the hands of experienced EU and national food inspectors is the most valuable asset to quickly identify and withdraw unsafe products from the market, ultimately reducing morbidity and mortality levels among EU citizens, while spotting establishments uncompliant with the food hygiene legislation and wrongdoers.
- Food fraud activities involve significant economic gain. There is a growing interest from criminal cartels in “agropiracy” because of the increasing financial opportunities. Targeted and swift intervention will be facilitated with improved traceability and quickly available information.

Also, in times of war, bioterrorism may become a stronger threat to EU citizens. Bioterrorists or hostile nations may target food supply chains compromising food security or even using food commodities as vectors for biological or chemical attacks.

Cooperation with stakeholders

A wise strategy would capitalise on the framework already in place to tackle food safety non-compliances and upscale it against other risks in the Food Risk Matrix (i.e. food fraud, food quality, and food defense). Therefore, it is crucial to liaise with the several stakeholders involved in different aspects of food fraud and food safety:

— Member States collect all data on non-compliances affecting their national food system(s). At the moment they are legally obliged to share cross-country cases with other Member States and EU institutions for non-compliances on food fraud, food safety and the organic sector, with no obligation to share national cases. On the other hand, most of police investigations (national and international) are shared with Europol on a voluntary basis.

— A dialogue with Member States' representatives (food safety authorities, customs, police authorities, Ministries) is necessary to increase cooperation to tackle all risks in the Food Risk Matrix. Willingness to share data on national non-compliances and investigations is the first step to strengthen and enrich the future EU database, and ultimately feed and empower more consistently the three capacities (*insight*, *investigative* and *anticipatory*) of the proposed IT system.

— Different aspects of the European food system(s) fall under the remit of several DGs of the EC. Setting up an Interservice Group, and at later stage a dedicated centre of competence on food integrity, will allow for the management of EU food systems in a comprehensive and more efficient manner.

— The civil society and the industry, in particular producers, manufactures, traders, retailers and consumers. The involvement and support from these stakeholders is necessary to proceed and scale-up the protection of the most vulnerable European food sector(s). Especially the stakeholders with economic interests (producers, manufactures, traders, and retailers) will benefit from mutual sharing of information.

— In parallel, a dialogue should be fostered with their representatives at EU and national level to build their own private traceability system (e.g. managed by umbrella organisations) to speed up information sharing in case public authorities need records covering one-step forward and one-step backward for their investigations.

Food risk vulnerability assessments (FRVAs)

In the context of the *anticipatory capacity*, in the best-case scenario the IT tool relies on quantitative values associated with each data item in order to build vulnerability profiles (in terms of food fraud and food safety) for each product/transaction inside the system. Some data items in the “Food ID Card” and “Transaction ID Card” are already associated with quantitative values (e.g. prices, GDP per capita, Corruption Index, quantities); while others are only related to qualitative factors.

Translating the qualitative information in quantitative values in terms of vulnerability will have to be performed by a dedicated expert group who will widen the scope of the currently used FFVAs in order to cover all aspects of the Food Risk Matrix, resulting in the newly called food risk vulnerability assessments (FRVAs). The expert group should assign values not only for drivers and vulnerabilities in terms of food fraud risks, but also in terms of food safety risks. The EU legislative framework and international guidelines already encourage to perform risk-based official controls (Annex 4).

The expert group should be composed mostly by technical experts from the food industry and from academia, supervised (and in some cases joined) by staff working in the centre of competence on food integrity, capitalising on the experience from “The Model” developed by the US FDA FSMA and other international initiatives (Section 1.3.1).

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Regulation (EU) 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers

Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives

Regulation (EU) 2016/679 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation, GDPR)

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List of abbreviations and definitions

Abbreviations	Definitions
AAC	Administrative Assistance and Cooperation
AI	Artificial Intelligence
API	Application Programming Interface
BTI	Backward transaction ID
CN	Combined Nomenclature
CTE	Critical Tracking Events
CTI	Current Transaction ID
DG	Directorate-General
EFSA	European Food Safety Authority
EMA	Economically Motivated Adulteration
EORI	Economic Operators Registration and Identification
EPCIS	Electronic Product Code Information Services
EU	European Union
EUIPO	European Union Intellectual Property Office
EWS	Early Warning System
FBO	Food business operator
FDA	Food and Drug Administration
FFVA	Food Fraud Vulnerability Assessment
FRVA	Food Risk Vulnerability Assessment
FSMA	Food Safety Modernization Act
FTI	Forward Transaction ID
FTL	Food Traceability List
GDP	Gross domestic product
GI	Geographical Indication
GIIN	Global Intermediary Identification Number
HACCP	Hazard Analysis and Critical Control Points
HS	Harmonised System
IMSOC	Information Management System for Official Controls
IoT	Internet of Things
IPR	Intellectual property rights
ISAR	Import Screening for the Anticipation of Food Risks
ISIC	International standard industrial classification
IT	Information Technology
ITGS	International trade in goods statistics
ITRE	European Parliament's Committee on Industry, Research and Energy
IUU	Illegal, unreported and unregulated

JRC	Joint Research Centre
KDE	Key Data Element
LEI	Legal Entity Identifier
ML	Machine Learning
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
NUTS	Nomenclature of Territorial Units for Statistics
OCR	Official Controls Regulation
PRI	Political risk index
RASFF	Rapid Alert System for Food and Feed
SAD	Single Administrative Document
SCC	Supply Chain Complexity
SCL	Supply Chain Length
SSR	Self-sufficiency ratio
TLC	Traceability lot code
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
USA	United States of America
VACCP	Vulnerability Analysis and Critical Control Points
WCO	World Customs Organization
WUR	Wageningen University & Research
WWF	World Wildlife Fund

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Annex 1: Data Science, AI and data quality

Data Science

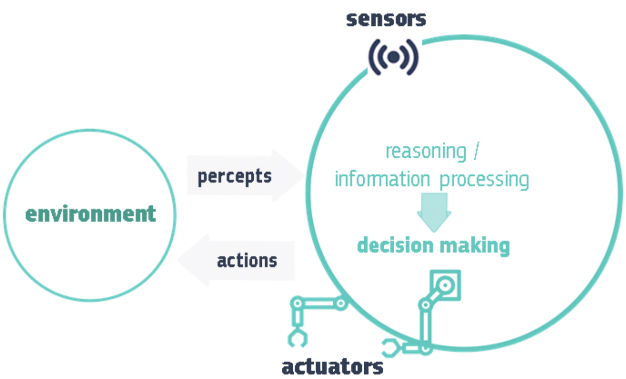
Data science is today considered the fourth approach to scientific discovery (together with *experimentation*, *modelling*, and *computation*), and a separate science embracing competencies belonging to different traditional academic sectors, not being simply a branch of mathematics. Data scientists integrate formal statistical theory, software development and database theory. Therefore, data scientists are versatile in designing and improving data collection/gathering, statistical analysis, data visualization and interpretation, and in coding innovative IT programmes tailored to accomplish such goals. There are two goals in analysing data[131]:

- **Predicting** what the responses are going to be to future input variables;
- **Inferring** how nature is associating the response variables to the input variables.

Machine predictions provide probabilistic results and a corresponding risk score.

The European Commission has already started to address the potentialities and risks brought forward by AI[132]. According to the *Ethics Guidelines for Trustworthy AI*[133], prepared by the High-level Expert Group on Artificial Intelligence, a trustworthy AI should be lawful, ethical and robust. The seven key requirements for a trustworthy AI are: (1) human agency and oversight; (2) technical robustness and safety; (3) privacy and data governance; (4) transparency; (5) diversity, non-discrimination and fairness; (6) environmental and societal well-being; and (7) accountability.

Figure 25: A schematic depiction of an AI system.



Source: High-level expert group on artificial intelligence. (2019). Ethics guidelines for trustworthy AI.

The JRC has published a report defining what AI is[134], identifying four commonalities in the assessed AI definitions:

- Perception of the environment, including the consideration of the real world complexity;
- Information processing: collecting and interpreting inputs (in form of data);
- Decision making (including reasoning and learning): taking actions, performance of tasks (including adaptation, reaction to changes in the environment) with certain level of autonomy;
- Achievement of specific goals: this is considered as the ultimate reason of AI systems.

131 Donoho, D. (2017). 50 years of data science. Journal of Computational and Graphical Statistics, 26(4), 745-766.

132 https://ec.europa.eu/digital-single-market/en/artificial-intelligence

133 High-level expert group on artificial intelligence. (2019). Ethics guidelines for trustworthy AI.

134 European Commission, Joint Research Centre, Samoili, S., López Cobo, M., Gómez, E. (2020). AI watch – Defining artificial intelligence : towards an operational definition and taxonomy of artificial intelligence, Publications Office

The baseline AI definition is the one established by the High-level Expert Group on Artificial Intelligence:

"Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions.

As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems)."

The European Parliament's Committee on Industry, Research and Energy (ITRE committee) has published a comprehensive study highlighting challenges and opportunities for using Artificial Intelligence[135]. The AI applications fit, broadly speaking, in two macro-categories: a) enhancement of the **performance and efficiency** of industrial processes; and b) **human-machine collaboration** (which relates to the project outline in this document). The food sector is not among those considered at the forefront in applying AI computational algorithms, although Europe shows competitive strengths in industries like automotive, healthcare, financial services, energy, tech and media.

Machine learning is considered a sub-discipline of AI, defined as "*where computers programs (algorithms) learn associations of predictive power from examples in data. Machine learning is most simply the application of statistical models to data using computers.*"[136] The most wide-spread machine-learning approaches are *supervised learning*, *unsupervised learning*, and *reinforcement learning*. Machine learning utilises methods not based on *a priori* assumptions about the distribution of data, but on finding patterns autonomously in difficult situations. Notably, machine learning can also reduce the baseline need for data harmonisation.

It is worth concluding by stressing the potential ethical, societal and legal controversies in using AI-based machine learning algorithms for decision-making, security and law enforcement purposes[137]. For example, the GDPR Regulation states that *"The data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her"*[138], protecting against misuse or abuse of citizens' personal data. The European Parliament Research Service has published as well a Study specific on biases and AI[139].

Data quality

Data quality is the degree to which dimensions of data meet requirements. Data quality (inputs) is pivotal to guarantee solid results from subsequent analysis (outputs). The most common twelve dimensions of data quality are[140]:

— **Accuracy** (i.e. correctness of data values): the degree of closeness of data values to real values.

— **Availability**: the degree to which data can be consulted or retrieved by data consumers or a process.

135 Eager, J, (2020) Opportunities of Artificial Intelligence, Study for the committee on Industry, Research and Energy, Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament, Luxembourg. https://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL_STU(2020)652713

136 Panch, T., Szolovits, P., & Atun, R. (2018). Artificial intelligence, machine learning and health systems. Journal of global health, 8(2).

137 Wynsberghe, A. V. (2020). Artificial intelligence: From ethics to policy. Panel for the Future of Science and Technology.

138 Art. 22.1 of Regulation (EU) 2016/679 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation, GDPR)

139 European Parliament, Directorate-General for Parliamentary Research Services, Miguel Beriain, I., Jiménez, P., Rementería, M. (2022). Auditing the quality of datasets used in algorithmic decision-making systems – , Publications Office of the European Union

140 http://www.dama-nl.org/data_quality/

- **Clarity**: the ease with which data consumers can understand the metadata.
- **Completeness of records** (i.e. coverage): the degree to which all required records in the dataset are present.
- **Completeness of data values**: the degree to which all required data values are present.
- **Consistency**: the degree to which data values of two sets of attributes (within a record, within a data file, between data files, within a record at different points in time) comply with a rule.
- **Currency**: the degree to which data values are up to date.
- **Punctuality**: the degree to which the period between the actual and target point of time of availability of a dataset is appropriate.
- **Timeliness**: the degree to which the period between the time of creation of the real value and the time that the dataset is available is appropriate.
- **Traceability**: the degree to which data lineage is available.
- **Uniqueness**: the degree to which records occur only once as a record in a data file.
- **Validity**: the degree to which data values comply with rules.

Other dimensions[141] of data quality cover:

- **Access security**: the degree to which access to datasets is restricted.
- **Accessibility**: the ease with which data can be consulted or retrieved.
- **Appropriateness**: the degree to which the format is suitable for use.
- **Ability to represent null values**: the degree to which a format allows null values in an attribute.
- **Coherence**: the degree to which datasets can be combined.
- **Comparability of populations**: the degree to which data values representing two populations have the same definition and are measured in the same way.
- **Comparability over time**: the degree to which data values over time have the same definition and are measured in the same way.
- **Compliance with laws, regulations, or standards**: the degree to which data and datasets are in accordance with laws, regulations, or standards.
- **Confidentiality**: the degree to which disclosure of data should be restricted to authorized data consumers.
- **Credibility**: the degree to which data values are regarded as true and believable by data consumers.
- **Equivalence**: the degree to which attributes stored in multiple datasets are conceptually equal.
- **Granularity**: the degree to which a single characteristic is subdivided in attributes.
- **Integrity**: the degree of absence of data value loss or corruption.
- **Interpretability**: the degree to which data are in an appropriate language and units of measure.
- **Latency**: the period of time between the point when the data is created and the point when it is available for use.
- **Linkability**: the degree to which records of one data file can be correctly coupled with records of another data file.
- **Metadata compliance**: the degree to which the data values are in accordance with their definition, format specification and value domain.

141 Adapted from: Black A., Nederpelt P. van. (2020) Dimensions of Data Quality Dimensions. Research paper. DAMA-NL; and Black A., Nederpelt P. van. (2020) Dictionary of dimensions of data quality (3DQ) Dictionary of 60 Standardized Definitions. DAMA-NL

- **Naturalness**: the degree to which the composition of datasets is aligned with the real-world objects that they represent.
- **Objectivity**: the degree to which the data values are created in an unbiased manner.
- **Obtainability**: the degree to which the data can be acquired.
- **Plausibility**: the degree to which data values match knowledge of the real world.
- **Portability** (Data): the degree to which data can be installed, replaced, or moved from one system to another while preserving the existing quality.
- **Portability** (Format): the degree to which a format can be applied in a wide range of situations.
- **Precision**: the degree of accuracy with which data values are recorded or classified, OR the degree to which the error in data values spreads around zero (in statistics).
- **Reasonability**: the degree to which a data pattern meets expectations.
- **Recoverability**: the degree to which datasets are preserved in the event of incident.
- **Redundancy**: the degree to which logically identical data are stored more than once.
- **Referential integrity**: the degree to which data values of the primary key of one data file and data values of the foreign key of another data file are equal.
- **Relevance**: the degree to which the composition of datasets meets the needs of the data consumer.
- **Reliability**: the closeness of the initial data value to the subsequent data value.
- **Reproducibility**: the degree to which a dataset can be recreated with the same data values.
- **Reputation**: the degree to which data are trusted or highly regarded in terms of their source or content.
- **Retention period**: the period that datasets are available until they can or must be deleted.
- **Value**: the degree to which data provide advantages from their use.
- **Variety**: the degree to which data are available from different data sources.
- **Volatility**: the degree to which data values change over time.

An important absent from the above list is the concept of "**Interoperability**". Interoperability describes the ability of two components or systems to exchange data and utilise efficiently those data. The concept of interoperability has been also addressed in the context of the Sustainable Development Goals[142].

According to the Cambridge dictionary[143], interoperability is "*the degree to which two products, programs, etc. can be used together, or the quality of being able to be used together.*"

According to Merriam-Webster[144], interoperability is "*the ability of a system (such as a weapons system) to work with or use the parts or equipment of another system*".

142 https://unstats.un.org/capacity-building/meetings/UNSD-DFID-SDG-Open-Data-Bangladesh/documents/Day-2-Interoperability.pdf

143 https://dictionary.cambridge.org/it/dizionario/inglese/interoperability

144 https://www.merriam-webster.com/dictionary/interoperability

Annex 2: The Transaction ID Card data items

Product

The classification/nomenclature of foods is highly variable among the various EU databases and systems. Consequently, this section will focus only on the many food nomenclatures utilised in the European Institutions, but given the high number of entities (sometimes thousands), no Annex will be provided with the details of each single classification.

- The **RASFF Portal**[145] classifies entries in 37 product categories covering food, feed, live animals, water and food contact materials. The categories are quite generic and broad, and are not organised hierarchically in sub-categories; therefore, the RASFF food classification may not be the best choice for a digital IT tool that has to identify specific vulnerabilities in specific food chains. For example, the category "Fats and oils" covers olive oils and other vegetable oils as well, the seconds often used to adulterated the firsts. Aggregating statistics for both products (the adulterant and the adulterated) is not effective to identify vulnerabilities specific for e.g. olive oil.

  The RASFF nomenclature is also used in the JRC Food Fraud Monthly Reports[146].
- The **EFSA FoodEx2 system**[147] is the food nomenclature that complements the Standard Sample Description data model. It was originally designed for risk assessment purposes (i.e. evaluating the exposure of consumers to specific foods); it contains around 4 400 terms related to food and around 700 terms related to feed, distributed across seven hierarchies[148].
- **Regulation 1333/2008**[149], covering food additives, established a food classification system[150] of 168 terminologies distributed across four hierarchies.
- The **Opson IX Report**[151] nomenclature includes 15 broad categories not organised hierarchically.
- The World Customs Organization (WCO)[152] **Harmonised System (HS)**[153] is a multipurpose international product nomenclature, updated every 5 years, based on six digits (Chapters, Headings, Subheadings) comprising more than 5000 commodity groups[154]. It is a classification utilised by all WCO countries (more than 200 countries) covering over 98 % of the merchandise in international trade.
- The DG TAXUD **Combined Nomenclature (CN)**[155] further expands the WCO HS and contains thousands of codes used for two purposes: Common Customs Tariff and the EU's external trade statistics. CN codes are also used for internal trade statistics. Most trading nations apply a similar nomenclature. CN codes are updated every year by amending Annex I to the basic Council Regulation (EEC) No 2658/87[156] and they arrive up to 8 digits distributed across four hierarchies. Part of Surveillance data use the CN codes, because exports usually use the CN codes. Part of the IMSOC systems use the CN codes as well.
- The DG TAXUD **TARIC nomenclature**[157,158] is a subdivision of the previous CN nomenclature, improving the granularity up to 10 digits. Out of 99 Chapters, TARIC shows 24 Chapters covering the food sector (Chapters 1-24) hosting in total 5 253 codes distributed across five hierarchies. TARIC codes are used for all imports into the EU, and more rarely for some exports; as a

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145 https://webgate.ec.europa.eu/rasff-window/screen/search

146 https://knowledge4policy.ec.europa.eu/food-fraud-quality/monthly-food-fraud-summary-reports_en

147 https://www.efsa.europa.eu/en/data/data-standardisation

148 European Food Safety Authority (EFSA). (2015). The food classification and description system FoodEx 2 (revision 2) (Vol. 12, No. 5, p. 804E)

149 Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives

150 https://webgate.ec.europa.eu/foods_system/main/?event=categories.search

151 EUROPOL (2021) Opson IX Report. https://www.europol.europa.eu/publications-documents/operation-opson-ix-%E2%80%93-analysis-report

152 http://www.wcoomd.org/

153 http://www.wcoomd.org/en/topics/nomenclature/overview/what-is-the-harmonized-system.aspx

154 http://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs-nomenclature-2022-edition/hs-nomenclature-2022-edition.aspx

155 https://taxation-customs.ec.europa.eu/business/calculation-customs-duties/customs-tariff/combined-nomenclature_en

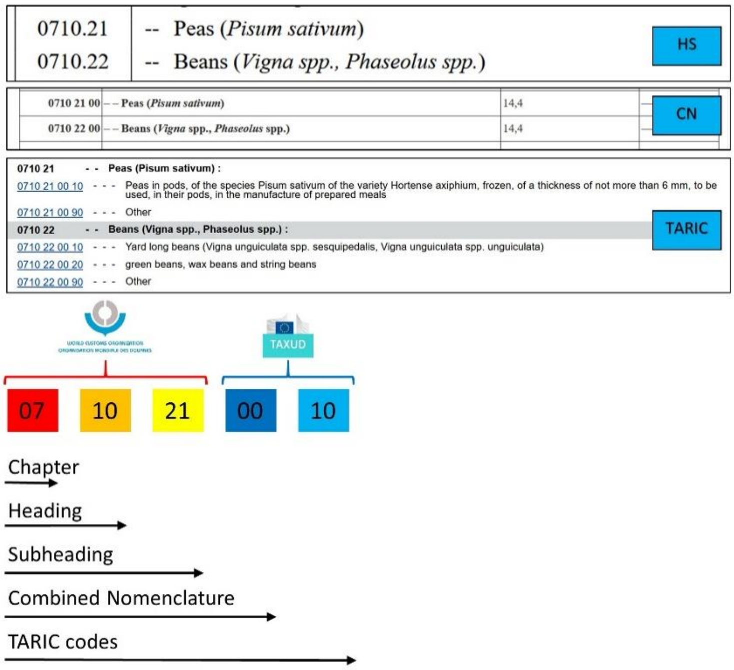
156 Council Regulation (EEC) No 2658/87 of 23 July 1987 on the tariff and statistical nomenclature and on the Common Customs Tariff

157 https://taxation-customs.ec.europa.eu/business/calculation-customs-duties/customs-tariff/eu-customs-tariff-taric_en

158 https://ec.europa.eu/taxation_customs/dds2/taric/taric_consultation.jsp?Lang=en&Expand=true&SimDate=20220715

consequence, part of Surveillance data use the CN codes, and THESEUS uses fully the TARIC codes for detailed analyses. Part of the IMSOC systems uses the TARIC codes as well. TARIC codes are updated every day.

Figure 26: Difference between HS, CN and TARIC nomenclature. The same commodities ("Peas" and "Beans") are classified up to 6 digits in the Harmonised System (upper part), up to 8 digits in the Combined Nomenclature (middle part), but the level of granularity in the classification of the same products increases up to 10 digits in the TARIC nomenclature (lower part).



Source: JRC; TARIC database.

The TARIC nomenclature (10 digits) seems the best option to classify food commodities in detail, being more accurate and updated daily. In case such level of granularity is not available, the CN codes (8 digits) may be the second best choice. Notably, some of the richest EU databases already utilise TARIC or CN codes for their classification, simplifying any envisioned future harmonisation.

Physical qualities and processing level

Product fraud is generally easier to achieve with liquid, ground, prepared and powdered products rather than whole foods[159,160], and complex foods with multiple ingredients generally offer greater fraud opportunity than simple, single-ingredient products. For example, processing techniques in the spice chain (grinding, chopping, milling) represent a great risk of adulteration (being hidden in ground or crushed material)[161]; similar observations can be applied to the fish supply chain, as recognizable external morphological features are typically removed when the fish is filleted or otherwise processed[162] (i.e. it is easier to declare the wrong species of a fish fillet compared to the whole fish). Frozen food is also more vulnerable to fraud, as inspectors may have difficulties to check the central part of a lot completely frozen, potentially hiding adulterated products. For this reason, a specific Working Group should establish a specific quantitative ranking to the different

159 Jack, L. (2015). Risk modelling of food fraud motivation:'NSF fraud protection model'intelligent risk model scoping project FS 246004.

160 Power, A. C., Jones, J., NiNeil, C., Geoghegan, S., Warren, S., Currivan, S., & Cozzolino, D. (2021). What's in this drink? Classification and adulterant detection in Irish Whiskey samples using near infrared spectroscopy combined with chemometrics. Journal of the Science of Food and Agriculture, 101(12), 5256-5263.

161 Silvis, I. C. J., Van Ruth, S. M., Van Der Fels-klerx, H. J., & Luning, P. A. (2017). Assessment of food fraud vulnerability in the spices chain: An explorative study. Food Control, 81, 80-87.

162 Wong, E. H. K., & Hanner, R. H. (2008). DNA barcoding detects market substitution in North American seafood. Food Research International, 41(8), 828-837

qualities of products in order to provide numerical inputs to the ideal digital IT tool; for example, a fish fillet would be valued quantitatively more risky/vulnerable than a whole fish.

Refrigeration

The need of being refrigerated during the transportation or storage phases presents critical safety risks in case the cold chain is interrupted. Although such data item does not relate much to food fraud, in case the ideal digital IT tool will also cover the food safety aspects it would be relevant to notice if specific products require refrigeration or not.

Supply situation

The local, regional and global supply situation for a specific product influences the probability of being targeted by fraudulent practices: if the demand is higher than the offer, there is a vacuum economically advantageous to be filled. The Covid-19 crises or the Ukrainian war have shown that more globalised and longer supply chains are more vulnerable to external shocks and unexpected shortages. Several databases, intelligence sources and IT system already over the global market, although it remains difficult to understand how to quantify this data item.

Transaction price

In this section, transaction price means the price as indicated in that specific lot, e.g. in a cargo.

Food fraudsters are agents who sell an adulterated product to the victim trying to convince them of its authenticity[163]. This kind of good is called *deceptive product*[164] and, in this category, consumers might look for lower prices, but they would not buy an outright fake good[163].

Food fraudsters have the maximization of profits and minimization of costs as objective[165,166] hence criminal enterprises will participate in the market also adopting strategies similar to the legitimate economic agents and one of those is price competition[163].

Prices have been under the scope of OLAF using the JRC-developed algorithm THESEUS to prevent import duties evasion, value-added tax (VAT) fraud and trade-based money laundering. The algorithm identifies price outliers in trade data by defining the product "fair price" and comparing it to the analysed cargo. This detection process have been proved to be reliable in *a-posteriori* controls[167]. The integration of this methodology may benefit the development of the ideal digital IT tool as the prices "*too good to be true*" can be detected and stopped.

Quantity

The quantity of products (usually kilograms, litres or units) within a specific consignment is correlated with the probability of being adulterated. Fraudsters can more easily hide fraudulent/unsafe products in larger orders, e.g. at the end of a container, where official controls are more difficult to be implemented. As a general rule, the smaller the amount purchased, the higher the probability to detect non-compliances, because with high quantities it is more difficult to perform sampling efficiently. Therefore, high-quantity lots are more vulnerable to food fraud.

Value adding features

Products may have certain attributes implying a relevant price premium. In the case of food production, there are three categories of goods:

163 Moyer, D. C., DeVries, J. W., & Spink, J. (2017). The economics of a food fraud incident–Case studies and examples including Melamine in Wheat Gluten. Food Control, 71, 358-364.

164 OECD (2008), "The markets for counterfeit and pirated goods", in The Economic Impact of Counterfeiting and Piracy, OECD Publishing, Paris

165 Everstine, K., Abt, E., McColl, D., Popping, B., Morrison-Rowe, S., Lane, R. W., ... & Chin, H. B. (2018). Development of a hazard classification scheme for substances used in the fraudulent adulteration of foods. Journal of food protection, 81(1), 31-36.

166 SSAFE. (2017). Food Fraud vulnerability assessment tool. https://www.ssafe-food.org/tools. (Accessed 19 December 2020).

167 Arsenis, S., Perrotta, D., & Torti, F. (2015). The estimation of fair prices of traded goods from outlier-free trade data. Tech. Rep. EUR 27696 EN, JRC-100018, European Commission, Joint Research Centre, Publications Office of the European Union, Luxembourg.

— **Search goods**: the consumer can verify the quality of the item before purchasing it, hence there is no information asymmetry;

— **Experience goods**: the consumer can determine the quality only after the transaction;

— **Credence goods**: the buyer cannot fully ascertain the quality of the good even after buying it[168].

This asymmetric information and the average higher prices combine in a very high fraud vulnerability[124]. As a matter of fact, organic food has a price premium of around 20-24%[169] whereas Geographical Indications' prices are 123% higher compared to their conventional counterparts[170]. Since the consumers are willing to pay more, then credence goods are more exposed to fraud[124,171].

The analysed scientific literature identifies the following features as the most relevant:

— **Organic goods**: their demand has been steadily growing[172] reaching in the EU the total value of 44.8 billion of euros in 2020[173]. Organic farming has a higher benefit/cost ratios of 20-24% compared to conventional farming[174] and is promoted through institutional trust (documentation, certificates, logos, etc…). The regulation governing the sector is stratified. The *Codex Alimentarius* Guidelines[175] and the International Federation of Organic Agriculture Movements Basic Standards supply the minimum international standard on organic production worldwide[176]. At the same time, each area and country has its own regulation[177] and private organizations can determine additional requirement exceeding the EU legislation[178]. It is clear how the label "organic" might entail different production standards and the identification of all the different characteristics is challenging, even with analytical tests[177]. Furthermore, purchases are made based upon institutional trust, i.e. logos, certification and standards, throughout the supply chain[171,179]. This type of transaction is deeply exposed to fraud as criminals might place organic symbols on conventional product with no possibility of identification, as within organic characteristics there is e.g. access to grazing or the space available to an animal[171]. Such frauds damage consumers, organic producers who are unable to compete at lower prices, and finally the trust in the organic symbols[177], endangering a farm management and food production system created to incentivize environmental sustainability and animal welfare[180].

— **Halal goods**: the halal market is increasing worldwide. At European level the Muslim community is growing too[181] due to immigration and higher birth rate[182], hence in the future the relevance of this market will grow[183]. Given the product characteristics, halal goods are credence goods since the Islamic dietary laws refer to the nature, origin and processing methods of foodstuff[184]. No analytical method can measure animal welfare, the ritual slaughter method, treatment and separation of halal animals, etc. in all the stages of the supply chain[185], hence the quality

168 OECD. (2010). Appellations of Origin and Geographical Indications in OECD Member Countries: Economic and Legal Implications.

169 Crowder, D. W., & Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. Proceedings of the National Academy of Sciences, 112(24), 7611-7616.

170 EUIPO. (2016). Infringement of protected geographical indications of wine, spirits, agricultural products and foodstuffs in the European Union. https://euipo.europa.eu/tunnel-web/secure/webdav/guest/document_library/observatory/documents/Geographical_indications_report/geographical_indications_report_en.pdf

171 Darby, M. R., & Karni, E. (1973). Free competition and the optimal amount of fraud. The Journal of law and economics, 16(1), 67-88.

172 Capuano, E., Boerrigter-Eenling, R., van der Veer, G., & van Ruth, S. M. (2013). Analytical authentication of organic products: an overview of markers. Journal of the Science of Food and Agriculture, 93(1), 12-28.

173 Statista. (2022). Organic retail sales value EU 2004-2020. Retrieved 7 June 2022, from https://www.statista.com/statistics/541536/organic-retail-sales-value-european-union-europe-statistic/

174 Crowder, D. W., & Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. Proceedings of the National Academy of Sciences, 112(24), 7611-7616.

175 Dumea, A. C. (2013). Factors influencing consumption of organic food in Romania. The USV Annals of Economics and Public Administration, 12(1 (15)), 107-113.

176 Essoussi, L. H., & Zahaf, M. (2009). Exploring the decision-making process of Canadian organic food consumers: Motivations and trust issues. Qualitative Market Research: An International Journal.

177 van Ruth, S. M., & de Pagter-de Witte, L. (2020). Integrity of organic foods and their suppliers: Fraud vulnerability across chains. Foods, 9(2), 188.

178 Janssen, M., & Hamm, U. (2014). Governmental and private certification labels for organic food: Consumer attitudes and preferences in Germany. Food Policy, 49, 437-448.

179 Lee, H. J., & Hwang, J. (2016). The driving role of consumers' perceived credence attributes in organic food purchase decisions: A comparison of two groups of consumers. Food quality and preference, 54, 141-151.

180 Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91, http://data.europa.eu/eli/reg/2007/834/2022-01-01

181 Lever, J., & Miele, M. (2012). The growth of halal meat markets in Europe: An exploration of the supply side theory of religion. Journal of Rural Studies, 28(4), 528-537.

182 The Economist. (2010). Cut-throat competition. https://www.economist.com/business/2009/09/17/cut-throat-competition.

183 Lever, J., & Miele, M. (2012). The growth of halal meat markets in Europe: An exploration of the supply side theory of religion. Journal of Rural Studies, 28(4), 528-537.

184 Verbeke, W., Rutsaert, P., Bonne, K., & Vermeir, I. (2013). Credence quality coordination and consumers' willingness-to-pay for certified halal labelled meat. Meat science, 95(4), 790-797.

185 Van der Spiegel, M., Van der Fels-Klerx, H. J., Sterrenburg, P., Van Ruth, S. M., Scholtens-Toma, I. M. J., & Kok, E. J. (2012). Halal assurance in food supply chains: Verification of halal certificates using audits and laboratory analysis. Trends in Food Science & Technology, 27(2), 109-119.

assessment is impossible even after the purchase[184]. Often, the main violations of halal prescriptions is the substitution of oil with lard perpetrated by food manufacturers (since the latter is cheaper than the former), or the addition of adulterants to more valuable goods to increase the quantity, reduce the cost or other fraudulent purposes[186]. Halal counterfeiting is also one of the most frequent violation in the meat sector[151].

- **Kosher goods**: the case is very similar to the halal market. It is impossible to determine whether the Jewish dietary laws were respected as also for kosher foods the rules cover the production, preparation and consumption. For this reason, together with the consumers' willingness to pay a premium to ensure the respect of the religious prescription[187], kosher foodstuff is deeply exposed to fraud[124].
- **Protected Designation of Origin, Protected Geographical Indication and Traditional Speciality Guaranteed products**: these quality labels were created by the EU to promote specific products associated with a certain area of production with associated characteristics[170,188,189]. Each label has specific requirements regarding the connection with the connected geographical area, e.g. Protected Designation of Origin requires products to be produced, processed and prepared in a circumscribed area whereas Protected Geographical Indication requires that at least one of the steps takes place in that area[190]. Food authenticity can be proven using analytical techniques performed in the laboratories of some regulatory authorities[191] but, given the price premium compared to their counterparts[124,170,192,193], they are particularly exposed to fraud.

Identification number

The data item "Identification number" refers to all numerical tags specific for each individual consignment. Examples may include the lot number, the delivery tracking number or livestock tags.

Means of transportation

In a globalised world, the modes of transportation used in logistics represent a vulnerable step in the supply chain.

No scientific review on which transportation modality is the most used for food fraud has been identified. Hence, the study may profit from the information available for other better explored markets, i.e. drugs and counterfeit goods.

The transport sector is recognised to be one of the economic sectors most vulnerable to criminal infiltration[194,195,196,197,198]. Analyses could be found for only few methods of transport, but there are some indications that all are as exposed to crime infiltration[197]. This is because transportation is characterised by a dynamic context[195] and is functional to illicit activities[199]. Transport firms can

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186 Fadzlillah, N. A., Man, Y. B. C., Jamaludin, M. A., Rahman, S. A., & Al-Kahtani, H. A. (2011). Halal food issues from Islamic and modern science perspectives. In 2nd international conference on humanities, historical and social sciences (Vol. 17, pp. 159-163). Singapore: IACSIT Press.

187 Havinga, T. (2010). Regulating halal and kosher foods: different arrangements between state, industry and religious actors. Erasmus L. Rev., 3, 241.

188 European Commission. (2013). Quality schemes explained. https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/quality-schemes-explained_en

189 Grunert, K. G., & Aachmann, K. (2016). Consumer reactions to the use of EU quality labels on food products: A review of the literature. Food Control, 59, 178-187.

190 Dias, C., & Mendes, L. (2018). Protected designation of origin (PDO), protected geographical indication (PGI) and traditional speciality guaranteed (TSG): A bibiliometric analysis. Food Research International, 103, 492-508.

191 Camin, F., Boner, M., Bontempo, L., Fauhl-Hassek, C., Kelly, S. D., Riedl, J., & Rossmann, A. (2017). Stable isotope techniques for verifying the declared geographical origin of food in legal cases. Trends in Food Science & Technology, 61, 176-187.

192 Danezis, G. P., Tsagkaris, A. S., Brusic, V., & Georgiou, C. A. (2016). Food authentication: state of the art and prospects. Current Opinion in Food Science, 10, 22-31.

193 Hajdukiewicz, A. (2014). European Union agri-food quality schemes for the protection and promotion of geographical indications and traditional specialities: an economic perspective. Folia Horticulturae, 26(1), 3.

194 Fijnaut, C. (Ed.). (1998). Organized crime in the Netherlands. Martinus Nijhoff publishers.

195 Savona, E., & Berlusconi, G. (2015). Organized crime infiltration of legitimate businesses in Europe: A pilot project in five European countries. Final report of project ARIEL–assessing the risk of the infiltration of organized crime in EU MSS legitimate economies: a pilot project in 5 EU countries.

196 Dandurand, Y. (2021). Tow Truck Wars (p. 26). Global Initiative Against Transnational Organized Crime's. https://globalinitiative.net/wp-content/uploads/2021/06/Tow-Truck-Wars-How-organized-crime-infiltrates-the-transport-industry-GITOC.pdf

197 van Duyne, P., van Dijk, M., von Lampe, K., & Newell, J. L. (2005). Organised crime economy: managing crime markets in Europe. Wolf Legal Publishers.

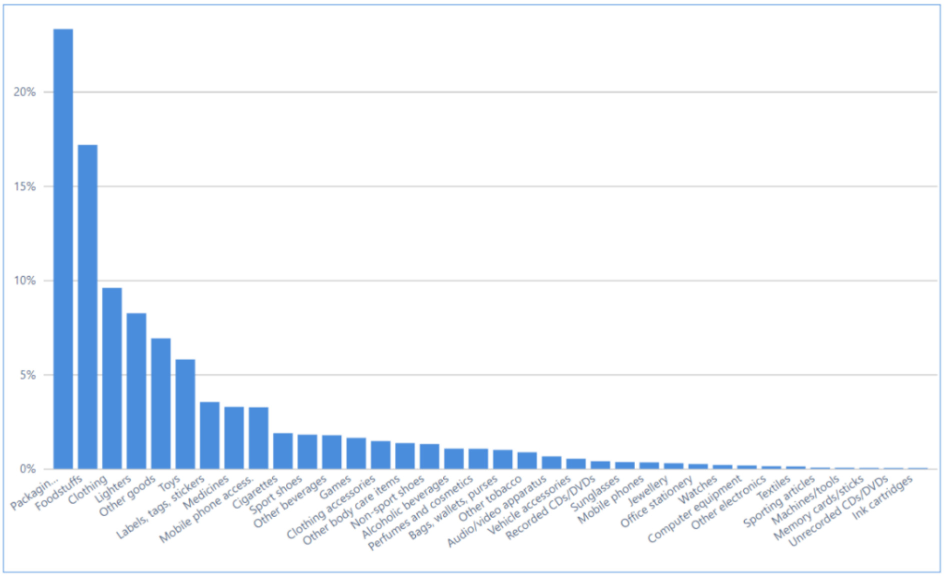
198 Savona, E. U., & Riccardi, M. (2018). Mapping the risk of Serious and Organised Crime infiltration in European Businesses: Final report of the MORE project. Transcrime-Università Cattolica del Sacro Cuore, Milan.

199 Savona, E. U., & Riccardi, M. (Eds.). (2015). From illegal markets to legitimate businesses: The portfolio of organised crime in Europe. Trento: Transcrime – Università degli Studi di Trento.

function as facilitators[200], moving illegal and counterfeit goods throughout the globe using the same legitimate distribution means used for legal goods[195,201,202].

Given the low availability of extensive studies on the topic, a 2020 EU report on IPR is used as a proxy. Foodstuff covered by IPR was one of the most seized counterfeit good (Figure 27). Overall, almost 82% of the all seized goods were imported. This percentage is similar to those of the previous years[203]. Almost 50% of all the seized counterfeit goods were shipped via sea, whereas the road transport (courier or postal traffic) contributed for 31% and air traffic for 7%. Taking into account the years 2017-2020, the preferred transportation methods were sea and road (Figure 28). Similar results are visible in Figure 29, showing the share of global food miles by transport method.

Figure 27: Top categories by number of seized articles infringing IPR in 2020. The y-axis represents the percentage of seized goods; the x-axis represents the categories of seized goods.



Source: European Union Intellectual Property Office. (2021). EU enforcement of intellectual property rights: Results at the EU border and in the EU internal market 2020. Publications Office.

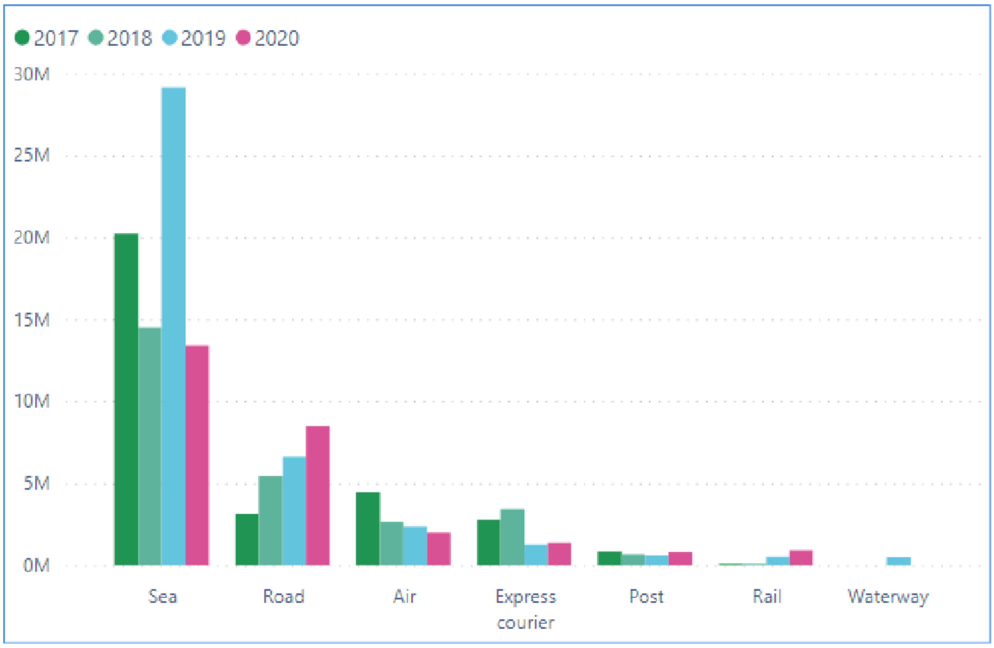
200 Klima, N. (2011). The goods transport network's vulnerability to crime: opportunities and control weaknesses. European Journal on Criminal Policy and Research, 17(3), 203-219.

201 Kennedy, J. P., & Wilson, J. M. (2017). Liabilities and responsibilities: ocean transportation intermediaries (OTIs) and the distribution of counterfeit goods. Maritime Economics & Logistics, 19(1), 182-187.

202 Kleemans, E. R. (2007). Organized crime, transit crime, and racketeering. Crime and Justice, 35(1), 163-215.

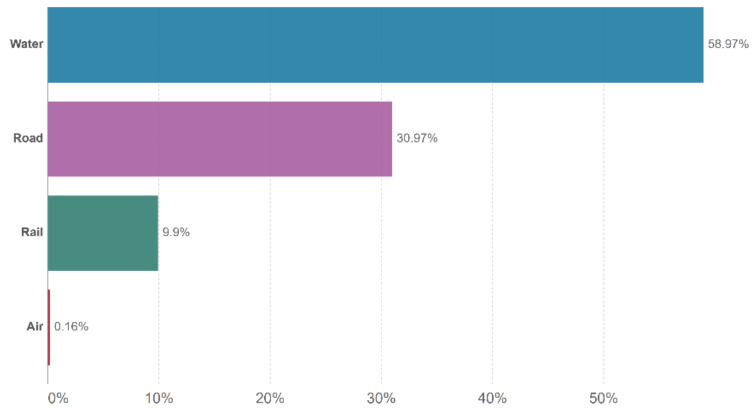
203 European Union Intellectual Property Office. (2021). EU enforcement of intellectual property rights: Results at the EU border and in the EU internal market 2020. Publications Office.

Figure 28: Detained articles infringing IPR by means of transport (2017-2020). The y-axis represents the amount of seized goods in millions; the x-axis represents the means of transport.



Source: European Union Intellectual Property Office. (2021). EU enforcement of intellectual property rights: Results at the EU border and in the EU internal market 2020. Publications Office.

Figure 29: Share of global food miles by transport method. The y-axis represents the means of transport; the x-axis represents the percentage of global food miles.



Source: Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987-992.

Road transport

The increasing competitive pressure[197], companies' poor financial condition, and contacts with professional criminals can push the transport firm to participate in illegal activities in order to increase revenues[200]. Often, organised crime members start the connection exploiting firms' economic condition, in order to create a situation of mutual dependence[204].

204 Kleemans, E. R., & de Poot, C. J. (2008). Criminal careers in organized crime and social opportunity structure. European Journal of Criminology, 5(1), 69-98.

The sector's start-up costs are significant and firms can rapidly fall under financial pressure. Small-medium enterprises, in particular, can enter a phase of distress if there are no orders, whereas bigger companies have an easier access to credit and can compensate more easily to such market fluctuations[200].

Truck driving is characterised by a high degree of autonomy and mobility, which are two important features needed to carry out criminal activities. In fact, they are independent and rarely supervised, hence creating conditions for carrying out illegal traffics. Often, drivers come in contact with criminal groups through social ties during their road life, e.g. at rest areas[205].

Air transport

This way of transport is mainly explored in the literature referring to drug trafficking, whereas a wide literature for goods smuggling could not be found. The criminal groups' *modus operandi* is different in airports compared to e.g. ports. In the latter, the main function is to transport not persons but goods, whereas in the former there is an enormous flow of goods and persons together. This translates in different modes of drug smuggling: in airports organised crime groups mainly use drug mules or hide it thanks to internal staff support[205], whereas in ports they hide commodities in deck cargos or containers[196]. In fact, in the two settings criminal groups rely on the major flow occurring in the logistical centre in order to conceal their loads[205].

Maritime transport

Ports are crucial centres of the global supply chain. In 2018 almost 60% of food travelled by sea[206] (Figure 47). In Italy, drug seizure (i.e. the most valuable smuggled good) took place for the 78.7% at the border, of which 98.1% at the maritime one. Organised crime groups do not choose ports based on territorial control, but on the support that they can gather[207]. Hence, port surveillance is fundamental for preserving the integrity of global trade flow from criminal activities[208].

In seaports, informal[209] and criminal activities are entwined with the operation process. Indeed, illegal economy runs on the same track as that of global economic exchanges[210] and the closeness between legal and illegal flows creates professional contacts and work environment that can be used as breeding ground for criminal activities[211,212] both in the legal and illegal economy[213]. Organised crime groups need a door (e.g. a corrupted person) to secure their shipments, and seaports represent the physical spaces that provide the needed market access for their goods. Being a border area, the port fosters a certain set of conventional rules and standards, creating "static relationships" that preserve internal dynamics, including criminal governance. At the same time, seaports are space for global trade. Thus, they tend to be outward looking, by promoting trade speed, fluidity and smoothness in business relationships[214], including criminal ones[215].

Ports are complex systems characterised by misaligned interests of governmental agencies (e.g. Port Authority, Customs Agency), private companies and regulatory entities (e.g. Ministry of Interior, Ministry of Infrastructure, local authorities)[214], where informality of agreements among actors and exchange of information with unconventional but established manners prevail[215]. Indeed, port labour is characterised by militancy, casual and close-knit communities where the workforce has its

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205 Madarie, R., & Kruisbergen, E. W. (2020). Traffickers in Transit: Analysing the Logistics and Involvement Mechanisms of Organised Crime at Logistical Nodes in the Netherlands: Empirical Results of the Dutch Organised Crime Monitor. In Understanding Recruitment to Organized Crime and Terrorism (pp. 277-308). Springer, Cham.

206 Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987-992.

207 Direzione Centrale per i Servizi Antidroga. Relazione Annuale. 2021, p. 376.

208 Eski, Y. (2016). Policing, Port Security and Crime Control: An Ethnography of the Port Securityscape (1st ed.). Routledge

209 The informal sector is broadly characterised as consisting of units engaged in the production of goods or services with the primary objective of generating employment and incomes to the persons concerned. These units typically operate at a low level of organisation, with little or no division between labour and capital as factors of production and on a small scale. Labour relations - where they exist - are based mostly on casual employment, kinship or personal and social relations rather than contractual arrangements with formal guarantees.

210 Sciarrone, R., & Storti, L. (2019). Le mafie nell'economia legale. Scambi, collusioni, azioni di contrasto (pp. 1-198). il Mulino

211 Kleemans, E. R., & Van de Bunt, H. G. (2008). Organised crime, occupations and opportunity. Global Crime, 9(3), 185-197.

212 Mars, G. (2016). Locating deviance: crime, change and organizations. Routledge.

213 UNODC (2013) Combating transnational organized crime committed at sea. Issue Paper. United Nations, New York

214 Wilmsmeier, G., & Monios, J. (2015). The production of capitalist "smooth" space in global port operations. Journal of Transport Geography, 47, 59-69.

215 Sergi, A., & Storti, L. (2020). Survive or perish: Organised crime in the port of Montreal and the port of New York/New Jersey. International Journal of Law, Crime and Justice, 63, 100424.

written and unwritten rules[216] and this defines them as logistical infrastructure and strategic locations ideal for criminal groups to operate in[217].

Railway transport

Figure 28 shows the relevance of railways in foodstuff shipment; their usage for drug trafficking is well established[218,219]. On the other hand, there is a limited use of them for counterfeit goods transport. No relevant scientific analysis of the characteristics of this mean of transport in the context of food fraud has been identified, nor of its use for illicit traffics.

In conclusion, a comparative analysis of the criminal infiltration and usage between all means of transport could not be found, but this brief overview shows how it is necessary to take into account this variable. The routes taken in the internal market will be arduous to control given the absence of internal borders, thus reinforcing the necessity of improving the internal traceability within the EU food supply chain. On the other hand, controlling imports may already ensure a good coverage, given the hints derivable from the EUIPO report. The latter covers solely products subject to IPR, but their data could be used as proxy for the entire phenomenon. Furthermore, control systems are already in place to achieve this task as the AFIS-CSM (developed by OLAF) and Import Control System 2 (ICS2) (developed by DG TAXUD). Hence, incorporating these methods will help achieving already a high level of coverage.

Seller/Buyer

The Transaction ID Card covers any transaction business-to-business taking place between two FBOs in the food supply chain. It is not intended to cover business-to-consumers transactions, at least in principle. There exists several possibility to connect identifiers and code to a single company:

- The Economic Operators Registration and Identification (EORI)[220] number is an EU registration and identification number for the economic operators who import or export in or out of the EU. The EORI number is valid throughout the EU and it is used as a common reference number for interactions with the customs authorities in any Member State. The EORI number consists of two parts: the Member State country code, and a unique code/number.

  The EORI number has two pitfalls: it does not apply to economic operators in third countries (unless they intend to lodge a customs declaration, an Entry Summary Declaration or an Exit Summary Declaration), and it only applies to the EU economic operators who have to deal with Customs.
- The Legal Entity Identifier (LEI)[221], launched by G20 in 2011, is a unique global identifier for legal entities involved in financial transactions (e.g. companies or governmental entities). The LEI codes are based on the ISO 17442 standard and include 20 digits (letters and numbers). Many regulatory bodies mandate LEIs in their legislation.
- The Global Intermediary Identification Number (GIIN)[222] is a 19-character code which states the approval of foreign financial institutions, financial institution branches, direct reporting non-financial foreign entities, sponsoring entities, sponsored entities, and sponsored subsidiary branches. The GIIN code is assigned by the FATCA registration system and must be confirmed on regular basis.

216 Bottalico, A. (2020). Towards a common trajectory of port labour systems in Europe? The case of the port of Antwerp. Case Studies on Transport Policy, 8(2), 311-321.

217 Ruggiero, V. (2013). Organised and transnational crime in Europe. In The Routledge Handbook of European Criminology (pp. 174-187). Routledge.

218 European Monitoring Centre for Drugs and Drug Addiction and Europol (2019), EU Drug Markets Report 2019, Publications Office of the European Union, Luxembourg

219 World Drug Report 2021 (United Nations publication, Sales No. E.21.XI.8).

220 https://taxation-customs.ec.europa.eu/customs-4/customs-procedures-import-and-export-0/customs-procedures/economic-operators-registration-and-identification-number-eori_en

221 https://www.lei-worldwide.com/

222 https://www.irs.gov/businesses/corporations/fatca-registration-and-ffi-list-giin-composition-information

— The VAT identification number[223] identifies taxable persons (businesses) or non-taxable legal entities in many countries around the globe. Every EU country issues its own national VAT number format. VAT numbers are used to identify the tax status of the customer, the place of taxation and the invoices.

Given the G20 endorsement and the global scope, the LEI code seems the best candidate to be chosen as preferred identifier for the Food ID Card. However, the data item may also list the other identification codes provided by the other systems, in order to deliver a more precise assessment of a FBO and to connect the various databases who may feed the overarching EU database for Transaction ID Cards, ultimately increasing its interoperability features.

Age

The longevity of a FBO can be measured in days, months and years. Given that established FBOs have theoretically a higher credibility with their buyers and final consumers, it is probable that newly established FBOs may more probably deliver fraudulent products e.g. in case a company is set up for a specific number of transactions before being closed and leave no traces within the supply chain. "Months" is therefore the most preferred option to measure the activity of FBOs: as a general principle to be discussed in specific working groups, the longer a FBO is active, the less probable it is that it will commit fraudulent activities.

Economic health

Through time there has been strong attention to the relationship between the economic health and the criminal behaviour of the firms. The topic has been of interest for economists, criminologists and organization theorists and all of them contributed from their own point of view. Economists explain the behaviour using the Beckerian model of expected benefit from criminal activity versus expected costs of punishment: given any prior poor economic performance, crime increases the short-run profitability of the firm and increases the short-run expected chance of job loss, thus the expected gain from crime[224]. This is because the theoretical cost of government sanctions may be perceived to be smaller than the cost deriving from the firm bankruptcy[225]; in other words: better to risk a fine rather than close the business. Organization theorists argue that pressure from the top of the hierarchy to keep profits may lead employees to commit crimes, whereas criminologists mention that pressure on individuals being part of a struggling organization may naturally lead some individuals to criminal behaviour on behalf of the firm to save their job[224]. Therefore, it is clear how all the fields of study have analysed the phenomenon and underline its importance.

The relevance of this variable is recognized also in the more specific field of food fraud as the possibility of economically motivated adulteration will undoubtedly increase in a firm with poor financial condition[226]. In the literature there are multiple indicators of financial distress: liquidity ratios, leverage ratio, financial leverage, and cash flow[227]. A panel of experts in business analysis may precisely identify the variable(s) to consider in the ideal digital IT tool.

Firm size

The firm size is one of the most important factors for white-collar crimes[228] and in particular fraud detection[229,230,231]. In the food sector, firm dimension influences significantly firm's perception over fraud vulnerability, with larger enterprises perceiving themselves as more exposed to fraud[302,232] for

223 https://taxation-customs.ec.europa.eu/vat-identification-numbers_en

224 Alexander, C. R., & Cohen, M. A. (1996). New evidence on the origins of corporate crime. Managerial and Decision Economics, 17(4), 421-435.

225 Baysinger, B. D. (1991). Organization theory and the criminal liability of organizations. BUL Rev., 71, 341.

226 Luo, J., Wang, X., Li, H., Xiao, S., Gao, Y., & Li, L. (2016). Analysis of motivation and reason for Economically Motivated Adulteration in food company. Science and Technology of Food Industry, 37(5), 281-282.

227 Dirman, A. (2020). Financial distress: the impacts of profitability, liquidity, leverage, firm size, and free cash flow. International Journal of Business, Economics and Law, 22(1), 17-25.

228 Sutherland, E. (1949). White Collar Crime New York. Holt, Rinehart.

229 van Ruth, S. M., Luning, P. A., Silvis, I. C., Yang, Y., & Huisman, W. (2018). Differences in fraud vulnerability in various food supply chains and their tiers. Food Control, 84, 375-381.

230 Persons, O. S. (1995). Using financial statement data to identify factors associated with fraudulent financial reporting. Journal of Applied Business Research (JABR), 11(3), 38-46.

231 Junger, M., Wang, V., & Schlömer, M. (2020). Fraud against businesses both online and offline: Crime scripts, business characteristics, efforts, and benefits. Crime science, 9(1), 1-15.

232 Holtfreter, K. (2005). Is occupational fraud "typical" white-collar crime? A comparison of individual and organizational characteristics. Journal of Criminal Justice, 33(4), 353-365.

multiple reasons (e.g. higher number of suppliers, larger orders, higher reputation, and international supply chains[302]). On the other hand, for these same reasons larger corporations have better controls compared to small-medium enterprises[233] and are also less exposed to competition (a phenomenon potentially driving the firm to commit fraud[234,235]).

Summarizing, larger firms may be more prone to receive adulterated products from their suppliers, but have more controls dedicated to fraud mitigation since criminal events are recognised to be the most harmful financially[236]. The literature does not identify the result of these two opposite forces determining the most fraudulent firm size.

Regarding the measurement of this variable, there are multiple possibilities. In the literature, total assets, sales, profits, market capitalization are the most common and number of employees and net assets when the others are not available. The choice of measurement always depends on data availability[237].
As data source, it may be resourceful to connect the new EU database with that of the Chambers of Commerce of the Member States to provide the necessary corporate data for firms located in the internal market. For those in third countries, already existing high quality private databases on firm characteristics may be used.

Recidivism

The majority of discovered food frauds are perpetrated by legitimate actors operating within the food supply chain and partially by organized crime groups[238]. The offences rate varies between isolated episodes to structured criminal groups active in the sector[239]. This means that the problem of recidivism must be tackled to prevent professional fraudsters from repeatedly polluting the market. In fact, if food fraud is considered apart from the food safety standpoint, the main drivers for food fraud are profit maximization[240] or cost minimization[241,242].

The majority of food frauds occurs in the regular supply chain, hence assimilating food frauds to any other corporate crime. The latter type of felony is perpetrated routinely in the everyday life[243] and an analysis has shown that a history of past corporate crimes (the fraud incident history) implies a 19 times higher likelihood of illegal behaviour in the future[244].

This shows the necessity of keeping track of previous offences committed by a firm, monitoring other factors (e.g. address and responsible person) to unmask any type of concealment.

The measurement of recidivism is a complicated issue. In a scenario in which a firm has multiple plants and one of them is reported to be more fraudulent than the others, then measuring the recidivism propensity at firm level will damage the other plants and the aggregated level of riskiness may be below the alert level, letting the adulterated foodstuff enter the market. On the other hand, the data for the firm-plant combination can be difficult to obtain.

In addition to that, the fraud dimension has to be taken into account. Given the same number of incidents per year, the ideal digital IT tool shall take into account the incident size. Hence, as a measure of recidivism the ideal digital IT tool may use two different variables: the frequency of

233 Silvis, I. C. J., Van Ruth, S. M., Van Der Fels-klerx, H. J., & Luning, P. A. (2017). Assessment of food fraud vulnerability in the spices chain: An explorative study. Food Control, 81, 80-87.

234 Yang, Z., Zhou, Q., Wu, W., Zhang, D., Mo, L., Liu, J., & Yang, X. (2022). Food fraud vulnerability assessment in the edible vegetable oil supply chain: A perspective of Chinese enterprises. Food Control, 138, 109005

235 Yan, J., Erasmus, S. W., Toro, M. A., Huang, H., & van Ruth, S. M. (2020). Food fraud: Assessing fraud vulnerability in the extra virgin olive oil supply chain. Food Control, 111, 107081.

236 Gatzert, N. (2015). The impact of corporate reputation and reputation damaging events on financial performance: Empirical evidence from the literature. European management journal, 33(6), 485-499.

237 Dang, C., Li, Z. F., & Yang, C. (2018). Measuring firm size in empirical corporate finance. Journal of banking & finance, 86, 159-176.

238 Lord, N., Flores Elizondo, C. J., & Spencer, J. (2017). The dynamics of food fraud: The interactions between criminal opportunity and market (dys) functionality in legitimate business. Criminology & Criminal Justice, 17(5), 605-623.

239 Rizzuti, A. (2021). Organised food crime: an analysis of the involvements of organised crime groups in the food sector in England and Italy. Crime, Law and Social Change, 1-20.

240 Ulberth, F. (2020). Tools to combat food fraud–a gap analysis. Food Chemistry, 330, 127044.

241 Mu, E., & Carroll, J. (2016). Development of a fraud risk decision model for prioritizing fraud risk cases in manufacturing firms. International Journal of Production Economics, 173, 30-42.

242 Everstine, K., Abt, E., McColl, D., Popping, B., Morrison-Rowe, S., Lane, R. W., & Chin, H. B. (2018). Development of a hazard classification scheme for substances used in the fraudulent adulteration of foods. Journal of food protection, 81(1), 31-36.

243 Mihret, D. G. (2014). National culture and fraud risk: exploratory evidence. Journal of Financial Reporting and Accounting.

244 Baucus, M. S., & Near, J. P. (1991). Can illegal corporate behaviour be predicted? An event history analysis. Academy of management Journal, 34(1), 9-36.

recidivism and its impact. The former shall be calculated using the average yearly violations over a given time span, whereas the latter shall use the average market value of the seizure calculated over the seizures that took place in the same or in a different time period. The interval length shall be decided by a panel of expert in the subject.

Address

The data item "Country" is recurring in several items within the ID card of a food product. The number of times that more data items "Country" are repeated within the "Food ID Card" is related to the complexity of the supply chains: intuitively, short supply chains will be characterised by less data items "Country" because less actors will move the product from one location to another (even within the same Country).

Having a standardised list to classify Countries is a plus to perform data analysis and potentially visualize the movement of the food products. The following Country classifications have been identified:

— *ISO 3166*[245]: developed to define internationally recognized codes of letters and/or numbers to be used when referring to countries and their subdivisions. However, it does not define the names of countries – this information comes from United Nations sources. Below a screenshot copied from their website for a better overview:

> **WHAT IS INCLUDED IN ISO 3166?**
>
> ISO 3166 has three parts: codes for countries, codes for subdivisions and formerly used codes (codes that were once used to describe countries but are no longer in use).
>
> The **country codes** can be represented either as a two-letter code (alpha-2) which is recommended as the general-purpose code, a three-letter code (alpha-3) which is more closely related to the country name and a three-digit numeric code (numeric-3) which can be useful if you need to avoid using Latin script.
>
> The **codes for subdivisions** are represented as the alpha-2 code for the country, followed by up to three characters. For example ID-RI is the Riau province of Indonesia and NG-RI is the Rivers province in Nigeria. Names and codes for subdivisions are usually taken from relevant official national information sources.
>
> The **formerly used codes** are four-letter codes (alpha-4). How the alpha-4 codes are constructed depends on the reason why the country name has been removed.

— *UN/LOCODE Code List by Country and Territory*: the United Nations Economic Commission for Europe (UNECE)[246] has established their list of Country codes[247] based on ISO 3166. Each Country is also characterised by codes specific for many territories and municipalities, thus increasing the granularity and detail of the data item. This classification is the one utilised by AFIS-CSM and IMSOC.

— *EUROSTAT*: EUROSTAT is using several classifications almost overlapping with the previous UN/LOCODE one, with minor changes for specific areas. There are few inconsistencies but EUROSTAT is working to solve them.

- An old classification[248] utilised by THESEUS, which is going to be dismissed and will not be relevant anymore.
- Geonomenclature[249] alias "GEONOM" [*Commission Implementing Regulation (EU) 2020/1470 of 12 October 2020 on the nomenclature of countries and territories for the European statistics on international trade in goods and on the geographical breakdown for other business statistics*[250]], utilised by the Surveillance and COMEXT databases. It is

245 https://www.iso.org/iso-3166-country-codes.html

246 https://unece.org

247 https://unece.org/trade/cefact/unlocode-code-list-country-and-territory

248 https://ec.europa.eu/eurostat/estat-navtree-portlet-prod/BulkDownloadListing?sort=-1&file=comext%2Fbulk_download%2FCOMEXT_METADATA%2FCLASSIFICATIONS_AND_RELATIONS%2FCLASSIFICATIONS%2FENGLISH%2FPARTNERS-ISO.txt

249 https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-22-004

250 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020R1470&qid=1657635392530

used for trade statistics, it is very detailed and it is updated annually to incorporate multiple needs for change. The International trade in goods statistics (ITGS)[251] Geonom (alpha or numerical version) is used to "code" the reporter and partner dimensions of the **detailed trade data**.

- SCL GEO codes[252]: used for geopolitical entities, and in line with the EU Interinstitutional Style Guide. The work is based on various international sources: Interinstitutional Style Guide, Nomenclature of Territorial Units for Statistics (NUTS) classification, ISO 3166 country codes (3166-1 alpha-2), and UN standard country and area codes classification. The country codes correspond to the ISO 3166 classification with the exception of United Kingdom where the code "UK" was adopted (instead of "GB") and Greece where the code "EL" was adopted (instead of "GR") in order to comply with the Interinstitutional Style Guide. The source of the regional codes for EU is the NUTS classification of ESTAT. From this GEO code List, EUROSTAT has derived simplified versions for the purpose of some specific statistics, i.e.:
  - Country/region of birth
  - Country of birth of father
  - Country of birth of mother
  - Country of birth of parents
  - Country of cabotage
  - Country, in which the controlling enterprise is located
  - Country of destination
  - Country/region of loading/embarking
  - Country of registration
  - Country of residence
  - Country of transit
  - Country/region of unloading/disembarking
  - Country/region of work
  - Country of citizenship
  - National and international organizations and institutions
  - Geopolitical entity (partner)

  This more general Eurostat online code list (SCL GEO) is used to code the reporting and partner countries (or geopolitical entities) of the **aggregated data** and also the datasets about trade in goods statistics by enterprise characteristics statistics.
- NUTS classification[253]: a hierarchical system for dividing up the economic territory of the EU and the UK, plus some other third countries close to the EU. It includes three levels: NUTS 1 (major socio-economic regions), NUTS 2 (basic regions for the application of regional policies) and NUTS 3 (small regions for specific diagnoses). Eurostat has established a link between postcodes and NUTS level 3 codes in order to exploit information which originally is coded only by postcodes[254]. As the NUTS classification lacks a global overview, it will not be analysed further.

— *TARIC*[255]: The codes are not *per se* obsolete, but the usage of TARIC as reference is obsolete.

Notably, not only the country codes change from one database to another, but also the name of the country itself may vary according to each classification.

251 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:International_trade_in_goods_statistics_(ITGS)

252 https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_NOM_DTL_VIEW&StrNom=CL_GEO&StrLanguageCode=EN&IntPcKey=48517890&IntKey=48517890&StrLayoutCode=HIERARCHIC&IntCurrentPage=1

253 https://ec.europa.eu/eurostat/web/nuts/background

254 https://ec.europa.eu/eurostat/web/nuts/correspondence-tables/postcodes-and-nuts

255 https://circabc.europa.eu/ui/group/0e5f18c2-4b2f-42e9-aed4-dfe50ae1263b/library/8a818a13-6bbb-451a-a749-ed8a2f7e0d4f/details

From a preliminary analysis, even though differences are minors, the best compromise for country classification is the one offered by **UN/LOCODE**, as it is almost identical to the one used by Surveillance and Geonomenclature, while increasing the granularity beyond the national level (region and municipality) even in third countries.

Maritime trade costs tripled compared to the pre-pandemic average. Therefore, import/export of products on long distances may have become more subject to fraud as mislabelling of country of origin (e.g. for luxury products from overseas). Quantifying the distance covered by the products may provide an insight regarding the risk of fraud on origin labelling.

Poverty and crime

Socio-economic drivers of crime have been widely explored in the economic literature. In 1942, Shaw and Mackay[256] established that poverty and/or social deprivation had the highest correlation with crime. In the 1960s, Fleisher[257] analysed the individual decision-making process proving the role of income on individual criminal decisions. The author stated that low income theoretically increases the propensity to commit crime as the legal earning alternative is much lower than the criminal one, and the potential cost of punishment is relatively low since the punishment (e.g. prison) will impose them lower costs because their future earnings will be modest too. This reasoning was successively modelled by Becker[258], followed by Ehrlich[259]; as they applied the conventional economic model to individual criminal choices. In this model, individuals decide to commit crimes based on expected costs and expected benefits. The higher the outcome of any illegal activity compared to legal alternatives, the higher will be the incentive to commit a crime. On the other hand, if individuals face tougher punishments, then they will have a lower motivation. Applying the model to food frauds:

- The lower the income, the higher the probability to commit fraud;
- The higher the earning (in relation to the income), the higher the probability to commit fraud;
- The higher the punishment, the lower the probability to commit fraud;
- The higher the chances to be detected, the lower the probability to commit fraud.

The consequences of this proposition are that given a certain punishment, people who would earn the most from a criminal act compared to lawful behaviour, will be the most incentivized to commit a crime. This angle can be useful when scanning the internal market for fraud. In a given country the punishment for illegal activities will be the same, but low-income areas will have higher relative returns to crime.

Empirical studies have also explored the topic. Buonanno's review[260] shows that poverty is one of the factors most closely related to criminal activity.

Crime encompasses different typologies, but the most relevant category to the present study is fraud. Economic literature has identified several economic variables that function as fraud drivers, the most cited being *GDP per capita*.

Most studies focused on the impact of fraud on economic growth, conversely less attention was dedicated to the opposite causal direction. Nevertheless, recent studies show a negative relation between economic development and fraud occurrence[261,262,263,264]. As a matter of fact, low economic growth produces low income for people and low revenues for firms. Stricter budget constraints increase the chance and number of fraudulent endeavours committed in order to achieve their goals,

256 Shaw, C. R., & McKay, H. D. (2010). Juvenile delinquency and urban areas: A study of rates of delinquency in relation to differential characteristics of local communities in American cities (1969). In Classics in environmental criminology (pp. 103-140). Routledge.

257 Fleisher, B. M. (1966). The effect of income on delinquency. The American Economic Review, 56(1/2), 118-137.

258 Becker, G. S. (1968). Crime and punishment: An economic approach. In The economic dimensions of crime (pp. 13-68). Palgrave Macmillan, London.

259 Ehrlich, I. (1973). Participation in illegitimate activities: A theoretical and empirical investigation. Journal of political Economy, 81(3), 521-565.

260 Buonanno, P. (2003). The socioeconomic determinants of crime. A review of the literature.

261 Türedi, S., & Altıner, A. (2016). Economic and political factors affecting corruption in developing countries. Int. J. Eco. Res, 7(1), 104-120.

262 Omidi, M., Min, Q., & Omidi, M. (2017). Combined effect of economic variables on fraud, a survey of developing countries. Economics & Sociology, 10(2), 267.

263 Achim, M. V., Borlea, S. N., Găban, L. V., & Cuceu, I. C. (2018). Rethinking the shadow economy in terms of happiness. Evidence for the European Union Member States. Technological and economic development of economy, 24(1), 199-228.

264 Ahmad, B., Ciupac-Ulici, M., & Beju, D. G. (2021). Economic and Non-Economic Variables Affecting Fraud in European Countries. Risks, 9(6), 119.

in the case of firms, or satisfy personal needs, in the case of individuals[264]. Taking into account economic growth (measurable using *GDP per capita growth rate*) means capturing not only the economic conditions in one precise year, but also its dynamic through time.

In conclusion, the relevance of economic drivers for the prediction of criminal behaviour, particularly in the case of fraud, is well established both in theoretical and empirical studies. This variable of interest can be significantly important to safeguard the internal market. Furthermore, in case of economic crisis, especially if asymmetric within the same country, taking into account economic outcome and its change can be relevant. The measurement of economic conditions can be performed using *GDP per capita at NUTS3 level for Member States*, which can be calculated dividing the GDP variable by the average population at NUTS3 level available on Eurostat. In fact, using the "GDP at current market prices by NUTS 3 regions" or [nama_10r_3gdp] database from Eurostat and the "Population on 1 January by broad age group, sex and NUTS 3 region" or [demo_r_pjanaggr3] database the GDP per capita can be obtained. For example, the GDP for the Arr. De Bruxelles Capitale in 2020 is provisionally 83846.54 and the corresponding population is 1223364, hence the GDP per capita is of 83846.54/1223364 = 0.06853768788 million per capita, hence 68537.68 euros per capita.

For third countries, the data can be used at country level and it is available on the World Bank database. Because economic growth is a relevant variable, *GDP per capita growth at NUTS3 level for Member States* can be used as a measure especially in case of economic crisis, since it can hit a country asymmetrically.

Corruption

Corruption is a facilitator to all illegal trades[265]. The link between corruption and fraud is widely recognised in the literature[266,267]. Even though each type of fraud has its own characteristics[264], the presence of corruption is common to all the different typologies, food fraud included[268,269]. Corruption is thus instrumental to illicit trades as it avoids controls and prevents or reduces punishment, if illegal goods are caught. The facilitation of illicit trades does not happen only at logistics hubs, but also along the supply chain[265].

In this analysis, the corruption variable can be useful for both the internal market and imports. In the first case, the higher the corruption level of a Member State, the higher the probability that any control on the supply chain can be bypassed. In the second case, also the potential corruption at border posts must be considered.

The goods crossing borders must comply with the legislation of both the destination and origin countries and the mix with social and organizational factors makes border control particularly prone to corruption[270]. Furthermore, the occasions are multiplied as border law enforcement officials process a larger number of transactions compared to the average street policeman[271]. Organised crime is among the actors most benefiting from this setting. Some researchers[272] believe that corruption is one of the defining characteristics of organised crime. However, in general there is wide consensus over the deep connection between organised crime groups and corruption[270,273,274]. This shows the relevance of the corruption variable in this analysis as organised crime groups play a significant role in the criminal sector of food fraud[275].

265 Shelley, L. I. (2018). Corruption & illicit trade. Daedalus, 147(3), 127-143.

266 Mihret, D. G. (2014). National culture and fraud risk: exploratory evidence. Journal of Financial Reporting and Accounting.

267 Mu, E., & Carroll, J. (2016). Development of a fraud risk decision model for prioritizing fraud risk cases in manufacturing firms. International Journal of Production Economics, 173, 30-42.

268 van Ruth, S. M., Huisman, W., & Luning, P. A. (2017). Food fraud vulnerability and its key factors. Trends in Food Science & Technology, 67, 70-75.

269 Spink, J., Fortin, N. D., Moyer, D. C., Miao, H., & Wu, Y. (2016). Food fraud prevention: policy, strategy, and decision-making-implementation steps for a government agency or industry. CHIMIA International Journal for Chemistry, 70(5), 320-328.

270 Jancsics, D. (2019). Border corruption. Public Integrity, 21(4), 406-419.

271 Parayno Jr, G. (2013). Combatting corruption in the Philippine customs service. Corruption and anti-corruption, 204.

272 Finckenauer, J. O. (2005). Problems of definition: what is organized crime?. Trends in organized crime, 8(3), 63-83.

273 Gamba, A., Immordino, G., & Piccolo, S. (2018). Corruption, organized crime and the bright side of subversion of law. Journal of Public Economics, 159, 79-88.

274 European Commission, Directorate-General for Migration and Home Affairs, Gounev, P., Bezlov, T. (2013). Examining the links between organised crime and corruption – , Publications Office..

275 Europol. (2021). Operation Opson IX – Analysis report. https://www.europol.europa.eu/cms/sites/default/files/documents/opson_ix_report_2021_0.pdf

The big challenge of analysing corruption is in its measurement as the phenomenon is intrinsically hidden. The vast majority of the literature uses measurements based on corruption perception[276] while the others use measurements that objectively identify the corruption levels but they are tailored to their settings, hence having poor external validity.

Measuring corruption using perception-based statistics entails that if in two countries with the same objective level of corruption, one with higher awareness than the other, then the proxy will capture a lower corruption level in the country with lower corruption awareness. Although, theoretically, this analysis might be biased, no other proxy is available given the intrinsic characteristics of corruption. It is necessary to rely on their vast use in the literature, conscious of the inherent flaws. There are multiple indicators used in the literature that try to capture the corruption phenomenon:

- The *Global Corruption Barometer*[277], realised by Transparency International, surveys ordinary citizens on their corruption perception in the public sector. It is not available for all the countries in the world and for those available the latest year may vary.
- The *Country Policy and Institutional Assessment*[278] is developed by the World Bank and assesses the transparency, accountability of the public sector and corruption. Each country is assessed base on 16 criteria developed by the World Bank staff. This index is available mainly for sub-Saharan countries.
- The *Corruption Perception Index*[279] is realised by Transparency International surveying experts and business people on the corruption levels in the public sector. The index aggregates corruption indexes produced by professional institutions with documented methods. It is available for 180 countries and it is available for all the years. Furthermore, the statistical methodology has been reviewed by the JRC[280] showing the soundness of its procedure. The only flaw found was corrected since the 2018 edition.

Given the characteristics of each of the mentioned indexes, the usage of the *Corruption Perception Index* is recommended. The data are readily available and easy to export, the methodology is proofed by a reliable institution and data are updated. The inherent flaw of being a perception index is due to the nature of the measured phenomenon but its usage in the literature proves its usefulness to capture corruption. Furthermore, after a comparison covering the available countries and years, the *Global Corruption Barometer* and the *Country Policy and Institutional Assessment* indexes are fairly comparable. Some differences are present, but may be due to the higher variability of latter compared to the former.

Country-based geopolitical risk

The analysis of country-based risk factors may be useful to assess food fraud vulnerabilities[281] for ingredient sourcing countries. In particular, laws and enforcement may represent a serious disincentive for fraudsters[282] as opaque and unclear legislation together with insufficient enforcement offer fraud opportunities[268]. It is clear that, following the Beckerian model of crime, it is possible to predict that tougher laws and stricter controls may increase the expected costs of crime as deterrence surges, although penalties for fraud-related crimes are generally lower than for other criminal activities.

A valuable source that can be used to evaluate the country-based risk is the Countries' Risk Classification[283] developed by amfori[284] (Figure 30), a stakeholder organisation of over 2 400 retailers, importers, brands and associations from more than 40 countries. The *Countries' Risk*

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276 Olken, B. A. (2009). Corruption perceptions vs. corruption reality. Journal of Public economics, 93(7-8), 950-964.

277 https://www.transparency.org/en/gcb

278 https://cpia.afdb.org/?page=home

279 https://www.transparency.org/en/cpi/2021

280 Álvarez-Díaz, M., Saisana, M., Montalto, V., & Moura, C. T. (2018). Corruption Perceptions Index 2017 Statistical Assessment. European Commission Joint Research Centre Technical Report.

281 Everstine, K., Popping, B., & Gendel, S. M. (2021). Food fraud mitigation: strategic approaches and tools. Food Fraud, 23-43.

282 De Lange, E. (2013). Food crisis, fraud in the food chain and the control thereof. European Parliament report 2013/2091(INI). Brussels: European Parliament.

283 https://www.amfori.org/resource/country-risk-classification-2022

284 https://www.amfori.org/content/about-amfori

Classification is based on the Worldwide Governance Indicators developed by the World Bank. The latter institute identifies six dimensions of governance:

- Voice and Accountability
- Political Stability and Absence of Violence/Terrorism
- Government Effectiveness
- Regulatory Quality
- Rule of Law
- Control of Corruption

All these indicators capture the governance ability of the 204 fully analysed (plus 9 partially assessed) countries. The indicators are updated with a lag of around two years, but - as testified by the report itself - it is rare that countries change its classification. In this analysis, the overall score may be useful to summarise the characteristics of the country, but the six individual factors identified by the World Bank may be taken into account as well.

Other parameters worthy to be considered by the ideal digital IT tool include[285]:

- The governance index of the country[286]
- Whether there is a legal system of the food in the country[287]
- The GDP of the country[288]
- The economic growth of the country[289]
- The supply chain index of the country[290]
- The political risk index of the country[291]
- The human development index of the country[292]
- Global Innovation Index of the country[293]
- The press index of the country[294]
- The food safety level of the country[295]

285 A holistic approach to food safety risks: Food fraud as an example

286 http://info.worldbank.org/governance/wgi/#home

287 https://data.worldbank.org/indicator/IC.LGL.CRED.XQ

288 https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

289 https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

290 https://www.fmglobal.com/#!year=2015&idx=Index&handler=map

291 https://www.prsgroup.com/

292 https://hdr.undp.org/data-center

293 https://www.globalinnovationindex.org/Home

294 https://rsf.org/en/index

295 https://impact.economist.com/sustainability/project/food-security-index/

Figure 30: An example of Country Risk classification as published by amfori (Countries' Risk Classification 2022).

Risk Countries

	Overall risk	Voice and Accountability	Political Stability & Absence of Violence	Government Effectiveness	Regulatory Quality	Rule of Law	Control of Corruption
Country	**2020**	**2020**	**2020**	**2020**	**2020**	**2020**	**2020**
Afghanistan	6.8	19.32	0.47	5.29	8.17	2.40	5.29
Albania	47.0	51.21	49.53	48.08	60.58	40.87	31.73
Algeria	21.4	18.36	17.45	33.65	9.13	21.63	28.37
Angola	19.1	25.60	26.89	11.06	15.87	16.83	18.27
Argentina	45.7	65.70	48.58	43.27	31.73	34.62	50.00
Armenia	49.1	49.28	25.94	48.56	61.06	51.92	57.69
Azerbaijan	25.7	5.80	21.70	44.71	39.90	25.96	16.35

Source: amfori.

Owner

The legal person responsible for a business. Often the same criminal can open multiple companies to hide transactions, or they can close a company after having deceived buyers and customers before opening a new company with virtually no connection to the previous one. Being able to identify the network of companies and sub-companies related to single individuals would certainly help in unmasking organised criminal networks and their activities in the food supply chain.

Certifications

A FBO may request an accredited private company to inspect and release a certification as established nationally or internationally by private standards. The world of private certification systems is immense, however there are some certifications that are internationally recognised and highly appreciated by the actors within the food supply chain.

Although private controls by accredited certification organisms cannot replace the official controls operated by public authorities, there is consensus that a FBO certified under recognised certification systems may be less prone to commit non-compliances compared to those never inspected by third-party audits or public official controls. FBOs who use to follow guidelines and rules internationally established may be also less prone to unintentional non-compliances on food quality and food safety.

Such approach is also supported internationally. The Codex Alimentarius Guidelines state "*The frequency and intensity of controls by inspection systems should be designed so as to take account of risk and the reliability of controls already carried out by those handling the products including producers, manufacturers, importers, exporters, and distributors*"[296].

Sector competition level

The level of competition may influence firm propensity to commit fraud[268,301,297]. Indeed, high market competition draws firms' margins down; hence, many enterprises may have difficulties having price advantages and accomplishing their financial goals. Markets characterized by fierce competition may push firms to commit frauds to survive[301].

Measuring the market sector competition level and its evolution through time may give the opportunity to identify a more vulnerable market or a market that is experiencing the entrance of

296 Article 31 of Codex Alimentarius (2010) Guidelines for the Design, Operation, Assessment and Accreditation of Food Import and Export Inspection and Certification Systems. CXG 26-1997.

297 Manning, L., Smith, R., & Soon, J. M. (2016). Developing an organizational typology of criminals in the meat supply chain. Food Policy, 59, 44-54.

new relevant firms, hence increasing the competition. The most accepted measure of market concentration is the Hefindahl-Hirshman Index calculated by squaring the market share of each firm present in the market and then summing the resulting values[298]. The problem of this measure and of any other market share measure is in the laboriousness of the definition of market boundaries. Both the geographical area and the relevant products have to be taken into account. In fact, it is not possible to hypothesize that, for example, there are no transportation costs. This means that for each firm the relevant market may not be necessarily the whole internal market or national market within each Member State. Regarding the relevant products, for example butter and margarine may be thought to be substitutes if consumers can substitute one for the other in response to a small and permanent change in relative prices.

In conclusion, if in theory the sector competition level would be a very strong predictor for fraud vulnerability, it is impossible to measure and update. Hence, it cannot be practically used in this analysis.

Supply chain position

There is scientific evidence showing that actors at different supply chain stages have different exposure to fraud[299]. There are different analyses focusing their assessment along three factors: opportunities, motivations, and control measures. The results do not agree on which position in the supply chain is the most vulnerable. Some studies believe that it is the wholesalers and traders (followed by retailers and food processors) as they have the least adequate control measures and, being in the middle of the supply chain, are more prone to pass to the next step the fraudulent product[300]. Other studies provided evidence that retailers risk the most, as producers are generally more aware of the goods, processes and the motivation behind adulteration[301]. Finally, studies carried out in specific markets have shown that milk processors in the Netherland feel to be more exposed than farmers[302], whereas in Canada the exposure to fraud is perceived to be increasing throughout the supply chain[303].

The results shown discuss the vulnerability to fraud victimization in supply chain tiers. In the effort to prevent such crimes, it is necessary to intervene in the level before the victimized one. The industry segments most exposed to fraud may change also based on the market in which they operate. For example, the supply chain involved in the production of animal by-products is more exposed compared to the livestock market[302].

In order to keep track of the position in the supply chain and the operational sector, the *Nomenclature statistique des activités économiques dans la Communauté européenne* (NACE) for the firms based in the Member States and the International standard industrial classification (ISIC) of all economic activities for firms located in third countries could be used. The two systems have the same structure, but the former is more detailed than the latter[304]. For example, there are cases where the two codes are the same, e.g. 0111 is the class "Growing of cereals (except rice), leguminous crops and oil seeds" in both the systems, whereas other codes. e.g. the 1012 "Processing and preserving of poultry meat", exist in NACE but is part of 1010 "Processing and preserving of meat", which is the broader definition comprehending three different NACE classes. A detailed conversion table is available through EUROSTAT[304]. There are two possibilities:

- To use solely the ISIC classification for all the firms regardless of the provenience;
- To use the NACE for the European firms and ISIC for firms based in third countries.

298 EUROSTAT. (2021). Glossary: Herfindahl Hirschman Index (HHI) . https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Herfindahl_Hirschman_Index_(HHI)

299 Roberts, M. T., Viinikainen, T., & Bullon, C. (2022). International and national regulatory strategies to counter food fraud. Food & Agriculture Organization.

300 van Ruth, S. M., Luning, P. A., Silvis, I. C., Yang, Y., & Huisman, W. (2018). Differences in fraud vulnerability in various food supply chains and their tiers. Food Control, 84, 375-381.

301 Yang, Z., Zhou, Q., Wu, W., Zhang, D., Mo, L., Liu, J., & Yang, X. (2022). Food fraud vulnerability assessment in the edible vegetable oil supply chain: A perspective of Chinese enterprises. Food Control, 138, 109005.

302 van Ruth, S. M., & Nillesen, O. (2021). Which company characteristics make a food business at risk for food fraud?. Foods, 10(4), 842.

303 Guntzburger, Y., Théolier, J., Barrere, V., Peignier, I., Godefroy, S., & de Marcellis-Warin, N. (2020). Food industry perceptions and actions towards food fraud: Insights from a pan-Canadian study. Food Control, 113, 107182.

304 EUROSTAT. (2008). NACE rev. 2. Office for Official Publications of the European Communities

In the latter case, there might be more detailed information for the internal market that is generally less controlled than imports (given the absence of borders), hence balancing this weakness and using more granular information.

In order to allow any digital IT tool to take into account for the firm supply chain position, it is necessary to associate each firm to its primary NACE or ISIC. As for any other firm level data, they can be accessed either through interaction with Chambers of Commerce or tax authorities is needed or the access to private databases can be available upon payment.

Checkpoint location

In the previous section "Address" the report has already analysed the influence of the territory on the quality of official controls. Similar reasoning apply to inspections carried out along the food chains: inspections performed in some countries are more vulnerable to corruption and inefficiencies compared to others.

Non-compliance

The Transaction ID Card should include any inspection carried out by official authorities related to a specific transaction. Data should include: a date, the results of the inspection, and in case of non-compliances the type of non-compliances and the actions taken.

There is neither a consensus nor a list legally established of non-compliances at EU level; therefore, it is pivotal to establish a standardised list of non-compliances for food fraud and food safety issues to be assessed by the ideal digital IT tool.

E-commerce

Consumers are increasing their reliance on technology (e.g. e-commerce) for food consumption[305] and the growth will be exponential in the future[306]. The business-to-consumers e-commerce allows consumers to acquire favourably groceries via multiple online marketplaces[307] but on the other side it represents an environment favourable for criminal behaviours to infiltrate the supply chains[308,309]. As a matter of fact, consumers make their purchases without face-to-face contact with sellers, without the opportunity to inspect food items and usually they have to pay before receiving the good. Furthermore, e-commerce may reduce traceability compared to brick-and-mortar shops since it connects consumers with businesses from all around the world through new and emerging operators[310]. Finally, even legitimate FBOs cannot have full control over the final delivery of the products[311]. These characteristics have made popular grocery items, like honey or olive oil, prime targets for e-commerce fraudsters[307].

Since e-commerce is now emerging, the literature is not extensive but experts are calling for further attention to the phenomenon[310]. Hence, for our purposes it may be reasonable to account for this variable, marking as more vulnerable any kind of transaction coming from e-commerce marketplaces.

Current Transaction ID (CTI)

One unique code to identify a single Transaction ID Card.

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305 Elferink, M., & Schierhorn, F. (2016). Global demand for food is rising. Can we meet it. Harvard Business Review, 7(04), 2016.

306 Bedford, E. (2022). Europe: Grocery sales value by sector 2021-2026. Statista. https://www.statista.com/statistics/979888/value-of-grocery-sales-in-europe-by-sector/

307 Lee , B., Fenoff, R., & Spink, J. (2022). Routine activities theory and food fraud victimization. Security Journal, 35(2), 506-530.

308 Farrand, B. (2018). Combatting physical threats posed via digital means: the European Commission's developing approach to the sale of counterfeit goods on the Internet. European Politics and Society, 19(3), 338-354.

309 Hunter, J. & Riefa, C. (2017). The challenge of protecting EU consumers in global online markets. In: The European Consumer Organisation and the Federation of German Consumer Organisations. https://www.vzbv.de/sites/default/files/downloads/2017/11/08/17-11-08_brochure-vzbv-beuc-lr3.pdf

310 FAO/WHO CAC (Codex Alimentarius Commission). (2017). Discussion Paper on Food Integrity and Food Authenticity. CX/FICS 17/23/5. Prepared by Iran with assistance from Canada and the Netherlands, Codex Committee on Food Import and Export Inspection and Certification Systems (CCFICS) (23rd Session), Mexico City, Mexico, 1-5 May 2017.

311 Comans, C. (2019). eCommerce of Food – International Conference on Trends and Official Control. Online Food Fraud. PowerPoint presented in Berlin. https://www.bvl.bund.de/SharedDocs/Downloads/10_Veranstaltungen/eCommerce2019/PPT/Comans_PPT.pdf?__blob=publicationFile&v=1

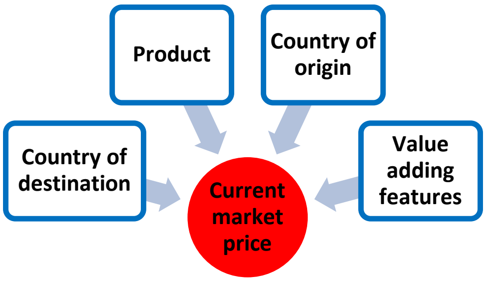
Backward Transaction IDs (BTIs)

A list of all CTIs of the Transaction ID Cards covering the ingredients of the food under analysis, even if the ingredients are the same and from the same company, but purchased with different transactions. Such information are theoretically already in the hands of FBOs, who have the legal obligation to store data on their suppliers. For example: in case a company produces a processed product, the CTI will include all the BTIs of the related ingredients.

Forward Transaction IDs (FTIs)

Within this data item there will be listed all the CTIs of the Transaction ID Cards covering the products that have included as their future ingredient the product covered by the CTI. Such information are theoretically already in the hands of FBOs, who have the legal obligation to store data on their buyers. For example, the data item FTIs will be automatically updated with the processed product including the food under analysis as an ingredient.

Current market price [Derived data item]



The product market price is a key factor to take into account when investigating foodstuff fraud vulnerability and it may result from a combination of other previous data items: *country of origin*, *country of destination*, *value adding features* and *product*. As a matter of fact, the higher is the commodity price, the higher the probability of adulteration[312,313] because of pressure on the supply chain. Since product fraud is economically driven[314], high unit profitability (i.e. the difference between the product price and its production cost) may incentivize adulteration[315]. If analysed in the context of the Beckerian model, given the fixed expected sanction in the case of discovery by the authorities, the higher the margin a fraudster can have for a product, the higher the probability that product will be targeted. There are many examples of relatively expensive products substituted by a cheaper one, e.g. spices mixed with flour, honey substituted by glucose syrup[301] or peanut shells used as filler in ground cumin[316].

In conclusion, high prices are clearly important in food fraud vulnerability assessment as they offer higher fraudulent profits thanks to low cost adulteration. Data availability on this topic may be an issue. To our knowledge different options are:

— Monthly market prices[317]: a database elaborated by DG AGRI providing price data at country level for beef (6 products), cereals (10 products), dairy (5 products), eggs and poultry (4 products), fruit and vegetables (46 products), olive oil (3 products), pigmeat (5 products) and sheep & goat meat (2 products) for all Member States. Not all foodstuff is covered and the granularity level is rather coarse;

312 Handford, C. E., Campbell, K., & Elliott, C. T. (2016). Impacts of milk fraud on food safety and nutrition with special emphasis on developing countries. Comprehensive Reviews in Food Science and Food Safety, 15(1), 130-142.

313 Huck, C. W., Pezzei, C. K., & Huck-Pezzei, V. A. (2016). An industry perspective of food fraud. Current Opinion in Food Science, 10, 32-37.

314 Smith, M., Ashraf, M., Austin, C., & Lester, R. (2021). Product fraud: Impacts on Australian agriculture, fisheries and forestry industries (p. 116).

315 OECD. (2007). The economic impact of counterfeiting and piracy.

316 Cavallaro, E., Date, K., Medus, C., Meyer, S., Miller, B., Kim, C., ... & Behravesh, C. B. (2011). Salmonella typhimurium infections associated with peanut products. New England Journal of Medicine, 365(7), 601-610.

317 https://agridata.ec.europa.eu/extensions/DashboardPrice/DashboardMarketPrices.html

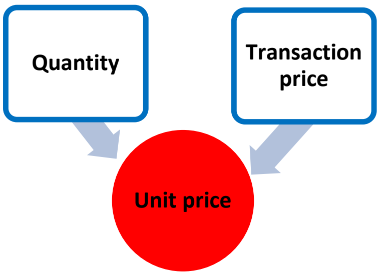
— FAO Food Price Index[318]: monthly index also calculated for cereals, vegetable oil, dairy, meat and sugar. The defined commodity groups cover only the main markets and are calculated at international level;

— Fair price calculated by THESEUS: an algorithm developed by the JRC that can calculate the so-called "fair price" of imported goods, i.e. an estimate of what can be the market price. The calculation is made at very high level of granularity, i.e. 10-digits CN, for combinations of origin and destination country, but an EU mean can be obtained too. Data at country level can be useful as they will give more specific information, but not necessarily that product with the associated cost will remain in the destination country instead of being retransferred within the internal market;

— EUMOFA database: developed by DG MARE, contains data on the prices of fisheries and aquaculture products throughout the supply chain. The database takes into account also the derivative products and import-export traffic[319].

The representativeness of imported goods prices compared to those produced within the internal market is an issue. For some products, the quality may be the same hence the price will converge. On the other hand, if - for the same product code - imported goods and EU products differ in average quality, then the average import price for that good may not be representative. Thus, using import prices as proxies for commodity prices at EU or national level is not straightforward and must be done with awareness of its downsides.

Unit price [Derived data item]



The unit price can be automatically calculated by dividing the *Transaction price* for the *Quantity*. The rationale of the importance of such data item is quite intuitive: if the price is "too good to be true", then there is a higher risk of buying a fraudulent product. The THESEUS IT tool is already capable of identifying outliers when scanning imported foodstuffs.

Future market price [Derived data item]

Considering the commodity price in a given moment does not give the full picture of the incentives that food fraudsters may have. Indeed, for a complete fraud risk assessment it is important to capture also price shifts[268]. Taking into account this variable is critical since it can capture a possible shift in fraud vulnerability, as the 2013 house meat scandal clearly showed. In fact, in that case horse meat was deceptively substituted with beef. It happened because in that period the economic recession led to the decrease of many commodity prices, hence putting many companies in financial distress. At the same time, beef prices increased 45% arriving at a price of $5 300/ton (compared to horse meat - $1 300/ton), hence clearly representing a relevant profit for fraudsters[320].

Price changes may also happen due to natural shocks (e.g. heat waves, droughts, floods) or external shocks (e.g. war or trade treaties). Being capable of predicting the effects of these phenomena would give the possibility to redirect controls with a timely manner, serving as red flag. Together

318 https://www.fao.org/worldfoodsituation/foodpricesindex/en/

319 https://www.eumofa.eu/data

320 Lawrence, F. (2013). Horsemeat scandal: The essential guide, The Guardian (UK). URL: http://www.theguardian.com/uk/2013/feb/15/horsemeat-scandal-the-essential-guide

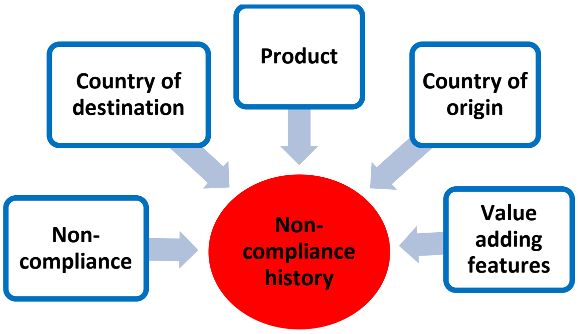
with exogenous shocks, product demand may change also due to seasonality[321], hence creating higher demand due to cyclical consumption (e.g. festivities, seasonal consumption patterns, etc…).

Indeed, a price increase will certainly allow higher profits for fraudsters since the expected gain from fraudulent activity will increase, hence given the same expected costs (e.g. fines, incarceration, etc…) criminal activity is expected to increase according to the Beckerian model of engagement in criminal activity.
To achieve the objective of timely control redirection, forecasting platforms shall be used. To our knowledge there are multiple alternatives:

- Short-term outlook[322]: issued three times per year by DG AGRI, covers only some key markets, i.e. cereals, oilseeds, protein crops, sugar, olive oil, wine, apples, oranges, milk, dairy products, beef, pigmeat, poultry, sheep and goat meat. The report also considers the macroeconomic outlook and exogenous shocks for the part that will affect the food sector. It provides year-to-year forecast changes in crop yield, imports and exports but not on the commodity prices.
- JRC MARS Bulletin[323]: issued monthly for the EU Member States and some neighbouring countries, and twice per year for Turkey, Ukraine, Kazakhstan, Russia and North Africa. The bulletin provides information on the condition of crops and weather affecting crop growth and development. It also provides crop yield forecasts. The analysed crop will depend on the analysed month since seasonal crops are taken into account.
- Medium-term outlook: published once a year, it provides the medium-term outlook for the EU-27 agricultural markets. In the report many variables are examined: the macroeconomic conditions, external shocks, commodity availability, links with the consumption of other commodities, import and exports. One of the simulation output will be the equilibrium price for the following commodity groups: cereals, oilseeds, oilmeals and vegetable oils, biofuels, protein crops and rice, feed, sugar, milk, dairy products, beef and veal, pigmeat, poultry meat, sheep and goat meat, olive oil, wine, fruit and vegetables.

Information are already present in several European databases and intelligence systems. In particular, the MARS Bulletin can be used to predict the evolution of the main crops throughout Europe. In this way, a prompt forecast of the evolution of crop yields could be doable, but in order to forecast the effect that e.g. natural disasters may have on the commodity price, an adjustment of the model developed according to the Medium-term outlook is needed.

Non-compliance history [Derived data item]



This derived data item should register how frequent a specific food *product* (with or without *value adding features*) is affected by a specific *non-compliance*, taking into account the *country of origin* and the *country of destination*. Official controls should take into account such analysis in order to understand which are the most common non-compliances affecting the various food supply chains, the reasoning behind and how to react efficiently. For example: it is quite common to adulterate honey with sugar syrups. In the ideal digital IT tool, the product "honey" would be frequently

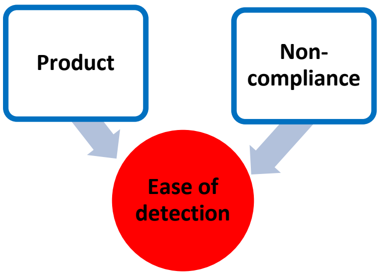
321 Preedy, V. R. (2016). Electronic noses and tongues in food science. Academic Press.

322 https://agriculture.ec.europa.eu/data-and-analysis/markets/outlook/short-term_en

323 https://joint-research-centre.ec.europa.eu/monitoring-agricultural-resources-mars/jrc-mars-bulletin_en

associated with the related non-compliance "adulteration", providing an analysis of the food chain and even triggering the development of new methodologies and/or policies to address the problem.

Ease of detection [Derived data item]



Different frauds show different difficulties in being detected, when considering the *product* and the *non-compliance*. For example: smuggling cereals without traceability documentation is easy to detect (requiring only visual inspection and checking the documents), whereas identifying the origin mislabelling on a wine, or the adulteration of oregano with olive tree leaves powder, requires several expensive analytical (molecular and/or biochemical) techniques and staff expertise not easily available everywhere.

Every data item may have a value for the ideal digital IT tool only if translated into numerical entities. Therefore, a specialised Working Group should be created in order to rank and quantify the difficulty of detection for each combination of food product and non-compliance. It is expected that frauds most difficult to detect are those attracting the attention of fraudsters.

Annex 3: The candidate food sector(s)

The best candidate commodity to test a pilot project should have the following characteristics:

— **A high market value in terms of EU imports**: according to the statistics provided by DG AGRI[324] and EUROSTAT[325], in 2020 the most valuable commodities imported into the EU were "*Edible fruit and nuts; peel of citrus fruits or melons*" (20.1 million Euros) and "*Fish and crustaceans, molluscs & other aquatic invertebrates*" (19.5 million Euros).

— **A high value for each individual product**: taking into account the perspective of Customs controls, expensive products (i.e. €/kg) provide a benefit because they require less efforts (e.g. fewer inspections) in order to identify non-compliances (e.g. safety risks, tax evasion, counterfeit).

— **Internationally recognised as a commodity with vulnerable value chains**: in 2020, the EU Food Fraud Network Report[326] listed (in decreasing order) "*fats and oils*", "*fish and fish products*" and "*poultry meat and poultry meat products*" as the most reported food categories in the AAC-FF System, whereas the food categories mostly covered by AA requests with potential suspicion of fraud were "*fruits and vegetables*", "*bivalve molluscs and products thereof*", "*meat and meat products (other than poultry)*", "*dietetic foods, food supplements, fortified foods*", "*fish and fish products*".

  In the 2021 Annual Report Alert and Cooperation Network[327], the food categories mostly notified with non-compliances were (in decreasing order) "*fruits and vegetables*", "*dietetic foods, food supplements, fortified foods*", "*meat and meat products (other than poultry)*", "*fish and fish products*", whereas the food categories mostly notified with fraud notifications were *"fish and fish products"*, *"fats and oils"* and "*meat and meat products (other than poultry)*".

  By analysing the food fraud cases covered within the Food Fraud Monthly Reports from September 2016 to December 2020, the JRC[328] identified as the most globally targeted commodities (in decreasing order): *seafood*, *wine and alcoholic beverages*, *meat products*, *milk and dairy*, *oils*, *herbs and spices*, and *honey*.

  Also the scientific literature[329] analysed the food fraud cases registered in EU (RASFF database) and USA (EMA database) between 2000 and 2015, identifying seafood as the most reported commodity.

— **Low level of self-sufficiency ratio (SSR) in the EU**: by manually calculating the 2018 SSR[330] (in terms of volume, and not economic value) of the EU for each individual commodity from the FAOSTAT Food Balance Sheets[331] (Table 5), the individual EU food supply chains mostly dependent on imports were (in decreasing order) "*stimulants*" (e.g. coffee and tea), "*spices*", "*seafood*", "*treenuts*" and "*vegetable oils*". Similar data were confirmed by other EU sources. The lower the SSR, the more dependant the EU is from imports. DG AGRI and DG MARE publish each year their market analyses that provide a clear overview of self-sufficiency rates for each commodity of commodity group (Table 6 and Table 7). The EU food supply chains mostly

324 Page 70 of European Commission (2021) Key figures on the European food chain — 2021 edition. ISBN: 978-92-76-41514-5

325 EUROSTAT, EU trade since 1988 by HS2-4-6 and CN8

326 European Commission, Directorate-General for Health and Food Safety, (2021). The EU agri-food fraud network and the administrative assistance and cooperation system – 2020 annual report, Publications Office

327 European Commission, Directorate-General for Health and Food Safety, (2021). Alert and cooperation network – 2021 annual report, Publications Office of the European Union

328 Siligato R., and Ulberth F. (2021) Four years of monitoring food fraud globally. New Food Magazine – Food Integrity Supplement. Volume 24, issue 02. https://www.newfoodmagazine.com/article/143865/food-integrity-supplement-april-2021/

329 Marvin, H. J., Bouzembrak, Y., Janssen, E. M., van der Fels-Klerx, H. V., van Asselt, E. D., & Kleter, G. A. (2016). A holistic approach to food safety risks: Food fraud as an example. Food research international, 89, 463-470.

330 "The self-sufficiency ratio (SSR) is defined as: SSR = production*100/(production + imports – exports). The SSR can be calculated for individual commodities, groups of commodities of similar nutritional values and, after appropriate conversion of the commodity equations, also for the aggregate of all commodities. In the context of food security, the SSR is often taken to indicate the extent to which a country relies on its own production resources, i.e. the higher the ratio the greater the self-sufficiency.While the SSR can be the appropriate tool when assessing the supply situation for individual commodities, a certain degree of caution should be observed when looking at the overall food situation. In the case, however, where a large part of a country's production of one commodity, e.g. other cereals, is exported, the SSR may be very high but the country may still have to rely heavily on imports of food commodities to feed the population. The self-sufficiency rate (as defined above) cannot be the complement to 100 of the import dependency rate, or vice-versa." Source: FAO. 2001. Food balance sheets. A handbook. Rome. https://www.fao.org/3/x9892e/x9892e00.htm

331 https://www.fao.org/faostat/en/#data/FBS/report

dependent on imports were (in decreasing order): *oranges (processed)*, *seafood (total)*, *oilseeds*, *oilmeals*. The EU is also the global largest importer of fishery products (one third of the total world trade in value)[332] and imports 60% of seafood products consumed.

Table 5: List of FAOSTAT commodities and the related Self-Sufficiency Ratio (SSR) values, from the lowest SSR value to the highest, related to the EU.

Self-sufficiency ratio (%) [quantities] for each Macro-category	**FAOSTAT Macro-category**	**FAOSTAT Micro-categories** included in the Macro-category
0	Stimulants	Coffee and products Cocoa Beans and products Tea (including mate)
19,3	Spices	Pepper Pimento Cloves Spices, Other
50,1	Fish, Seafood	Freshwater Fish Demersal Fish Pelagic Fish Marine Fish, Other Crustaceans Cephalopods Molluscs, Other
52,2	Treenuts	Nuts and products
68,3	Vegetable Oils	Soyabean Oil Groundnut Oil Sunflowerseed Oil Rape and Mustard Oil Cottonseed Oil Palmkernel Oil Palm Oil Coconut Oil Sesameseed Oil Olive Oil Ricebran Oil Maize Germ Oil Oilcrops Oil, Other
68,6	Oilcrops	Soyabeans Groundnuts Sunflower seed Rape and Mustardseed Cottonseed Coconuts - Incl Copra Sesame seed Palm kernels Olives (including preserved) Oilcrops, Other
77,2	Aquatic Products, Other	Aquatic Animals, Others Aquatic Plants
82,1	Pulses	Beans Peas Pulses, Other and products
86,7	Fruits - Excluding Wine	Oranges, Mandarines Lemons, Limes and products Grapefruit and products Citrus, Other Bananas Plantains Apples and products Pineapples and products

332 FAO. (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome

		Dates Grapes and products (excl wine) Fruits, other
99,9	Sugar Crops	Sugar cane Sugar beet
102,0	Cereals - Excluding Beer	Wheat and products Rice and products Barley and products Maize and products Rye and products Oats Millet and products Sorghum and products Cereals, Other
103,6	Sugar & Sweeteners	Sugar non-centrifugal Sugar (Raw Equivalent) Sweeteners, Other Honey
105,9	Milk - Excluding Butter	Milk - Excluding Butter
106,5	Eggs	Eggs
107,0	Animal fats	Butter, Ghee Cream Fats, Animals, Raw Fish, Body Oil Fish, Liver Oil
111,7	Starchy Roots	Cassava and products Potatoes and products Sweet potatoes Yams Roots, Other
112,1	Alcoholic Beverages	Wine Beer Beverages, Fermented Beverages, Alcoholic Alcohol, Non-Food
112,6	Vegetables	Tomatoes and products Onions Vegetables, other
114,2	Meat	Bovine Meat Mutton & Goat Meat Pigmeat Poultry Meat Meat, Other
271,4	Offals	Offals, Edible

Source: 2018 FAOSTAT Balance Sheet of the European Union. https://www.fao.org/faostat/en/#data/FBS/report

Table 6: Self-sufficiency rates by seafood commodity group in 2019.

Commodity groups (share of total apparent consumption in 2019)	Self-sufficiency rates (2019)
Freshwater fish (5%)	13%
Crustaceans (7%)	20%
Groundfish (25%)	21%
Miscellaneous aquatic products (3%)	23%
Tuna and tuna-like species (13%)	29%
Salmonids (12%)	29%
Cephalopods (6%)	37%

Other marine fish (7%)	55%
Flatfish (1%)	69%
Bivalves and other molluscs and aquatic invertebrates (9%)	79%
Small pelagics (12%)	101%
Total	41,2%

Source: European Commission (2021) The EU Fish Market 2021 edition. ISBN 978-92-76-28905-0.

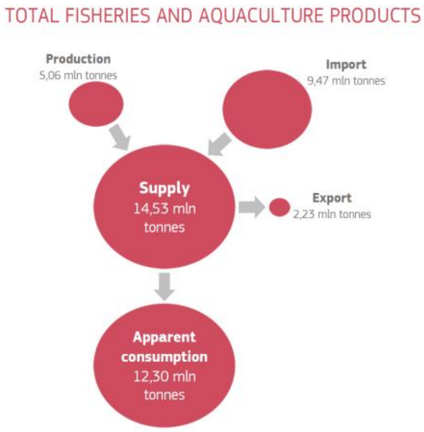
Table 7: EU-27 self-sufficiency rates by agriculture commodity group in 2021.

Commodity groups	EU-27 self-sufficiency rate 2021
Oranges (processed)	38
Oilseeds	61
Oilmeals	63
Sorghum	73
Vegetable oils	73
Protein crops	79
Durum	85
Maize	89
Oranges (fresh)	93
Tomatoes (fresh)	94
Sheep and goat meat	95
Triticale	100
Sugar	101
Oats	103
Peaches and Nectarines (fresh)	103
Fresh dairy products	104
Rye	106
Apples (processed)	107
Beef/veal	108
Butter	110
Cheese	112
Poultry meat	112
Apples (fresh)	115
Wine	119
Barley	120
Pigmeat	125
Tomatoes (processed)	130
Peaches and Nectarines (processed)	133
Soft wheat	139
Olive oil	141
Whey	145
Whole milk powder (WMP)	172
Skim milk powder (SMP)	209

Source: European Commission (2022) Short-term outlook for EU agricultural markets in 2022 (Summer Edition) - Annex. ISSN 2600-0873.

The **seafood sector** seems to be the best candidate, also considering the increasing attention of the EU on IUU fishing[333]. Seafood commodities are subject to fraudulent practices and food safety risks, and the EU is heavily dependent on imports in terms of quantities and economic value. According to the EUMOFA 2021 Yearly report[334,335,336], in 2020 extra-EU imports of fishery and aquaculture products totalled 6.15 million tonnes worth 24.21 billion €. Per capita apparent consumption is estimated at almost 24 kg. In 2019, the EU self-sufficiency ratio[337] was 41.2% (Figure 31). The trend is worsening, as EU catches are diminishing and imports are increasing.

Figure 31: EU supply balance (2019, live weight equivalent, food use only).



Source: European Commission (2021) The EU Fish Market 2021 edition. ISBN 978-92-76-28905-0

Notably, according to the Farm to Fork Strategy[338] (Section 2.1) "*The proposed revision of the EU's fisheries control system will contribute to the fight against fraud through an enhanced traceability system. The mandatory use of digitalised catch certificates will strengthen measures to prevent illegal fish products from entering the EU market*". The Opson IX Report also states: "*The threat related to this category of product* [seafood] *is increasing and becoming more complex, as it might involve concurrent illicit deeds, such as illegal fishing, food safety issues but also IPR* [Intellectual Property Rights] *crimes especially related to products subjected to the designation of origin*"[339], although seafood is not among the food commodities mostly targeted in the Opson operations. Finally the European Commission has stated that "*The EU is largely self-sufficient for key agricultural products, being a main wheat and barley exporter and largely able to cover its consumption for other staple crops such as maize or sugar. [...] However, the EU is a considerable net-importer for specific products which may be difficult to (swiftly) substitute, such as feed protein, sunflower oil or seafood*" [340] and "*The fish sector has a high degree of import-dependency, the EU self-sufficiency being at 14% for the top five species consumed*"[341].

In addition, the World Wildlife Fund (WWF) in a recent report highlighted that the EU "[...] *is also the world's largest seafood importer, importing more than half of what it consumes. Some of this*

333 European Parliament Research Service (2022) Illegal, unreported and unregulated (IUU) fishing. PE 614.598

334 https://www.eumofa.eu/the-eu-fish-market-2021-edition-is-now-online

335 https://oceans-and-fisheries.ec.europa.eu/news/eu-fish-market-2021-edition-now-online-2021-11-22_en

336 European Commission (2021) The EU Fish Market 2021 edition. ISBN 978-92-76-28905-0

337 Ratio between EU production and apparent consumption of the EU market. It measures the capacity of EU Member States to meet demand with their own production.

338 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system [COM(2020) 381 final]

339 EUROPOL (2021) Opson IX Report. https://www.europol.europa.eu/publications-documents/operation-opson-ix-%E2%80%93-analysis-report

340 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Safeguarding food security and reinforcing the resilience of food systems. COM/2022/133 final

341 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Contingency plan for ensuring food supply and food security in times of crisis. COM/2021/689 final

seafood comes from tropical regions where local communities rely on these fish stocks for protein, but are facing declining catches due to overfishing and climate change"[342].

The US FDA reached similar conclusions. The U.S. Government Accountability Office noted collaboration issues for the three federal agencies primarily responsible for detecting and preventing seafood fraud[343]. As the United States import 94% of its seafood supply, the FDA has run a pilot of its Artificial Intelligence Imported Seafood Pilot program[344,345,346] in order to react quickly to imported seafood potentially posing a threat to public health. The pilot program utilised ML to target seafood shipments.

342 Ruiz-Mirazo, J. (2022). Europe eats the world. WWF European Policy Office. https://www.wwf.eu/?6642391/Europe-eats-the-world

343 Upton, H. F. (2015). Seafood fraud. Congressional Research Service.

344 https://www.fda.gov/food/cfsan-constituent-updates/fda-moves-second-phase-ai-imported-seafood-pilot-program?utm_medium=email&utm_source=govdelivery

345 https://www.fda.gov/news-events/fda-voices/import-screening-pilot-unleashes-power-data-and-leverages-artificial-intelligence

346 https://www.fda.gov/food/cfsan-constituent-updates/fda-moves-third-phase-artificial-intelligence-imported-seafood-pilot-program

Annex 4: The legal bases for risk-based official controls

The EU legislation and international guidelines already recommend utilising risk-based strategies to optimize resources and personnel in the routine official control activities.

Recital 32 of the **Official Controls Regulation** (OCR)[347] states that "*Competent authorities should perform official controls regularly, on a risk basis and with appropriate frequency, on all the sectors and in relation to all operators, activities, animals and goods governed by Union agri-food chain legislation. The frequency of official controls should be established by the competent authorities having regard to the need to adjust the control effort to the risk and to the level of compliance expected in the different situations, including the possible violations of the Union agri-food chain legislation perpetrated through fraudulent or deceptive practices. Accordingly, the likelihood of non-compliance with all the areas of the Union agri-food chain legislation which fall within the scope of this Regulation should be taken into account where adjusting the control efforts. In some cases, however, and in view of the issuance of an official certificate or attestation which is a pre-requisite for the placing on the market or for the movements of animals or goods, Union agri-food chain legislation requires that official controls be performed irrespective of the level of risk or the likelihood of non-compliance. In such cases, the frequency of the official controls is dictated by the certification or attestation needs.*" Recital 38 continues with "*the competent authorities should have the power to perform official controls at all stages of production, processing and distribution of animals and goods concerned by that legislation*" and "*should draw up and maintain a list or register of the operators to be controlled*". Recital 39 stresses the last point by stating "*Competent authorities should also, subject to certain conditions, be entitled to publish or to make available information about the rating of individual operators based on the outcome of official controls. The use of rating schemes by Member States should be allowed and encouraged as a means to increase transparency along the agri-food chain, provided that appropriate guarantees of fairness, consistency, transparency and objectiveness are offered by such schemes*".

Speaking about imports, Recital 53 of the OCR highlights "*Official controls performed on animals and goods entering the Union from third countries are of key importance since these controls ensure compliance with legislation applicable within the Union and, in particular, with the rules established to protect human, animal and plant health, animal welfare and, as regards GMOs and plant protection products, also the environment. Such official controls should take place before the animals or goods are released for free circulation within the Union. The frequency of official controls should adequately address risks to human, animal and plant health, animal welfare and to the environment that animals and goods entering the Union might pose, taking into account the operator's history of compliance with the requirements provided for in Union agri-food chain legislation, the controls already performed on those animals and goods in the third country concerned, and the guarantees given by that third country that animals and goods exported to the Union meet the requirements laid down in Union legislation*". Recital 58 continues with "*The frequency of physical checks should be determined and modified on the basis of risks to human, animal or plant health, animal welfare or, as regards GMOs and plant protection products, also to the environment. That approach should enable the competent authorities to allocate resources for controls where the risk is highest. The frequency of identity checks should also be subject to reduction or limited to the verification of a consignment's official seal where this is justified by a reduced risk posed by the consignments entering the Union. The risk-based approach to identity checks and physical checks should be pursued by making use of available data sets and information, and of computerised data collection and management systems*".

Recital 86 of the OCR, although referring to the IMSOC system, established the very bases for the creation of a future information system as described in this report: "*To support a more efficient management of official controls, a computerised information system integrating and upgrading as necessary all relevant existing information systems should be set up by the Commission, allowing for the use of advanced communication and certification tools, and for the most efficient use of the data and information related to official controls. In view of avoiding unnecessary duplications of*

347 Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products

information requirements, the design of such computerised system should take into account the need to ensure, wherever appropriate, the compatibility and inter-operability of such a computerised system with other information systems operated by public authorities and through which relevant data is automatically exchanged or made available".

The OCR legal text strongly echoes what is framed within the Recitals. Article 9.1 and 9.2 state that:

"*1. Competent authorities shall perform official controls on all operators regularly, on a risk basis and with appropriate frequency, taking account of:*

(a) identified risks associated with:

(i) animals and goods;

(ii) the activities under the control of operators;

(iii) the location of the activities or operations of operators;

(iv) the use of products, processes, materials or substances that may influence food safety, integrity and wholesomeness, or feed safety, animal health or animal welfare, plant health or, in the case of GMOs and plant protection products, that may also have an adverse impact on the environment;

(b) any information indicating the likelihood that consumers might be misled, in particular as to the nature, identity, properties, composition, quantity, durability, country of origin or place of provenance, method of manufacture or production of food;

(c) operators' past record as regards the outcome of official controls performed on them and their compliance with the rules referred to in Article 1(2);

(d) the reliability and results of own controls that have been performed by the operators, or by a third party at their request, including, where appropriate, private quality assurance schemes, for the purpose of ascertaining compliance with the rules referred to in Article 1(2); and

(e) any information that might indicate non-compliance with the rules referred to in Article 1(2).

2. Competent authorities shall perform official controls regularly, with appropriate frequencies determined on a risk basis, to identify possible intentional violations of the rules referred to in Article 1(2), perpetrated through fraudulent or deceptive practices, and taking into account information regarding such violations shared through the mechanisms of administrative assistance […].

Border control posts are addressed in Article 44 of the OCR:

"1. To ascertain compliance with the rules referred to in Article 1(2), the competent authorities shall perform official controls regularly, on a risk basis and with appropriate frequency, on animals and goods entering the Union and to which Articles 47 and 48 do not apply.

2. On animals and goods referred to in paragraph 1 the appropriate frequency of the official controls shall be determined, taking into account:

(a) the risks to human, animal or plant health, animal welfare or, as regards GMOs and plant protection products, also to the environment, associated with different types of animals and goods;

(b) any information indicating the likelihood that consumers might be misled, in particular as to the nature, identity, properties, composition, quantity, durability, country of origin or place of provenance, method of manufacture or production of goods;

(c) the history of compliance with the requirements established by the rules referred to in Article 1(2) applicable to the animals or goods concerned:

(i) of the third country and establishment of origin or place of production, as appropriate;

(ii) of the exporter;

(iii) of the operator responsible for the consignment;

(d) the controls that have already been performed on the animals and goods concerned; and

(e) the guarantees that the competent authorities of the third country of origin have given with regard to compliance of the animals and goods with the requirements established by the rules referred to in Article 1(2) or with requirements recognised to be at least equivalent thereto.

4. Notwithstanding paragraphs 1 and 3, the competent authorities at border control posts and other points of entry into the Union shall perform official controls on the following whenever they have reason to believe that their entry into the Union may pose a risk to human, animal or plant health, animal welfare or, as regards GMOs and plant protection products, also to the environment:

(a) means of transport, including where empty; and

(b) packaging, including pallets."

Article 54 states that the frequency rate of identity checks and physical checks on animals and goods should be adjusted according to the level of risk, taking into account:

"(i) information collected by the Commission in accordance with Article 125(1);

(ii) the outcome of controls performed by Commission experts in accordance with Article 120(1);

(iii) operators' past record as regards compliance with the rules referred to in Article 1(2);

(iv) data and information collected via the information management system for official controls (IMSOC) referred to in Article 131;

(v) available scientific assessments; and

(vi) any other information regarding the risk associated to the categories of animals and goods;"

The **Codex Alimentarius Commission** has also produced a Guideline[348] document covering control systems. Codex Guidelines have no legal validity; however, it is worthy to mention briefly how the United Nations address the topic. Some paragraphs especially focus on the need to develop risk-based control programs for fraud and deception:

"17. A competent authority should make decisions within a national food control system based on scientific information, evidence and/or risk analysis principles as appropriate."

"36. A national food control system should possess three main characteristics which, among other things, can be used in self-assessment or other evaluation to determine if the system is fully functional and effective:

i) ***Characteristic 1*** *Situational awareness means that a national food control system avails itself of accurate and current information on the entire food chain.*

ii) ***Characteristic 2*** *Pro-activity means that a national food control system is capable of identifying existing or emerging hazards before they materialise as risks in the food production and/or processing chain and at the early stages rather than in the end product. Early warning and/or rapid alert systems, traceability and contingency planning for managing and preparing for potential food safety incidents should be an inherent part of a pro-active control system.*

iii) ***Characteristic 3*** *Continuous Improvement means that a national food control system should possess the capability to learn through a process of review and reform utilising mechanisms that check and evaluate whether the system is able to achieve its objectives."*

"45. An appropriate system design should consider a range of factors including (but not limited to) product risk, current scientific information, industry based controls and system review findings. It should also provide for flexibility in the application of control measures to reflect variations in these factors."

"46. Development of an effective method of data collection across the food chain is important for situational awareness, performance measurement and continuous review and system improvement. For instance, surveillance and monitoring programs can be used to target priority risks."

348 Codex Alimentarius Commission. (2013). Principles and Guidelines for National Food Control Systems; CAC/GL 82-2013; Food and Agriculture Organization of the United Nations: Rome, Italy. World Health Organization: Geneva, Switzerland.

"47. The competent authority should utilise findings from laboratories to monitor trends in the food chain and assist in compliance and enforcement. Laboratory access and capacity should be commensurate with the need to address priority food risks."

"50. Control programs should be based on risk and designed to take into account a number of factors including but not limited to:

- *Food safety hazards associated with different products and the risk to human health posed by the food or food related products;*
- *Risk of unfair practices in the food trade associated with different products, such as potential fraud or deception of consumers;*
- *Information that may be available from a range of sources including government, academia, scientific institutions and industry data;*
- *Statistical data on production, trade and consumption;*
- *Results of previous controls including analytical results;*
- *The effectiveness and reliability of controls including those of food business operators;*
- *Knowledge of operators at various stages of the food chain typical and atypical use of products, raw materials and by-products; structure of production and supply chains; production technologies, processes and practices; relevant product tracing information; and*
- *Epidemiological data on food borne disease."*

"57. Compliance and enforcement programs should be designed to provide the ability for the competent authority to take corrective action to ensure the situation is remedied where the food business operators are not meeting their obligations or a product or process is found not to be in conformity. Programs should be designed to:

- *Be proportionate to the degree of public health risk or potential fraud or deception of consumers;*
- *Encourage acceptance of responsibility and compliance by all participants; and*
- *Provide for a full range of responses from provision of information or education material, imposing of corrective actions, setting of sanctions.*
- *Take into account repeated non-conformity by food business operators."*

"60. The design of a national food control system should incorporate timely access to adequate information relating to the surveillance, investigation and response to food borne illness and food related incidents. Such information can identify the risks or issues that need to be addressed and also whether or not the controls or measures in place are effective"

"81. Where a product or process is found not to be in conformity, the competent authority should take action to ensure that the operator remedies the situation. The resulting measures should take into account any repeated non-conformity of the same product or process to ensure that any action is proportionate: to the degree of public health risk, potential fraud or deception of consumers. As an example to illustrate this point the specific measures that may be applied in continuous cases of non-conformity may include:

- *Increased intensity of audits and/or inspection and/or monitoring of products and/or processes; identified as being not in conformity and/or the undertakings concerned; and*
- *In the most serious or persistent cases, de-registration of the producer and/or processor or closure of the relevant establishment."*

"85. The review of food-related non-compliances and/or incidents is an opportunity to learn which can be used as a feedback loop for the planning process by the competent authority. A competent authority should use these opportunities to engage in continuous improvement by assessing an incident from first signal through response and incorporating lessons learned in the design and planning phase."

A similar approach is echoed by the related Codex Alimentarius Guidelines[349,350], where risk assessment is praised as the underlining principle to ensure food safety. Risk assessment should take into account commodities, processing methods, and the country of origin. The extent and stringency of requirements for imported food should be "*proportionate to risk, noting that risk may vary from one source to another because of factors such as specific and/or similar situations in the region of origin, technology employed, compliance history, etc. and/or examination of relevant attributes of a sample of products at import*". Legislation should provide the competent authority with "*the ability to apply risk-based sampling plans, taking into consideration the compliance history of the particular food, the validity of accompanying certification, and other relevant information*". The frequency of inspection and testing of imported food should take into account several factors as e.g.: the risk to human health; the likelihood of non-compliance; history of conformity of the food chain actors; adequacy of laws, regulations and policies in the exporting country; history of compliance of the food; previous reports and certificates.

349 Codex Alimentarius Commission. (1995). Principles for Food import and Export inspection and certification. CAC/GL, 20. [CXG 20-1995]

350 Codex Alimentarius Commission. (2003). Guidelines for Food Import Control Systems. Document CAC/GL, 47-2003. [CXG 47-2003]

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