# 3D IMAGING AND SENSING - TECHNOLOGY AND MARKET TRENDS 2021

Market & Technology Report - June 2021

*Can Apple's use of direct Time-of-Flight (dToF) sensors in the iPhone 12 Pro accelerate and consolidate the use of ToF 3D sensing technology?*

## WHAT'S NEW

- Updated mobile adoption rate/ASP/ revenue forecasts through 2026
- Forecast analysis per sub-component
- Added scenario for 3D cameras in consumer products
- Update rear 3D camera application
- 3D imaging and sensing ecosystem update
- Updated trends for all markets
- Technology cost breakdown
- New 3D sensing technologies

## KEY FEATURES

- 3D imaging and sensing - market forecast in Munits through 2026
- 3D imaging and sensing - market forecast in $M through 2026
- 3D imaging and sensing - ecosystem mapping
- Application trends - mobile and consumer, automotive and transportation, medical, industrial, defense and aerospace
- Technology trends – ToF, LiDAR and others

## THE RISE OF THE MOBILE 3D SENSING MARKET IS SLOWING, BUT THE NEXT WAVE IS COMING

In mobile markets there is a temporary hiatus in growth of 3D sensing due to the ban of Huawei in the US as well as the fact that the Android camp has abandoned the technology.

The shipment volume of 3D sensing products recorded in 2020 is about 80% of the previous forecast. The gap between previous optimistic forecasts widened as sales leveled off. But under-display camera technology became mature, and there are more low-cost indirect Time-of-Flight (iToF) sensing solutions. These could drive higher 3D sensing adoption and a return to growth around 2023.

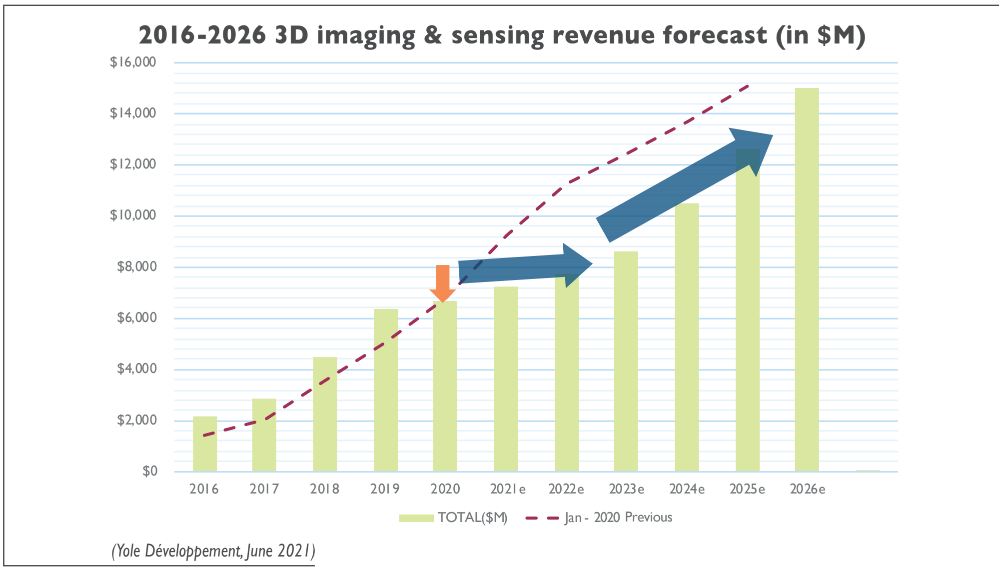
Apple continues to use front-facing structured light throughout all iPhone series. It also introduced a 3D camera with a direct ToF (dToF) array sensor into the iPhone 12 Pro, a step forward for the 3D sensing market.

Besides mobile phones, 3D sensing technology has a broad consumer market, including tablets, Virtual and Augmented Reality (VR/AR), robot vacuum cleaners, and Artificial Intelligence combined with the Internet of Things (AIoT).

Increased labor costs and manufacturing upgrades are accelerating development of machine vision, including 3D visual systems, increasing 3D vision penetration every year. Electric vehicles have ramped up in 2020, which exploit autonomous driving, as do fully robotic vehicles. This market is going to boom. We believe that it will be the next wave of 3D sensing.

Yole Développement expects the global 3D imaging and sensing market to expand from $6.8B in 2020 to $15.0B in 2026, at a 14.5% Compound Annual Growth Rate (CAGR).

3D imaging and sensing technology is an important means to acquire information in the perception of the real world. It provides a basis for the reconstruction of the real geometry of an object and subsequent 3D modeling, detection and recognition. It is used in augmented reality, gaming, autonomous driving and a wide range of applications. This latest edition of Yole's popular report offers you key insights for navigating 3D imaging and sensing's growth.



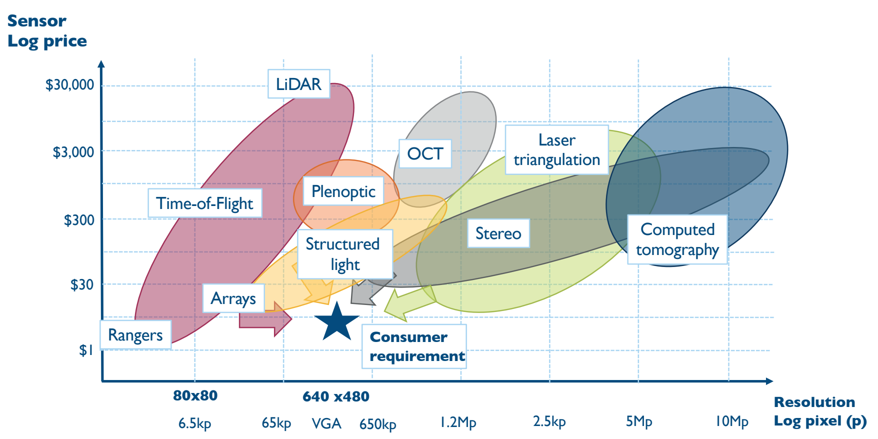

(Yole Développement, June 2021)

## DIRECT TIME-OF-FLIGHT IS CHANGING THE VALUE OF THE 3D SENSING MODULE, BUT CURRENTLY STRUCTURED LIGHT STILL MAINTAINS ITS FIRST POSITION

In the mobile and consumer worlds, some bigger players have paused upgrading of cameras with 3D sensing temporarily. However, we are seeing some small smartphone players start to use iToF cameras to enhance photography, such as Sony and Meizu. Apple, on schedule, used a dToF rear module on the iPad Pro and the iPhone 12 Pro in 2020. It still uses structured light as its face identification in its whole series of products. This report reveals the penetration rate for major mobile phone makers in 2021. Yole forecasts that 69.2 million smartphones with ToF cameras will be shipped globally in 2021.

The adoption of dToF technology in iPhones could attract a large number of component suppliers to join the supply chain. This would bring more choice to the market and prompt iToF makers to lower costs to compete. That will allow ToF technology to infiltrate non-mobile areas very quickly. For example, machine vision is slowly adopting ToF technology instead of traditional laser triangulation for simple robot picking-up functions. iToF and dToF will become the mainstream 3D sensing schemes by virtue of their cost advantage, longer distance detection and excellent real-time perception ability. Especially in VR/AR, where there is a high demand for time delay to avoid vertigo, ToF is the most suitable spatial positioning technology.

**3D Sensing market trend**



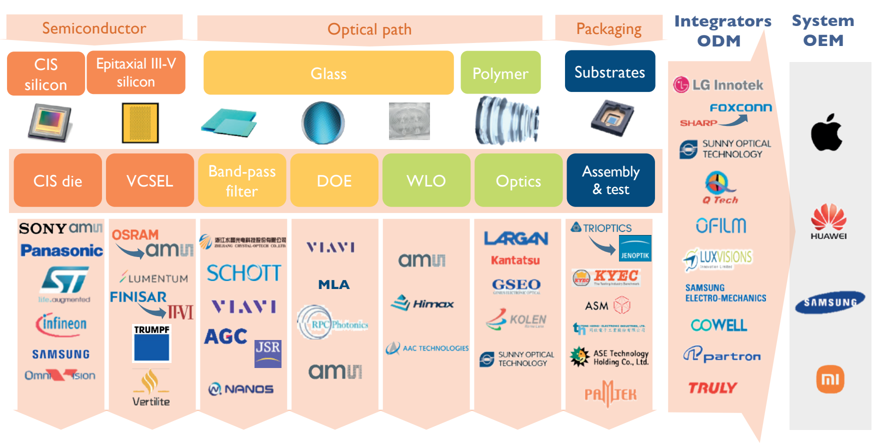

*(Yole Développement, June 2021)*

Structured light can be found in all iPhones now. And the Android camp hasn't given up on structured light either. Instead, companies are aiming at under-display structured light. One of them, ZTE, has already shown its under-display structured light technology in 2021. Structured light is the best technology for facial recognition currently. It can be used widely in facial payment and access control. Yole Développement estimates that the volume of structured light modules will reach 473.7 million in 2026, accounting for about 54% of the whole 3D sensing market.

## STMICROELECTRONICS AND LUMENTUM BENEFIT THE MOST IN APPLE'S SUPPLY CHAIN. WHO IS NEXT?

In mobile 3D sensing, Apple's supply chain is stable and growing. STMicroelectronics and Lumentum are the most profitable, followed by AMS, II-VI and LG Innotek. The Android camp is less healthy. Neither the transmitter component suppliers, such as Trumpf and Vertilite, nor the receiver companies, like Omnivision and PMD Technology, have benefited much. The good news is that they're already actively working on 3D sensing in the non-mobile space, such as Vertilite in automotive and PMD in consumer applications. We expect they'll reap the benefits.

**3D Sensing – Mobile & consumer supply chains**




*(Yole Développement, June 2021)*

Sony is an exception. It is not only the leader of iToF sensors, but also the only manufacturer that can provide dToF sensor arrays for consumer applications. It is very competitive. We will not be surprised if it keeps its number one position no matter how the market changes.

The 3D sensing market is developing rapidly and has great opportunities. In addition to the mobile phone market, automotive Advanced Driver Assistance Systems (ADAS) are set to be a big 3D sensing application. Especially in 2020, the rapid growth of electric vehicles with very high intelligence and ADAS brings LIDAR adoption forward. This has attracted a wide range of players, from LiDAR suppliers in traditional industries like Valeo and Velodyne to electronics giants Sony, Huawei, and start-ups like Livox and XAOS.

In all the 3D sensing markets, China is an emerging market. It shows great vitality not only in the 3D back-end application market but also in the 3D front-end supply chain. This has been driven by the policy of China cultivating local supply chains in the middle of the US-China trade conflict. Facial payment has been driven by platform vendors AliPay and WeChat, and supported by technology provider Orbbec. In 3D machine vision, Hikrobot and Huaray are starting to compete with the likes of Sick and Lucid. In the automotive, the entry of Chinese players has played a decisive role in the price decline of LiDAR.

## COMPANIES CITED IN THE REPORT (non exhaustive list)

II-VI, AAC, Abbott, ABAX Sensing, Adaps Photonics, Actlight, ams, Apple, Arcsoft, Artilux, ASC, Baidu, Basler, Baumer, BAE Systems, Benewake, Bosch, Canon, Cognex, Continental, Core Photonics, Cowell, DJI, Denso, Deptrum, Ecovacs, Facebook, Faceshift, First Sensor, Foxconn, Genious Optical, Google, Gpixel, Hamamatsu, Hexagon Metrology, Himax, Hikrobot, Huawei, Huaray, IDS, Infineon, Intel, Innoviz, IFM, IQE, iRobot, iRay, Keyence, Largan, Leddartech, Leica, LG Innotek, Linx, Lips, LMI, LUCID, Lumentum, Luxvisions, Mantis Vision, Medtech, Megvii, Melexis, Namuga, Nordson Dage, Oculus, O-film, Omnivision, On Semi, Opnous, Optovue, Oppo, Orbbec, Panasonic, Pebbles, Percipio.xyz, Philips Photonics, Photoneo, Pix4D, PMD, Q-tech, Quanergy, San'an, Samsung, SmartSens, Sensl, Sensetime, SEMC, Sick, Silicon integrated, Softkinetic, Soitec, Sony, St. Jude Medical, STMicroelectronics, Sunny Optical, Raytrix, Teledyne Dalsa, Tong Hsing, Topcon, Toshiba, Trinamix, Trumpf, Truly, Valeo, Velodyne Lidar, Vertilite, Viavi, Vivo, Waymo, Willsemi, Xiaomi, Zimmer, Zeiss Meditech, ZF and more.

## REPORT OBJECTIVES

Ecosystem identification and analysis:
- Determination of the application range
- Technical market segmentation
- Market trends and forecasts
- Key players by market and analysis

Analysis and description of markets and technologies involved:
- Detailed applications per market segment
- Major global players
- Technology trends
- Main technical challenges

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## RELATED REPORTS, MONITORS & TRACKS

- CMOS Image Sensor Quarterly Market Monitor
- Machine Vision for Industry and Automation 2021
- Status of CMOS Image Sensor Industry 2020
- LiDAR for Automotive and Industrial Applications 2020
- Smartphone 3D Sensing Modules Comparison 2020

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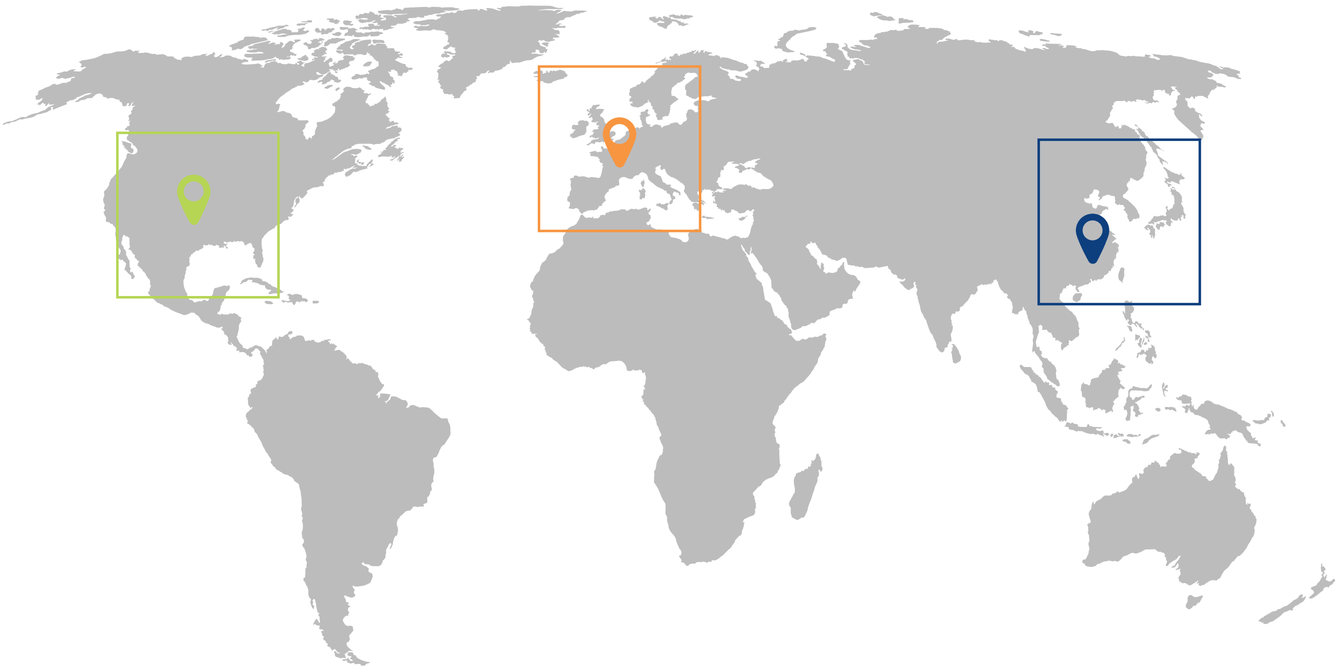
# CONTACT



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# ABOUT YOLE DEVELOPPEMENT

Founded in 1998, Yole Développement (Yole) has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services, reverse engineering and reverse costing services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole group of companies has expanded to include more than 120 collaborators worldwide covering MEMS and Image Sensors, Compound Semiconductors, RF Electronics, Solid-state Lighting, Displays, Software, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Power Electronics, Batteries & Energy Management and Memory.
The "More than Moore" market research, technology and strategy consulting company Yole Développement, along with its partners System Plus Consulting, PISEO and Blumorpho, supports industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

## CONSULTING AND ANALYSIS

- Market data & research, marketing analysis
- Technology analysis
- Strategy consulting
- Reverse engineering & costing
- Design and characterization of innovative optical systems
- Financial services (due diligence, M&A)

*More information on www.yole.fr*

## MEDIA & EVENTS

- i-Micronews.com website, application & related e-newsletter
- Communication & webcast services
- Events: TechDays, forums

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## REPORTS & MONITORS

- Market & technology reports
- Market and reverse technology quarterly monitors
- Structure, process and cost analysis and teardowns
- Cost simulation tool

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- Marketing & Communication: Jean-Christophe Eloy (eloy@yole.fr)

# General Terms and Conditions of Sale

Definitions: **"Acceptance":** Action by which the Buyer accepts these General Terms and Conditions of Sale in their entirety. It is done by signing the purchase order which states "I hereby accept Yole Développement's General Terms and Conditions of Sale".

**"Buyer":** Any business user (i.e. any person acting in the course of its business activities for its business needs) placing an order pursuant to these General Terms and Conditions of Sale, with the exclusion of any individual consumer acting for his/her sole personal interest.

**"Seller":** Headquartered in Villeurbanne (France), Yole Développement provides marketing, technology and strategy consulting, media and corporate finance services, reverse engineering/costing services as well as IP and patent analysis. With dedicated teams of technology & market analysts, Yole Développement operates worldwide with the key industrial companies, R&D institutes and investors to help them understand the market and technology trends.

"Contracting Parties" or **"Parties":** The Seller on the one hand and the Buyer on the other hand.

**"Intellectual Property Rights"** ("IPR") means any rights held by the Seller in its Products, including any patents, trademarks, registered models, designs, copyrights, inventions, commercial secrets and know-how, technical information, company or trading names and any other intellectual property rights or similar in any part of the world, notwithstanding the fact that they have been registered or not and including any pending registration of one of the above mentioned rights.

**"Products"**
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Reports are established in PowerPoint and delivered in a PDF format with an additional Excel file. 30 min of Q&A session with an analyst/author can be included for all purchased reports (except the ones bought as a one user license). More time can be allocated on a fee basis.

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Monitors are established and delivered in Excel. An additional PDF can also be added. Q&A with an Analyst is possible for each monitor (except where specified otherwise). Frequency of the release vary according to the monitor or service (quarterly and monthly). All monitor products are eligible for a Corporate License.

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- Multi-User License: The report can be shared by an identified user at the Company purchasing the report with an unlimited number of employees of said Company, working in the country where the identified user is based. No rights are granted to any employees of any Subsidiaries or Joint Ventures of the Company.
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1.1 Both Contracting Parties undertake to comply with these General Terms and Conditions of Sale.
ANY ADDITIONAL, DIFFERENT, OR CONFLICTING TERMS AND CONDITIONS IN ANY OTHER DOCUMENTS ISSUED BY THE BUYER AT ANY TIME ARE HEREBY OBJECTED TO BY THE SELLER, ARE DEEMED WHOLLY INAPPLICABLE TO ANY SALE MADE HEREUNDER, AND SHALL NOT BE BINDING IN ANY WAY ON THE SELLER.

1.2 These General Terms and Conditions of Sale shall be deemed valid and enforceable between the Contracting Parties after acceptance of an order from the Buyer by the Seller pursuant to Article 1.3 below. For such purpose, the Buyer, when signing the purchase order which mentions "I hereby accept Yole Développement's Terms and Conditions of Sale" is deemed to have fully and unequivocally accepted these Terms and Conditions of Sale.

1.3 Orders are deemed to be accepted only upon written acceptance and confirmation by the Seller, within [7 days] from the date of order, to be sent either by email. In the absence of any confirmation in writing, no order shall be deemed to have been accepted.

### 2. MAILING OF THE PRODUCTS

2.1 Products are sent by email to the Buyer after Seller's confirmation:
- Within a few days from the Seller's confirmation of the order for Products already released and paid; or
- Within a reasonable time for Products ordered prior to their effective release. In this case, the Seller shall use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in progress.

2.2 The Seller shall by no means be responsible for any delay pursuant to Article 2.1 above, in particular in cases where a new event or access to new contradictory information would require the Seller analyst to dedicate extra time to compute or compare the data in order to enable the Seller to deliver a high quality Product.

2.3 The mailing of the Product will occur only upon payment by the Buyer, in accordance with the conditions contained in Article 3 above.

2.4. The mailing is operated through electronic means either by email via the sales department or automatically online via an email/password. The Buyer is responsible for ensuring that the Buyers platform has the required capacities and authorisations to receive the Product(s) emailed by the Seller. If the Product's electronic delivery format is defective, the Seller undertakes to replace it at no charge to the Buyer provided that the Seller is informed of the defective formatting within 90 days from the date of the original download or receipt of the Product.

2.5 The person receiving the Products on behalf of the Buyer shall immediately verify the quality of the Products and their conformity with the order. Any claim for apparent defects or for non-conformity shall be sent in writing to the Seller within 8 days of receipt of the Products. For this purpose, the Buyer agrees to produce sufficient evidence of such defects.

2.6 No return of Products shall be accepted without prior written notification from the Buyer to the Seller, even in case of delayed delivery. Any Product returned to the Seller without the Buyer providing prior notification to the Seller as required under Article 2.5 above shall remain at the Buyer's risk. In no event shall the Seller incur any liability for Products erroneously ordered by the Buyer, or for any request from the Buyer to replace a Product previously ordered by a different Product.

### 3. PRICE, INVOICING AND PAYMENT

3.1 Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to annual subscriptions. They are deemed to be inclusive of all taxes applicable in the country where the Seller is based (except for France where VAT will be added). The prices are re-evaluated from time to time by the Seller. The effective price is deemed to be the one applicable at the time of the order.

3.2 Payments due by the Buyer shall be sent by cheque payable to Yole Développement, or made by credit card or by electronic transfer to the following account:
HSBC, 1 place de la Bourse 69002 Lyon France
Bank code: 30056
Branch code: 00170
Account n°: 0170 200 1565 87
BIC or SWIFT code: CCFRFRPP
IBAN: FR76 3005 6001 7001 7020 0156 587
To secure the payments due to the Seller, the Seller reserves the right to request down payments from the Buyer. In such case, the need for a down payment will be mentioned on the corresponding order.

3.3 Payment is due by the Buyer to the Seller within 30 days from invoice date, except as otherwise specifically agreed in writing by the Buyer and the Seller. If the Buyer fails to pay at the due date and fails to request and obtain from the Seller a payment extension, the latter shall be entitled to invoice interest in arrears based on the annual rate Refi of the "BCE" + 7 points, in accordance with article L.441-6 of the French Commercial Code.

3.4 The Seller publications (reports, monitors, tracks...) are due for delivery only after receipt by the Seller of any payment due by the Buyer prior to delivery.

3.5 In the event of termination of the contract by the Seller attributable to Buyer misconduct during the contract, the Seller will have the right to invoice all work performed at the time of termination, and to take legal action for damages.

### 4. LIABILITIES

4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the Products for its business activities, shall be solely responsible for the choice of the Products purchased as well as for the use and interpretations the Buyer makes of the documents it purchases, of the results the Buyer obtains, and of the advice and acts the Buyer bases thereon .

4.2 In no event shall the Seller be liable for:
a) Damages of any kind, including without limitation, incidental or consequential damages (including, but not limited to, damages for loss of profits, business interruption and loss of programs or information) arising out of the use of a Product or the use of or the inability by the Buyer to use the Seller's website, or any information provided on the website, or contained in a Product;
b) Any claim attributable to errors, omissions or other inaccuracies in a Product or interpretations thereof.

4.3 All the information contained in the Products has been obtained from sources believed to be reliable. The Seller does not warrant the accuracy, completeness adequacy or reliability of such information, which cannot be guaranteed to be free from errors.

4.4 Any Product that the Seller sells may, upon prior notice to the Buyer from time to time be modified by Seller or substituted with a similar Product meeting the needs of the Buyer. Such modification shall not lead to any liability of the Seller, provided that the Seller ensures the substituted Product is similar to the Product initially ordered.

4.5 In the case where, after inspection, it is acknowledged that a Product contain defects, the Seller undertakes to replace the defective product to the extent reasonably feasible and without indemnification or compensation of any kind for labour costs, delays, loss caused or any other reason being due by the Buyer . This undertaking from the Seller shall be effective for a maximum of two months starting from the delivery date but shall not be applicable in the event of force majeure as defined in Article 5 below.

4.6 The deadlines that the Seller is asked to provide for the mailing of a Product are given for information purposes only and are not guaranteed. If such deadlines are not met, this shall not, without the agreement of the Seller lead to any claim for damages or right of cancellation of one or more orders by the Buyer, except for non-acceptable delays exceeding [3] months from the stated deadline. In such case only i.e. only in the event of a delay exceeding (3) months from the stated deadline the Buyer shall be entitled to ask for a reimbursement of any down payment previously made to the Seller, to the exclusion of any other damages.

4.7 The Seller does not make any warranties, express or implied, including, without limitation, those of sale ability and fitness for a particular purpose, with respect to any Products. Although the Seller shall take reasonable steps to screen Products for infection of viruses, worms, Trojan horses or other codes containing contaminating or destructive properties before making Products available, the Seller cannot guarantee that any Product will be free from infection.

### 5. FORCE MAJEURE

The Seller shall not be liable for any delay in performance directly or indirectly caused by or resulting from acts of nature, fire, flood, accident, riot, war, government intervention, embargoes, strikes, labour difficulties, epidemics, major health event (e.g. Corona virus), equipment failure, late deliveries by suppliers or other difficulties which are beyond the control, and not attributable to the fault of the Seller.

### 6. PROTECTION OF THE SELLER'S IPR

6.1 All the IPR attached to the Products are and remain the property of the Seller and are protected under French and international copyright law and conventions.

6.2 The Buyer agreed not to disclose, copy, reproduce, redistribute, resell or publish a Product, or any part of it to any other party other than employees of the Buyer Company (and only in the country of the Primary User for Multi-User Licenses). The Buyer shall have the right to use Products solely for its own internal information purposes. In particular, the Buyer shall therefore not use any Product for purposes such as:
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- Recordings and re-transmittals over any network (including any local area network);
- Use in any timesharing, service bureau, bulletin board or similar arrangement or public display;
- Posting any Product to any other online service (including bulletin boards or the Internet);
- Licensing, leasing, selling, offering for sale or assigning a Product or any derivative thereof.

6.3 If the Buyer would like to use data coming from a Product for presentations, press announcements and any other projects, the Buyer needs to contact Yole Développement's Public Relations Director (info@yole.fr) to get an official authorization and confirm that the data are up to date. In return the Seller will make sure to provide up-to-date data under a suitable public format.

6.4 The Buyer shall be solely responsible towards the Seller for any infringement of the obligation described in Article 6.3 above, whether such infringement originates from the Buyer's employees or any person to whom the Buyer has sent the Products. Furthermore, the Buyer shall initiate and personally take care of any related proceedings in coordination with the Seller, and the Buyer shall bear the related financial consequences in their entirety.

6.5 The Buyer shall define within its Company an identified user who shall serve as a contact person for the License purchased by the Buyer. This person will be the recipient of each new report. This person shall also be responsible on behalf of the Buyer, for compliance with all copyrights and other obligations relating to the protection of the Seller's IP rights and general compliance with the terms of the License purchased by the Company. In the context of Bundle and Annual Subscriptions, the contact person shall decide within the Buyer which person(s) shall be entitled to receive the protected link that will allow the Buyer to access the Products.

6.6 It is acknowledged and accepted by the Buyer that whether purchased in the form of Bundles or Annual Subscription, all unselected reports will be deemed cancelled and lost after a period of 12 month following acceptance of the corresponding order by the Seller in accordance with provisions of Article 1.3 above .

6.7 It is further acknowledged and agreed by the Buyer that any investor in the Buyer Company, any external consultant of the Buyer Company or any joint venture done with a third party in which the Buyer Company is involved , is not entitled to use a Product, without paying to the Seller the full price for a license to the required Product..

### 7. TERMINATION

If the Buyer cancels the order in whole or in part or postpones the date of mailing, the Buyer shall indemnify the Seller for the entire costs that have been incurred as at the date of notification by the Buyer of such delay or cancellation. This may also apply for any other direct or indirect consequential loss that may be incurred by the Seller, pursuant to such cancellation or postponement.

### 8. MISCELLANEOUS

8.1 All the provisions of these General Terms and Conditions of Sale are for the benefit of the Seller, but also for that of its licensors, resellers and agents. Each of them is entitled to assert and enforce these provisions against the Buyer.
Any notices under these Terms and Conditions shall be given in writing and shall be effective upon receipt by the other Party.

8.2 The Seller may, from time to time, update these General Terms and Conditions of Sale, and the Buyer, shall be deemed to have accepted the latest version of such General Terms and Conditions of Sale, once they have been duly communicated to the Buyer by the Seller.

### 9. GOVERNING LAW AND JURISDICTION

9.1 Any dispute arising out or linked to these General Terms and Conditions of Sale or to any Licenses or Products purchased in application thereof shall be submitted to the French Commercial Court of Lyon, which shall have exclusive jurisdiction upon such issues.

9.2 French law (without reference to any applicable conflict of law provisions) shall apply to these General Terms and Conditions of sale and any agreement between the Buyer and the Seller made pursuant thereto.