

ULTRA-PREMIUM FLAGSHIP SMARTPHONES IMAGE PERFORMANCE: END-USER PERSPECTIVE 2021

Performance and Technologies Report - November 2021

End-user performance does not correlate with main sensor resolution in ultra-premium flagships; bigger is not necessarily always better.

KEY FEATURES

- Ultra-premium flagships 2020-2021 DXOMARK detailed analysis
- Apple iPhone 12 Pro Max, Huawei Mate 40 Pro Plus, Samsung Galaxy S21 Ultra 5G, Xiaomi Mi 11 Ultra - technical comparisons
- Ultra-premium flagships 2020-2021 photo performance measurements
- Ultra-premium flagships 2020-2021 video performance measurements
- Ultra-premium flagships 2020-2021 teardown insights
- Ultra-premium flagships 2020-2021 performance versus technology analysis
- 2020-2026 mobile market demand

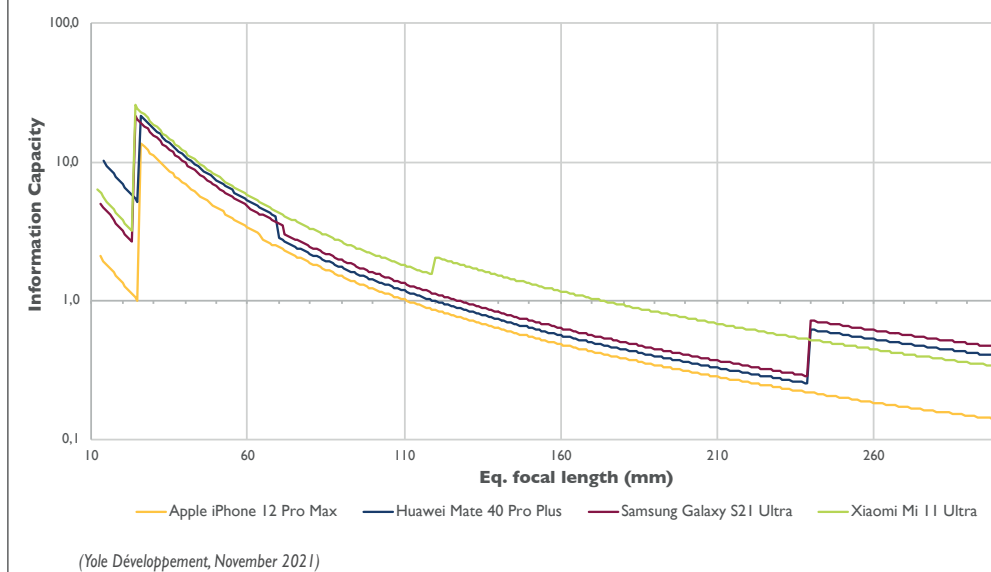
DXOMARK PARTNERS WITH YOLE DÉVELOPPEMENT AND SYSTEM PLUS CONSULTING TO DELIVER A NEVER SEEN BEFORE ANALYSIS

The smartphone industry has for long been the theater of an arms race between the major OEMs. Every year, imaging capabilities improve and are at the forefront of the OEM's branding, as imaging has become one of the biggest differentiating factors between OEMs. Every year, Yole Développement and System Plus Consulting provide the industry with detailed analyses of imaging in general, and smartphones in particular: technology and applicative trends, supply chain movements, market trends, reverse engineering and costing, and so on. Since 2008, DXOMARK provides imaging performance measurements from the end-user's point of

view, with a voice that resonates all over the industry.

To bring a comprehensive view regarding imaging, from material and equipment to end-user performance, Yole Développement, System Plus Consulting and DXOMARK have teamed up to produce this report combining their respective expertise. DXOMARK's unique testing capabilities and detailed scientific test reports, making the link with Yole Développement and System Plus Consulting analyses, will provide the reader with a comprehensive understanding of the elements that drive quality from market trends to components to the actual user experience.

Photo tele zoom - DXOMARK tele scores per range



This report has been performed in collaboration between Yole Développement, System Plus Consulting and DXOMARK. It includes DXOMARK's evaluation of image quality from the end user perspective, System Plus consulting teardown of camera module technical choices and Yole Développement analyses on technologies and supply chain.

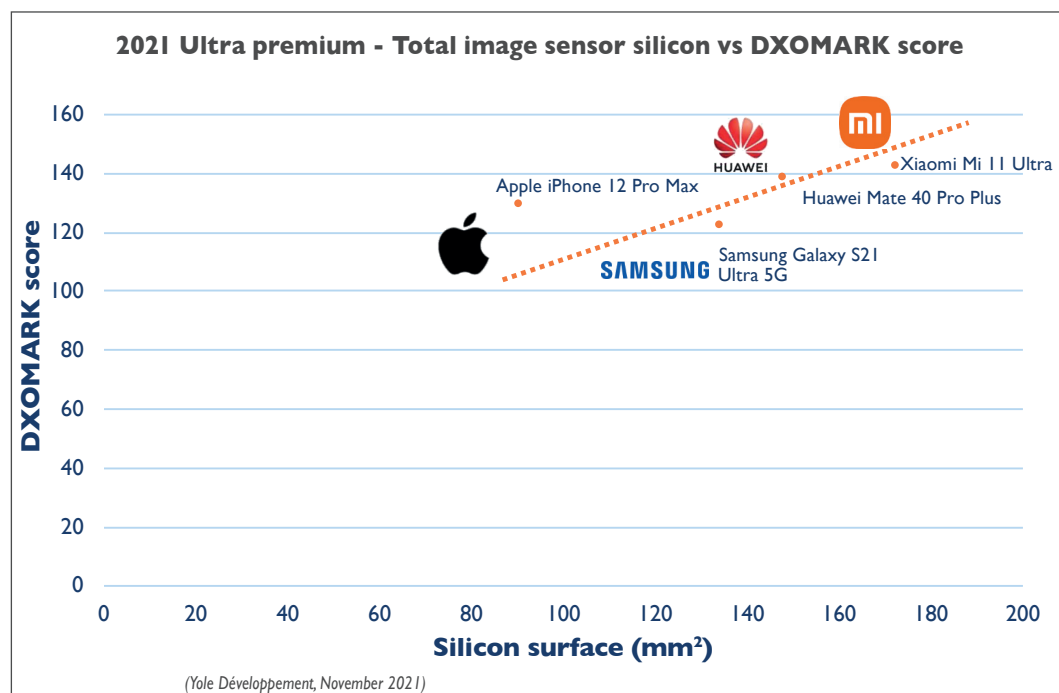
SUPPLY CHAIN AND TECHNOLOGIES IMPLY HUGE REPERCUSSIONS ON THE END-USER EXPERIENCES FOR PHOTOS AND VIDEOS

As for every new generation, the iPhones reshuffle the cards of the flagship battle. In this report, we decided to provide the industry with a thorough analysis of the four major flagships which have brought major improvements of experience in 2021: the Apple iPhone 12 Pro Max, the Samsung Galaxy S21 5G Ultra, the Huawei Mate 40 Pro, and the Xiaomi Mi 11 Ultra. You will also find market data on smartphones with a specific

perspective on flagships and the positioning of each OEM. This will help in understanding the overall DXOMARK score for each of these four flagships, which will then be detailed in terms of various features and attributes: exposure, color, autofocus and depth of field, texture and noise, bokeh, night, preview, and tele-zoom. Performance of each attribute is further explained and illustrated in details for both photo and video use cases, with an

underlying explanation and many illustrations. This will allow the reader to reach a proper understanding of the technical choices of OEMs





and the repercussions of these choices in semiconductor content, assembly challenges, and end-user performance.



A GOOD USER EXPERIENCE RELIES ON MORE THAN JUST HARDWARE CHOICES

The most significant results were not necessarily the most obvious. All OEMs aim to deliver the very best photo & video experience to the end user. Choices are endless between camera setups, functionalities, and specifications. But, in order to bring the best experience to consumers, all elements have to be put in balance and tuning will be key, enabling manufacturers to reach very different results. For instance, packing more pixels does not necessarily translate into better image quality. While Samsung includes a 108MP sensor on their latest flagship, Apple, with its iPhone 12 Pro Max, choosing a lower resolution, ends up in getting a higher DXOMARK score. Specifically on hardware, we see through the DXOMARK scores that Huawei and Xiaomi combine great hardware -

including larger camera modules - with excellent software integration, while Apple provides very high-quality images despite their smaller camera module, thanks to its combination of hardware and software. The key complementarity between hardware and software is highlighted in HDR measurements; this feature has been around for long, but still today, huge differences appear without exceptional hardware and software integration - even among flagships. In the future, with this new phase opening up with the iPhone 13 Pro Max, we expect OEMs to continue adopting these balanced hardware architectures while continuously improving their software solutions to further enhance end-user performance.

Image sensor silicon content (in mm ²)				
	 Apple iPhone 12 Pro Max	 Huawei Mate 40 Pro Plus	 Samsung Galaxy S21 Ultra 5G	 Xiaomi Mi 11 Ultra
Imagesensor silicon surface				
Primary	43	83	80	111
Ultra-wide	23	26	30	38
Tele1	17	17	19	38
Tele2	0	12	19	0
3D camera	18	24	0	0
Total silicon w/o 3D	82	138	149	187
Total silicon (mm²)	100	162	149	187

(Yole Développement, November 2021)

DXOMARK is a French technology company and the international leader in the quality assessment of smartphone cameras, display, audio and battery, and other consumer electronics (such as cameras and speakers). As a private and independent company, DXOMARK's mission is to help Original Equipment Manufacturers develop high-quality products for the benefit of the end user. To this effect DXOMARK provides quality evaluation services & detailed scientific test reports and commercializes its proprietary turnkey laboratories (Analyzer). To guide users in their choice, DXOMARK provides on its website - dxomark.cn & [.com](http://dxomark.com) - the largest database of quality evaluations of products in the form of an overall score. DXOMARK, based in Boulogne-Billancourt near Paris, employs 120 people, including a hundred engineers. These engineers have carried out thousands of tests each year for more than 10 years in the company's 16 state-of-the-art laboratories, which have been developed in-house.



REPORT OBJECTIVES

Understand 2021 flagships image performance:

- Leading smartphone camera
- From the End-user perspective
- What are the performance drivers : Hardware and Software?

Offer key technical insights and analyses into high-end smartphone photography application:

- Exposure / Color / AF DoF / Texture & Noise / Bokeh / Night / Preview/ Tele Zoom
- Key players performance comparison : Apple / Huawei / Samsung / Xiaomi
- Analysis of the performance compromise / strategy

Deliver an in-depth understanding of the technological levers:

- What are the hardware solutions to improve image performance?
- What are the software solutions to improve image performance?

COMPANIES CITED IN THE REPORT (non exhaustive list)

AAC Technologies, Ability Opto, AGC, AMS, Alps, Apple, Asia Optical, ASM, Brigates, BYD Microelectronics, Calin Technology, Cammsys, Cha Diostech, Chicony, Continental, Cowell Optics, Cresyn, Crystal-Optech, Ddk, DJI, Foxconn, Fujifilm, Fujinon, Fujitsu, Galaxycore, Genius Optical, Google, Gopro, Haesung Optics, Himax, Hirose, Hoya, Hozel, Huawei, IM, Intel, Jawah, Jabil, JSR, Kantatsu, Kinko Optical, Kolen, Kyocera, Largan, Lenovo, LG Innotek, Luxvision, Magna, Materion, Mcnex, Microsoft, Mitsumi, Mobileye, Nalux, New Shicoh, Nidec, NTK, Ofilm, Omnivision, On Semiconductor, OPPO, Optis, Panasonic, Parrot, Partron, Pixart, Pixelplus, Powerlogic, Primax, Q-Tech, Ricoh, Samsung, Schott, Semco, Sharp, Sekonix, SK Hynix, Softkinetic, Sony, STMicroelectronics, Sunny Optical, Sunex, Superpix, Suyin, TDK, Toshiba, Truly, Valeo, Viavi, Vivo, Volvo, Xiaomi, Xperi, Zeiss, Zeon, ZTE, and more.

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RELATED REPORTS, MONITORS & TRACKS



- Status of CMOS Image Sensor Industry 2021
- Status of the Camera Module Industry 2021
- Camera Module Comparison 2021 – Vol. 1
- Camera Module Comparison 2021 Vol. 2 – Apple iPhone Evolution
- Camera Module Comparison 2021 Vol. 3 – Samsung Galaxy S Evolution

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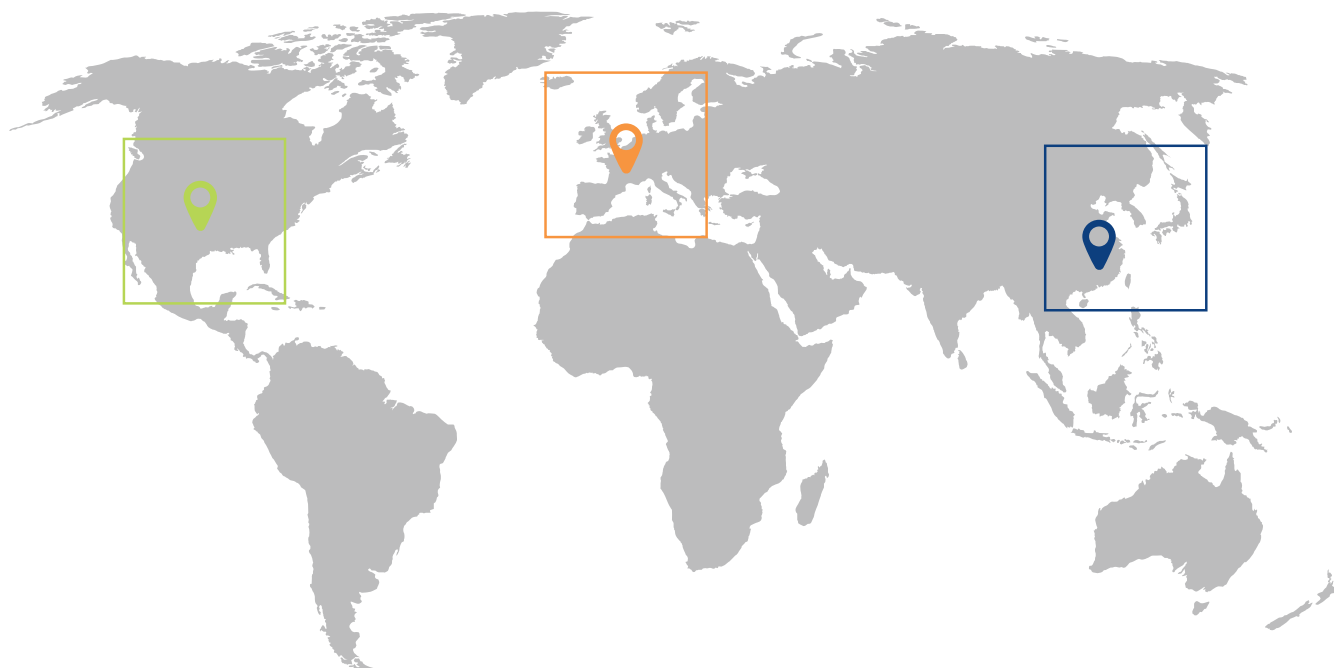
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Hervé Macudzinski started his career as a research engineer for DXOMARK in 2006 and has since then been instrumental in designing DXOMARK's camera tests for sensors, lenses & smartphones. He is an Image Science Engineer from Pierre & Marie Curie University in Paris whose expertise in image science extends to drones, video surveillance and action cameras as well. As a leader in image quality testing, he concerns himself with ensuring that DXOMARK's test protocols are always challenging the latest technologies in the market.



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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

More information on www.i-Micronews.com

REPORTS & MONITORS

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

More information on www.i-micronews.com/reports

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- Public Relations: Sandrine Leroy (sandrine.leroy@yole.fr)
- Marketing & Communication: Brice Le Gouic (brice.legouic@yole.fr)

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”

Our products can be bought either on a unit basis or as a bundled offer (i.e. subscription for a period of 12 calendar months).

“Report”

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.

“Monitor”

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.

“Tracks”

Yearly subscription to access a web-based interactive portal to view features and specs of a device or component based on a complete turnaround process.

“License”

For the reports 3 different licenses are proposed. Buyer has to choose one license type:

- One User License: The report is intended for only one identified user at the Company purchasing the report - Sharing is strictly forbidden
- 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.
- Corporate License: The report or monitor can be shared by an identified user of the Company purchasing the report with an unlimited number of employees of said Company on a global basis. Subsidiaries controlled by the Company are included, however Joint Ventures involving the Company are excluded.

DISCLAIMER: Notwithstanding the fact that certain persons within an organisation may be entitled to access a report pursuant to a Multi-User or a Corporate License, Yole Développement shall in no event incur any liability in any form whatsoever, if Yole Développement should sell one or more licenses directly to any such persons.

1. SCOPE

- 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 described 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:

- Information storage and retrieval systems;
- 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.