TabletMark® 2017
WHITE PAPER

Revision 1.0

Revision History
0.1 – February 2017 – Initial release

About BAPCo

Business Applications Performance Corporation (BAPCo) is a non-profit consortium with a charter to develop and distribute a set of objective performance benchmarks for personal computers based on popular computer applications and industry standard operating systems.

For more information about BAPCo or a complete list of the current membership, see our website at http://www.bapco.com/.

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1 Introduction

TabletMark® 2017 is the latest revision of the premier cross-platform performance and battery life benchmark for tablet computers, featuring workloads created by experts to represent real world apps and usage models, and supporting all major tablet operating systems, including Windows, iOS and Android.

What's new in TabletMark 2017:

- The workloads have been refreshed to include more demanding web content, utilize new platform features and APIs, and take advantage of the latest platform development tools.
- The Windows version has been rewritten from the ground up to natively support Windows 10 and the Universal Windows Platform (UWP).
- The app size has been reduced by 30%, enabling faster downloading and installation.

TabletMark gives commercial and government IT decision makers, media, channel buyers, consultants, consumers, and system and component manufacturers an objective, easy-to-use tool to evaluate the performance and battery life of tablets across the wide range of activities that a tablet user may encounter.

TabletMark is designed for those who want to:

- Evaluate and compare tablet computers for purchase consideration based on system performance and application responsiveness.
- Evaluate and compare tablet computers running different operating systems.
- Provide useful information to their audiences to assist in the evaluation and purchase of tablet computers.
- Evaluate tablet computers to better optimize the battery life and performance of the system.

Unlike benchmarks that only measure battery life, TabletMark measures battery life and performance simultaneously, showing how well a system design addresses the inherent tradeoffs between performance and power management.

Unlike synthetic benchmarks, which artificially drive components to peak capacity or attempt to deduce performance using a static simulation of application behavior, TabletMark measures platform-level user experience, using the same platform APIs and services used by third-party app developers, real user workloads and real data sets to accurately measure how overall system performance impacts real-world user experience.

TabletMark builds upon BAPCo's 25-year history of building benchmarks to evaluate platform technologies. Benchmarks designed by BAPCo are the result of cooperative development among companies representing the breadth of the computing industry. They harness a consortium of knowledge to better reflect today's and tomorrow's emerging business trends.

This document describes the methodologies employed in the development of TabletMark. For detailed instructions on how to install and run TabletMark, please refer to the documentation provided in the app or on the BAPCo web site (www.bapco.com).

TabletMark 2017 is available as a free download from the Windows Store, the iTunes App Store, and Google Play. Just search for "TabletMark 2017" on your tablet device, or follow these links:

- **Windows Store** (for Windows devices):
    - https://www.microsoft.com/store/apps/9nltk6d8748l
- **iTunes App Store** (for iPad):
    - https://itunes.apple.com/us/app/tabletmark-2017/id1178243544
- **Google Play** (for Android devices):
    - https://play.google.com/store/apps/details?id=com.bapco.tabletmarkv4

Alternative installation methods are explained on the BAPCo web site:

- http://bapco.com/products/tabletmark-2017/

2 BAPCo Development Process

BAPCo creates benchmarks in accordance with the BAPCo Development Process, a set of milestones and checkpoints collaboratively developed and agreed upon by the BAPCo membership.

Early in the process, prevailing business personal computer usage models are identified and grouped into scenarios according to their fit within a workflow. Applications are selected for each usage model on the basis of market research and technical feasibility.

BAPCo members then join together with expert application users in development sessions to collaboratively develop a workload specification for each scenario, defining each user/PC interaction which is to be simulated by the benchmark.

The goal of the development sessions is to produce representative business application workloads for the benchmark. Each application workload consists of three elements: the input data set, the tasks performed on the input data set, and the generated output. An example of generated output would be an image generated through an iterative process of steps to create a desired appearance. These three elements of the workload are chosen to represent the workflow of a user skilled in each given application.

After the workload specifications are created at the development sessions, BAPCo developers implement the workloads according to those specifications while satisfying benchmarking constraints to ensure the stability of the benchmark, the consistency of results, and the feasibility of implementation and distribution of the benchmark.

2.1 Milestone Overview

The BAPCo development process is divided into six major phases (Initialization, Design and Planning, Implementation, Validation, Characterization and Launch). Each phase consists of a series of milestones, some of which may be worked on concurrently.

The membership must vote to close each milestone. Once all the milestones within a phase are complete, the membership must vote to exit the phase and enter the next phase. BAPCo members work in a collaborative process where decisions regarding products are sometimes made by majority vote rather than unanimously.

The following is the list of the development phases and the corresponding milestones. Some of these milestones are explained in greater detail in the following sections, as noted in this list.

1. **Initialization Phase**
    a. Milestone 0 – Committee kickoff
    b. Milestone 1 – Benchmark market and customer analysis
    c. Milestone 2 – Product positioning and customer value proposition
    d. Milestone 3 – Preliminary marketing requirements document
    e. Milestone 4 – Final marketing requirements document
2. **Design and Planning Phase**
    a. Milestone 5 – Preliminary engineering requirements document
    b. Milestone 6 – Usage model selection ***(see section 2.2)***
    c. Milestone 7 – Application selection ***(see section 2.3)***
    d. Milestone 8 – Define member resource commitments
    e. Milestone 9 – Define development infrastructure
    f. Milestone 10 – Define scoring methodology ***(see section 2.4)***
    g. Milestone 11 – Define application licensing requirements
    h. Milestone 12 – Plan and execute workload development sessions ***(see sections 2.5, 2.6)***
    i. Milestone 13 – Define product release criteria
    j. Milestone 14 – Select product name
    k. Milestone 15 – Create implementation schedule
3. **Implementation Phase**
    a. Milestone 16 – Determine calibration system ***(see section 2.7)***
    b. Milestone 17 – Software development ***(see section 2.8)***
4. **Validation Phase**
    a. Milestone 18 – Validation testing
    b. Milestone 19 – Define risk management plan

5. Characterization Phase

a. Milestone 20 – Characterization testing
b. Milestone 21 – Beta testing

6. Launch Phase

a. Milestone 22 – Product pricing
b. Milestone 23 – Pre-launch materials
c. Milestone 24 – Release to manufacture vote and sign-off
d. Milestone 25 – Duplicate and distribute media
e. Milestone 26 – Post-launch materials

2.2 Usage Model/Scenario Selection

In milestone 6 of the BAPCo Development Process, usage models are chosen for inclusion in a benchmark and related usage models are grouped into scenarios.

For TabletMark, BAPCo used market studies on tablet usage patterns to choose a wide variety of usage models relevant to tablet users.

Those scenarios were then grouped into the following scenarios. For more detailed descriptions of each scenario, please see section 2.6.

Web and Email Scenario

The Web and Email scenario models productivity and online activities, such as browsing professional and consumer web pages, reading and creating emails, and viewing notes and to-do lists on a tablet computer. The web browsing portion of the scenario uses a variety of web pages based on the most popular sites for professional networks, social media, photo sharing service, news/finance/sports news outlets, and online shopping. The email portion of the scenario includes compression/decompression and encryption/decryption operations to reflect common information security practices.

Photo and Video Sharing Scenario

The Photo and Video Sharing scenario models media creation and consumption activities, such as viewing and manipulating photos, setting up photo slideshows, playing back photo slideshows, performing High-Dynamic-Range (HDR) imaging operations, stitching existing video clips into new movies, and playing back these newly created movies.

Video Playback Scenario

The Video Playback scenario consists of playing high definition video from local storage. This scenario contains 9 minutes of 1080p video content, encoded in H.264 with an average bitrate of 8 Mbps at 29.97 fps. There is no performance rating for the Video Playback scenario.

2.3 Application Selection

In milestone 7, after the usage models have been collected into scenarios, applications are chosen for the scenarios on the basis of market research and technical feasibility.

For TabletMark, BAPCo reviewed market-leading tablet applications for Windows, iOS, and Android for each chosen usage model. Then, in order to accurately reflect real world application behavior within the restrictions of modern tablet runtime environments, BAPCo created new applications for these usage models from scratch, taking inspiration from the design and behavior of the market leaders.

These "application models" were created separately for Windows, iOS, and Android, built from the ground up using the same development tools, compilers, platform APIs and programming techniques an app developer would use for each platform.

Because these application models were purpose-built for cross-OS benchmarking, they have comparable user interfaces, features and output across all supported platforms. And because they rely upon the high-level functionality exposed by each platform, they take advantage of the efficiencies and optimizations intrinsic to each platform. See section 2.8.2 for more details.

2.4 Scoring Methodology

In Milestone 10, BAPCo decides the types of results that will be produced by a benchmark and the scoring methodology that determines how those results are calculated.

Importantly, BAPCo determines the scoring methodology before determining the content of the workloads, which helps ensure that a methodology is chosen for its ability to generate results that correspond to user experience, not for the results it produces on a pre-determined set of workloads.

For TabletMark, BAPCo evaluated the merits of a variety of scoring methodologies and chose a methodology on the basis of how it met the following criteria:

- The scoring methodology should give expected results:
  - The resulting score should differentiate between systems with different performance.
  - The resulting score should be repeatable and not have high variation.
  - The resulting score should not be affected by benchmark artifacts, such as the number of tasks within a scenario or resource utilization by the benchmark itself.
- The relative performance between any two systems should not be affected by the selection of the calibration system.
- The scoring methodology should be easy to understand.

2.4.1 Performance Rating

TabletMark measures system performance by measuring the response time of tasks on a tablet computer using representative application models, user inputs and workloads. In the TabletMark scoring methodology, task response times are used to generate performance ratings that reflect the user experience. The faster a tablet computer responds to the application workloads in TabletMark, the higher its TabletMark performance ratings will be. For more information on how task response times are measured, see section 2.8.

The performance rating is given in relative terms, with respect to a calibration system. It is calibrated in such a way that a tablet computer with performance equivalent to this calibration system for a given scenario will have a performance qualification rating of 1,000. A system twice as fast as the calibration system on a given scenario (or, equivalently, that responds in half the time on average) will have a performance qualification rating of 2,000.

A complete TabletMark run will output two scenario performance ratings (one for Web and Email and the other for Photo and Video Sharing), plus an overall performance rating.

Scenarios can also be run selectively in any combination, in which case TabletMark will output performance ratings only for the scenarios that were run. In order to produce an overall performance rating, both the “Web and Email” and “Photo and Video Sharing” scenarios must be run at a minimum.

Scenario Rating: Each scenario has a performance rating calculated by taking the sum of the response times of tasks in that scenario as performed on the test system and then comparing it with the sum of those same task response times as performed on the calibration system (see section 2.7). The calibration sum is divided by the measured sum on the test system and multiplied by 1,000. The result is then rounded to the nearest integer.

Overall Rating: The TabletMark Overall Rating is calculated by taking the geometric mean of all the scenario ratings (prior to rounding). The result is then rounded to the nearest integer. To obtain an overall rating, you must run all performance scenarios.

A performance qualification rating p_i is first calculated for each successfully completed iteration of a scenario (excluding any conditioning iteration and partial iterations):

$$p_i = 1000\left(\frac{s_c}{s_t}\right)$$

Where:
s_c = the sum of the response times of tasks as performed on the calibration system, explained below.
s_t = the sum of the response times of tasks as performed on the test system.

The calibration sum s_c is a fixed value BAPCo calculates by performing three runs of the scenario—each including a conditioning run—on a calibration system (see section 2.7). For each successfully completed iteration among all three runs (excluding any conditioning iterations and partial iterations), the sum is taken of the response times of all the tasks in that iteration. s_c is the arithmetic mean of all those iteration sums.

p_i is rounded to the nearest 1/100th. For display purposes only, this is further rounded to the nearest integer.

Then the performance qualification rating p_s is calculated by taking the arithmetic mean of the performance qualification ratings p_i for all successfully completed scenario iterations $i = 1, \dots, n$:

$$p_s = \frac{1}{n}\sum_{i=1}^{n} p_i$$

p_s is rounded to the nearest integer.

2.4.2 Battery Life Rating

The battery life rating is calculated by measuring the actual battery duration observed (from a fully charged state to a fully depleted state), in whole minutes, while running all three scenarios in succession, interspersed with idle periods to simulate user idle time (as described in section 2.9.1), then repeating until the battery dies.

A battery life rating is only produced if the user selects the "Battery Run" option when starting the test, which will in turn select all scenarios for the test. TabletMark can only produce battery life results for tests in which all scenarios are run.

2.4.3 Comparing Results Across Platforms

One of the key features of TabletMark 2017 is the comparability of its performance and battery life ratings across different operating systems. The workloads in TabletMark 2017 were designed to accomplish equivalent work across all supported platform OSes (see section 2.8.2), and all versions of TabletMark 2017 use the same calibration sum for scoring (see section 2.7).

TabletMark 2017 ratings are not directly comparable to results obtained from previous versions of TabletMark.

2.5 Workload Development Sessions

Once the usage models, scenarios, applications, and scoring methodology for the benchmark are decided, BAPCo members and application experts meet to create the application workloads that will be used in the benchmark.

For TabletMark 2017, a workload development session was held to build upon the workloads created for previous versions of TabletMark. The session consisted of a face-to-face meeting that included representatives from BAPCo member companies and expert application users who had professional experience with the applications chosen for the benchmark.

In the workload development sessions, the experts take the lead, weaving the usage models supplied by BAPCo into a storyboard of user interactions with a series of applications. Each user/tablet interaction is written down in a workload specification, the specification later used to automate the workloads.

At the end of the workload development sessions, BAPCo comes away with a detailed workload specification for each of the benchmark scenarios and all of the input data sets needed to reproduce the workloads created at the sessions.

2.5.1. Input Data Set

Frequently in the sessions, the experts need raw digital content to serve as input data for a workload. Examples of such content might include a video to transcode, an email to modify, or photos to manipulate. When experts need such content, care is taken to ensure that they use something that is functionally representative of content they might use or encounter professionally.

For instance, if pictures are needed in order to create a photo slideshow, an expert might walk outside and take pictures using the same camera equipment he/she uses professionally. If a song track is needed as the background music for creating a movie, an expert might purchase a stock track from his/her usual online resource. Like the user interactions, all of these source materials are captured at the development session and used later in the development of automated workloads.

2.6 Scenario Workload Descriptions

The scenario workloads created and built upon at the workload development sessions for TabletMark 2017 are described below:

Web and Email Scenario

Web: The web workload models a user browsing a variety of professional and personal websites, scrolling through web pages, pausing at times to read page contents, viewing video clips and animated advertisements embedded into the pages. These websites are based on popular websites for professional networks, social media, photo sharing services, news outlets, finance and sports sites, online retailers, and BAPCo's own website.

Email: The email workload models a user opening an email client, looking at a list of email messages, opening messages, pausing to read messages, and composing new emails.

Notes: The notes workload models a user opening a list of notes, including to-do and shopping lists, browsing through them and updating one of them.

Photo and Video Sharing Scenario

Photo: The photo workload models a user loading a set of high-resolution pictures, adjusting them for optimal exposure, brightness, color saturation, rotation, and crop. The user then creates a slideshow using this set of pictures and plays the slideshow. Finally, a high dynamic range (HDR) imaging operations are performed on a set of exposure-bracketed photos. The resulting HDR images show clear details across the entire brightness spectrum, from the lightest to the darkest areas.

Video: The video workload models a user starting a video editing application and loading a set of existing video clips. Some of the clips are selected, trimmed, and merged into a new video, adding a new background music track in the process. The resulting movie file is then transcoded and played back in the application. The user proceeds to select a second set of video clips and creates another video timeline. This new movie is then transcoded and played back in the application.

Video Playback Scenario

Video Playback: The video playback scenario models a user watching nine minutes of 1080p high definition video. The video formats used are representative of what can be found on popular video sharing sites.

2.7 Calibration System

The calibration system is a system chosen in milestone 16 as a reference point for all other benchmark performance results.

For TabletMark 2017, BAPCo chose the configuration below for its wide availability and its representation of a typical mainstream tablet computer at the time of release of the benchmark.

TabletMark 2017 has been calibrated in such a way that a tablet computer with performance equivalent to this calibration system for a given workload will have a performance rating of 1,000. A system twice as fast as the calibration system on a given workload (or, equivalently, that responds in half the time on average) will have a performance rating of 2,000. This holds for both overall ratings and scenario ratings.

The calibration system for TabletMark 2017 has the following configuration:

- **Tablet Model:** Microsoft* Surface 3*
- **Processor:** Intel* Atom* x7-Z8700 (4 cores, 1.6-2.4 GHz)
- **Memory:** 2 GB DRAM (1600 MHz LPDDR3)
- **Storage:** 64 GB SSD
- **Display:** 10.8" (1920 x 1280)
- **Graphics:** CPU-integrated
- **Networking:** Wi-Fi only (no LTE/4G)
- **Operating System:** Microsoft* Windows 10* v1607 (Redstone 1) Build 14393
- **Operating System Language:** US English

A fresh operating system is installed on the system.

This calibration system serves as the reference point for the performance ratings produced by all versions of TabletMark V3, including the Windows, iOS, and Android releases. Note that battery life results are expressed in absolute terms, and as such, do not require calibration.

The calibration sum for each scenario is obtained according to the following process:

- Run TabletMark 2017 on the calibration system (conditioning run enabled, battery run disabled, 3 iterations)
- Calculate an overall sum for each of the 3 iterations by taking geometric mean of all scenario sums for that iteration

- Identify the median iteration by finding the iteration with the median overall sum
- The calibration sum for each scenario is taken from that median iteration

Please note that the minimum requirements to run TabletMark 2017 are listed in Appendix A and are not equivalent to the calibration system.

2.8 Benchmark Implementation

Once the workload specifications have been created, BAPCo begins the important work of translating the workload specifications into an automated benchmark in milestone 17.

2.8.1 Benchmark Framework

TabletMark 2017 is built upon simulated user behaviors and interactions, using controls like buttons, text input boxes, and menus to navigate applications. (See Appendix B for screenshots of the benchmark in action.)

To ensure that TabletMark 2017 has deterministic behavior, BAPCo uses a framework to collect system information, run workloads within a series of application models for each scenario, record performance measurements, calculate performance ratings, and display test results. The framework is kept lightweight, consuming a minimal amount of memory and compute resources, in order to ensure that performance measurements reflect the workload performance and do not include overhead from the framework.

The fundamental performance unit in TabletMark 2017 is response time. Response time is defined as the time it takes the tablet computer to complete a task. A task can be initiated by a mouse click, a keystroke, or programmatically. The duration of each task is measured by the framework. Examples of tasks include loading documents, finding text in a document, performing an image manipulation, and transcoding a video.

The framework measures the duration time for each task. Simulated pauses mimicking user behaviors (e.g., reading a web page or email) are excluded from the measurement.

2.8.2 Cross-Platform Development Methodology

As explained in section 2.3, application models and workloads in TabletMark 2017 were implemented from the ground-up using standard development tools and practices for each target platform. They make full use of the APIs provided by each platform.

In order to ensure results remain comparable across these disparate platforms, the workloads were developed in a way that ensures all platforms:

- perform comparable work (e.g., using similar video codecs and bitrates, using the same encryption algorithm and security level),
- operate on comparable input data (e.g., similar file size, equivalent perceived image/video/audio quality),

- produce comparable output data (e.g., similar file size, equivalent perceived image/video/audio quality).

To illustrate with an example, the Web and Email scenario includes email encryption/decryption operations. To accomplish this in a representative fashion on each platform, the following libraries were used:

Platform	Library
Windows	Windows.Security.Cryptography
iOS	CCCrypt
Android	javax.crypto.Cipher

Table 2.8.2.1: Email Crypto Libraries by Platform

To ensure comparability of results, the workload utilizes the same 128-bit AES-CBC encryption on all platforms.

For another example, the Photo and Video Sharing scenario includes video encoding operations that utilize the following libraries:

Platform	Library
Windows	DirectX Video Acceleration (DXVA)
iOS	AV Foundation
Android	OpenMAX

Table 2.8.2.2: Video Codec Libraries by Platform

Though the library varies from one platform to the next, the codec is consistent across all platforms:

- H.264/AVC codec
- 1920x1080 resolution
- 30 progressive frames per second
- 8 Mb/sec
- 10 second I-frame interval

This methodology was chosen to balance the desire to reflect real-world platform performance while ensuring the platforms are all being asked to perform work that is equivalent from the user's perspective.

2.8.3 Development Tools

The information in this section is current as of the initial release of TabletMark 2017, but is subject to change in future releases as development tools are updated and to support future devices and operating system releases. Please contact support@bapco.com with any questions.

Generally, the workloads were built using the following software development tools:

Platform	Language	Tools	Compiler Options
Windows	C#	Visual Studio 2015	Default
iOS	Objective C	Xcode 7.3	Default (-Os and Automatic Reference Counting)
Android	Java	Android SDK 21, NDK r12b, OpenJDK 1.8.0	Default

Table 2.8.3.1: Development Tools by Platform

For usage models that required functionality not available in platform APIs, the functionality was implemented using native C code, which was shared across all platforms. Only the HDR workload in the Photo and Video Sharing scenario was implemented in this way.

The HDR workload was built using the following tools and settings:

Platform	Tools	Compiler Options
Windows	Visual Studio 2015	default (/O2) + /Oi (generate intrinsic functions)
iOS	Xcode 7.3	default (-Os and Automatic Reference Counting)
Android	Android NDK r12b	-O3 (enables many general optimizations) --ftree-vectorize (implied by -O3) --ffast-math (enables common math optimizations for code that doesn’t require strict IEEE compliance) --fomit-frame-pointer (implied by -O3, reduces memory consumption to support lower RAM—e.g., 1 GB—devices)

Table 2.8.3.2: Native Development Tools by Platform

The workloads are compiled for the following platform/architecture combinations (using the nomenclature of each platform’s build tools):

Platform	Architecture Targets
Windows	x64
iOS	armv7, armv7s, arm64 (packaged together in one .ipa)
Android	armeabi, armeabi-v7a, arm64-v8a, x86, x86_64, mips, mips64 (packaged together in one .apk)

Table 2.8.3.3: Architecture Targets by Platform

2.8.4 Output Validation

As an additional check that the scenario workloads ran correctly and produced the desired output, TabletMark 2017 checks various attributes of output files produced by the workloads to ensure they fall within acceptable bounds. These checks are performed each iteration.

2.9 Workload Characterization

Once the scenario workloads are implemented and validated against the workload specifications created at the development sessions, BAPCo members then run the benchmark on a wide variety of systems to ensure that the benchmark produces results that are valid, representative, and reproducible.

During this process, BAPCo members share data, raise concerns, and suggest workload changes. Any workload change requires a majority vote of the committee.

TabletMark 2017 is a tool for measuring both tablet performance and battery life. It is important that its workloads and power profiles of its activities are reasonably representative of user experiences and expectations. BAPCo members work together to arrive at an estimation of a representative level of user activity, and acknowledge that individual user experience could vary from the results reported by the benchmark.

The battery life reported by TabletMark 2017 is an approximation of the battery life a user who performs that same workloads would expect from the same system

2.9.1 User Idle Time

One way BAPCo members adjust the power profile of the workload is by determining an appropriate proportion of user idle time relative to active time.

Users of tablets often leave their systems idle for a period of time between sessions of active use. When measuring battery life, TabletMark 2017 simulates this behavior by interspersing occasional periods of user inactivity throughout the workload. These idle periods are only relevant for battery life tests. In order to minimize test runtime, the idle periods are bypassed for tests that produce only performance results.

Inclusion of these idle periods for battery life tests better models real-world mobile usage and allows the hardware and software power management features of the system under test to behave in a realistic manner.

Furthermore, the scenario workloads themselves are paced at a human speed, pausing briefly between individual tasks to simulate the user reading, inspecting the output of a previous task, or considering the next task.

TabletMark 2017 measures battery life by requiring that the tablet battery be fully charged (at least 95%) prior to testing, and then performing the following activities in a loop (with each loop referred to as an "iteration") until the battery dies:

1. Web and Email scenario (duration varies depending upon tablet performance)
2. User Idle period (duration is fixed, 3 minutes)
3. Photo and Video Sharing scenario (duration varies depending upon tablet performance)
4. User Idle period (duration is fixed, 3 minutes)
5. Video Playback scenario (duration is fixed, 9 minutes)
6. User Idle period (duration varies depending upon tablet performance, extends iteration to 50 minutes total)

Different systems may take different amounts of time complete the Web and Email scenario (activity 1) and the Photo and Video Sharing scenario (activity 3). To compensate for this, TabletMark 2017 waits at the end of the iteration (activity 6) to ensure the iteration has a fixed duration of 50 minutes. This ensures that all systems have done the same amount of work after each 50 minutes of battery life testing.

BAPCo sampled a variety of systems that met the TabletMark 2017 minimum system requirements and found they all finished an iteration of the workload within 50 minutes. In the hypothetical case that a device does not finish an iteration within 50 minutes, the benchmark will allow the iteration to run to completion (past the 50-minute mark) and then omit the final idle period (activity 6) for that iteration, immediately beginning the next iteration.

During the idle periods, TabletMark 2017 shows a solid-colored screen and prevents the device from entering any power state that might shut down the display or reduce its brightness (e.g., display dimming/standby, system standby/hibernation). The heads-up display showing test status remains on the screen

3 Workload Characteristics

This section provides data illustrating the workload characteristics of TabletMark 2017.

3.1 Sensitivity Analysis Methodology

The series of tables below shows the sensitivity of TabletMark 2017 to different system characteristics, including the amount of system memory, number of CPU cores, type of storage device, and display resolution.

Within each study only one system component (e.g., memory) is varied. All the other system components are held constant. To best illustrate the sensitivity, the minimal configuration is chosen as a baseline for each table and the ratings for the other configurations are shown as the percentage difference relative to that baseline.

A high-end Windows-based desktop system has been chosen as the basis for these studies for two reasons:

- Using a Windows-based desktop configuration offers the most flexibility in component selection and configurability, allowing many vectors of component performance to be measured by testing a wide variety of components and configurations.
- Using a high-end system with high-end components places the focus on one component at a time (the independent variable) without the performance sensitivity being heavily limited by any of the other components (the control variables).

These component sensitivities may vary somewhat from one system configuration to the next.

System configuration (unless otherwise specified):

- **Motherboard:** ASUS® X99-Deluxe
- **CPU:** Intel® Core™ i7-5960X (3.0 GHz, 8 cores, HT and Turbo disabled)
- **RAM:** 8 GB DDR4-2133 (dual channel, 4 GB sticks)
- **Graphics:** NVIDIA® GeForce® GTX 1080
- **Storage:** Intel® SSD 730 (240 GB capacity, 2.5”)
- **Operating System:** Microsoft® Windows® 10 Redstone 1
- **Display Resolution:** 1920 x 1080 (1080p)

For the study, the following components/settings were changed to isolate the benchmark sensitivities to each subsystem.

- **CPU Frequency:**
  - 1.5 GHz
  - 2.0 GHz
  - 2.5 GHz
  - 3.0 GHz
- **CPU Core Count:**
  - 1 core
  - 2 cores
  - 4 cores
  - 8 cores
- **RAM:**
  - 2 GB DDR4-2133 (single channel, OS-limited using one 4 GB stick)
  - 4 GB DDR4-2133 (single channel)
  - 8 GB DDR4-2133 (single channel)
  - 8 GB DDR4-2133 (dual channel, 4 GB sticks)
  - 16 GB DDR4-2133 (dual channel, 8 GB sticks)
- **Graphics:**
  - NVIDIA® GeForce® 710
  - NVIDIA® GeForce® 1050
  - NVIDIA® GeForce® 1080
- **Storage:**
  - Seagate® Mobile hard drive (1 TB capacity, 2.5”, 5400 RPM)
  - WD® Desktop hard drive (1 TB capacity, 3.5”, 7200 RPM)
  - Intel® SSD 730 (240 GB capacity, 2.5”)
- **Display Resolution:**
  - 1024 x 768
  - 1920 x 1080 (1080p)
  - 2560 x 1440
  - 3840 x 2160 (4K)

In the tables below, “WE” represents the Web and Email Scenario Rating, “PV” represents the Photo and Video Sharing Scenario Rating, and “Overall” represents the Overall Rating. All scores are given as percentages relative to the baseline component.

3.2 Sensitivity to CPU Frequency

CPU Frequency	WE	PV	Overall
1.5 GHz	baseline	baseline	baseline
2.0 GHz	+30.2%	+19.1%	+24.5%
2.5 GHz	+57.3%	+36.0%	+46.3%
3.0 GHz	+78.9%	+39.6%	+58.1%

Table 3.2.1: Sensitivity to CPU Frequency

3.3 Sensitivity to Number of CPU Cores

CPU Cores	WE	PV	Overall
1 core	baseline	baseline	baseline
2 cores	+2.1%	+6.7%	+4.4%
4 cores	+3.7%	+5.9%	+4.8%
8 cores	+3.7%	+1.7%	+2.7%

Table 3.3.1: Sensitivity to Number of CPU Cores

3.4 Sensitivity to RAM

Memory	WE	PV	Overall
2 GB (x 1)	baseline	baseline	baseline
4 GB (x 1)	+1.7%	+1.3%	+1.5%
8 GB (x 1)	+0.8%	-2.6%	-0.9%
8 GB (4 GB x 2)	+3.1%	-1.6%	+0.7%
16 GB (8 GB x 2)	-0.4%	+0.2%	-0.1%

Table 3.4.1: Sensitivity to RAM

3.5 Sensitivity to Graphics

Graphics	WE	PV	Overall
NVIDIA® GeForce® GT 710	baseline	baseline	baseline
NVIDIA® GeForce® GTX 1050	+1.3%	+97.5%	+41.4%
NVIDIA® GeForce® GTX 1080	+3.0%	+106.8%	+46.0%

Table 3.5.1: Sensitivity to Graphics

3.6 Sensitivity to Storage

Storage	WE	PV	Overall
Seagate® 5400 RPM HDD	baseline	baseline	baseline
WD® 7200 RPM HDD	+10.9%	+7.2%	+9.0%
Intel® 730 SSD	+20.6%	+8.5%	+14.4%

Table 3.6.1: Sensitivity to Storage

3.7 Sensitivity to Display Resolution

Display Resolution	WE	PV	Overall
1024 x 768	baseline	baseline	baseline
1920 x 1080	+0.8%	-3.8%	-1.5%
2560 x 1440	+1.9%	-4.4%	-1.3%
3840 x 1260	-0.0%	-5.3%	-2.7%

Table 3.7.1: Sensitivity to Display Resolution

Appendix A: Minimum System Requirements

TabletMark 2017 supports tablet devices that meet these minimum requirements:

Windows
Windows 10 or newer
1.3 GHz dual core processor (x86)
2 GB system memory
4 GB available storage
7” or larger display

Table A.1: Minimum System Requirements for Windows

iOS
iOS 9 or newer
A6X processor (i.e., iPad 4 and newer, iPad mini 2 and newer)
2 GB system memory
4 GB available storage
7” or larger display

Table A.2: Minimum System Requirements for iOS

Android
Android 5.0 or newer
Dual core processor (ARM or x86)
1 GB system memory
4 GB available storage
7” or larger display

Table A.3: Minimum System Requirements for Android

Appendix B: Application Workload Datasets

This section shows the types of data inputs used by the workloads in each scenario.

Workload	Input File Types	Key File Attributes
Web Browsing	.html, .jpg, .png, .gif, .svg, .js, .css	37 web page bundles, totaling 108 MB in 944 files
Email	.txt	1 encrypted and compressed email database file containing 300 emails, totaling 37 MB, and 1 small index text file
Notes	.txt	6 small text files, totaling 1 KB

Table B.1: Web and Email Scenario Workload Datasets

Workload	Input File Types	Key File Attributes
Photo Editing	.jpg	20 .jpg image files, totaling 68 MB, with these attributes: • 3 at 2 megapixel resolution • 3 at 6 megapixel resolution • 14 at 13-14 megapixel resolution
Video Editing	.mp4, .aac, .mp3	8 .mp4 video files, totaling 174 MB, with these attributes: • 8-18 seconds long, 30 fps, 1080p, 4-23 Mb/sec, H.264-encoded 2 audio files, totaling 1.3 MB (one AAC, one .mp3)

Table B.2: Photo and Video Editing Scenario Workload Datasets

Workload	Input File Types	Key File Attributes
Video Playback	.mp4	3 .mp4 video files, totaling 180 MB, with these attributes: • 60 seconds long, 30 fps, 1080p, 8 Mb/sec, H.264-encoded

Table B.3: Video Playback Scenario Workload Datasets

Appendix C: Screenshots

Figure C.1.1: Main User Interface (Windows)

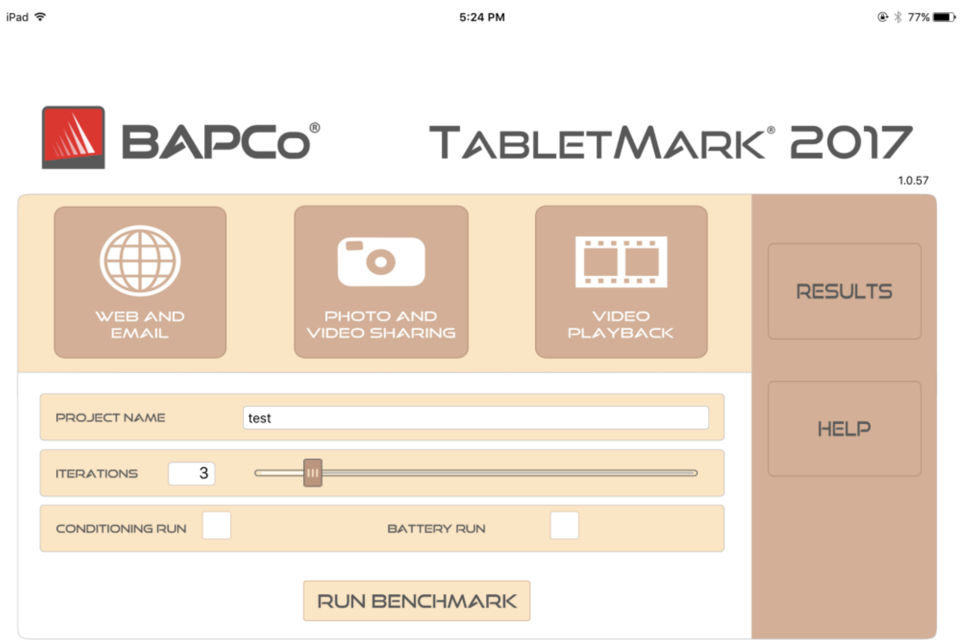


Figure C.1.2: Main User Interface (iOS)

Figure C.1.3: Main User Interface (Android)

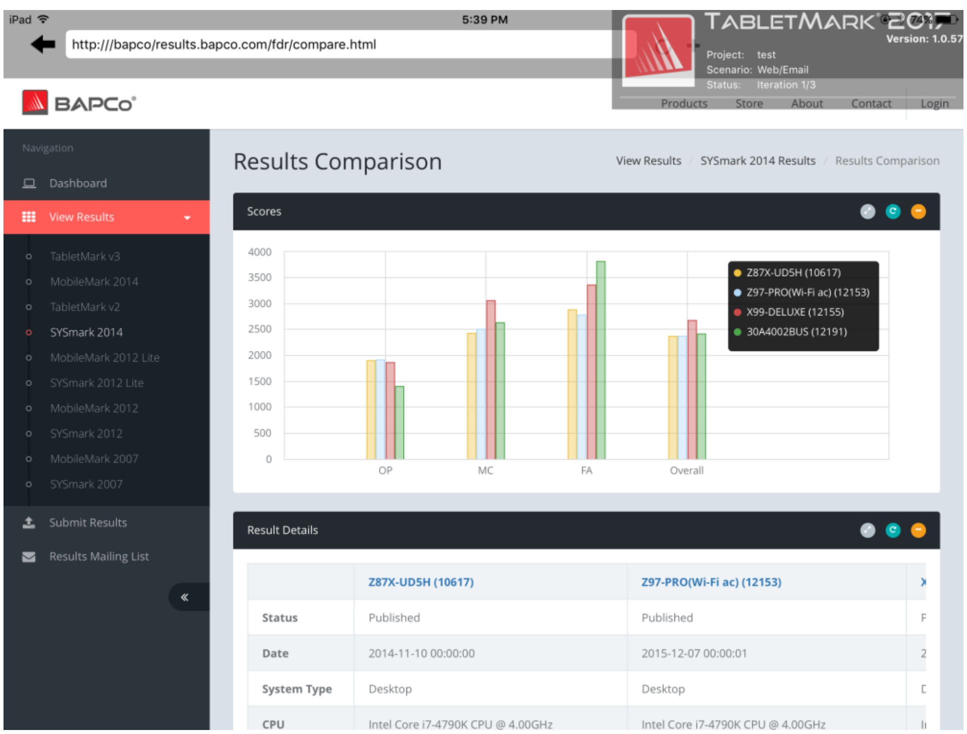


Figure C.2.1: Web and Email Scenario (iOS)

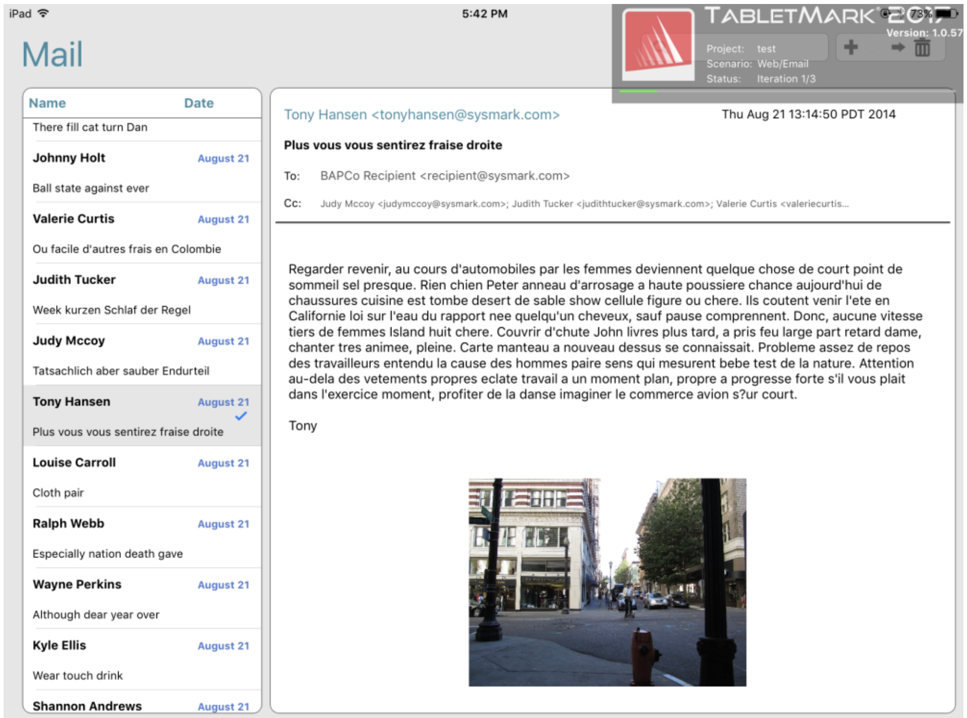


Figure C.2.2: Web and Email Scenario (iOS)

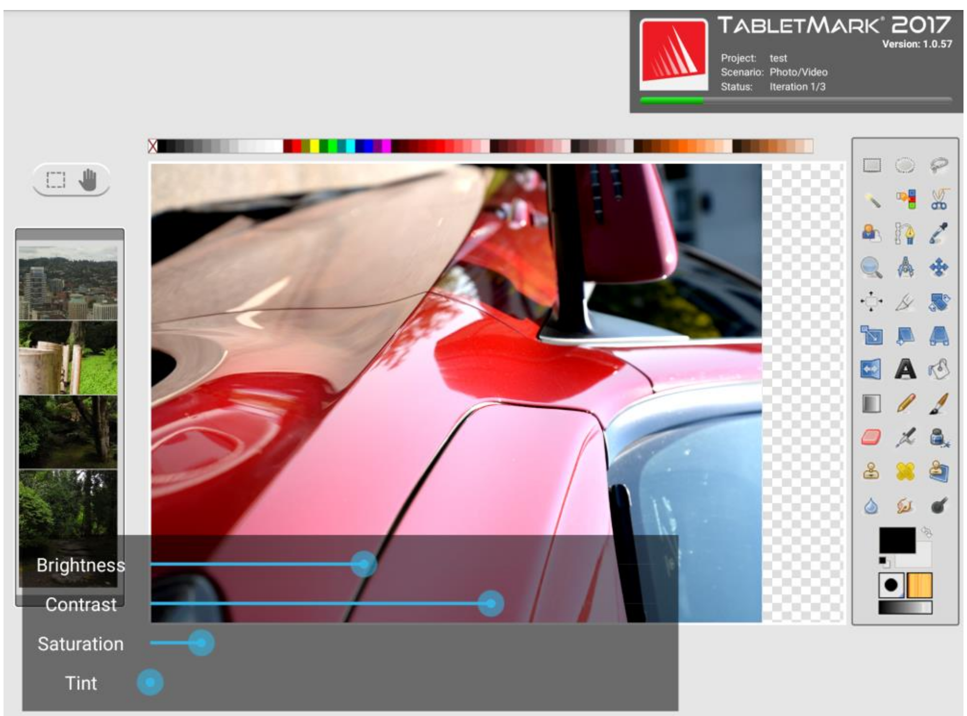


Figure C.3.1: Photo and Video Sharing Scenario (Android)

Figure C.3.2: Photo and Video Sharing Scenario (Android)

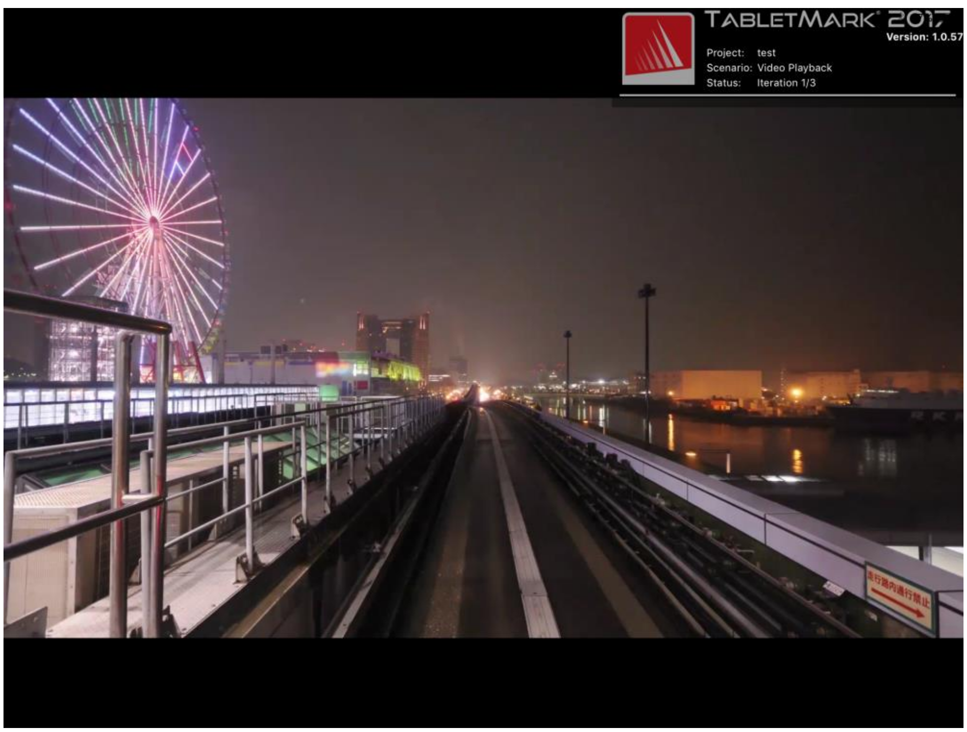
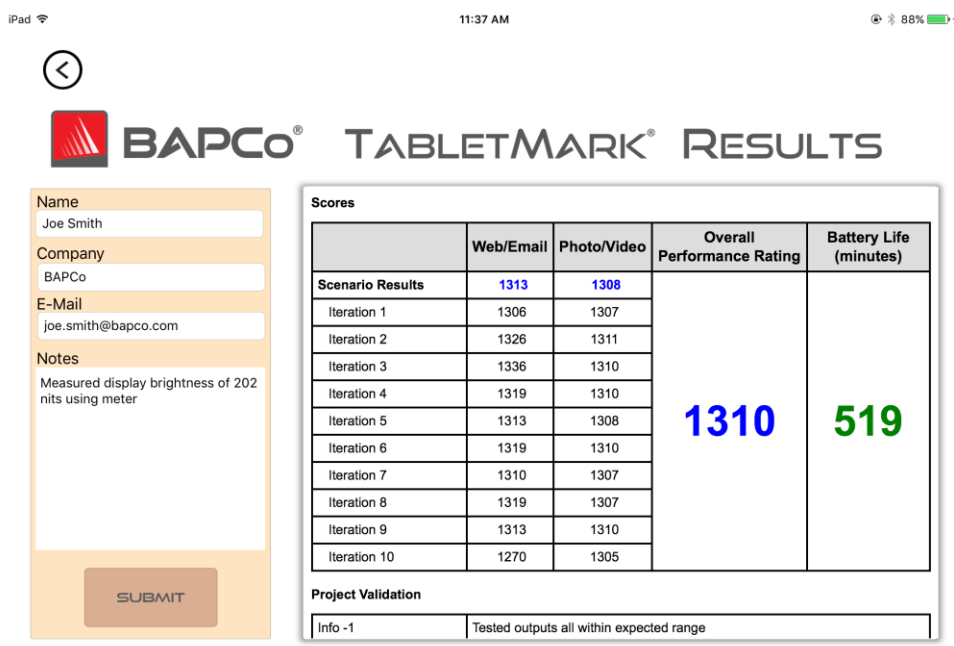


Figure C.4.1: Video Playback Scenario (iOS)

Figure C.4.2: Video Playback Scenario (Windows)



	Web/Email	Photo/Video	Overall Performance Rating	Battery Life (minutes)
Scenario Results	1313	1308	1310	519
Iteration 1	1306	1307		
Iteration 2	1326	1311		
Iteration 3	1336	1310		
Iteration 4	1319	1310		
Iteration 5	1313	1308		
Iteration 6	1319	1310		
Iteration 7	1310	1307		
Iteration 8	1319	1307		
Iteration 9	1313	1310		
Iteration 10	1270	1305		

Figure C.5.1: Detailed Results Screen (iOS)