

# Lifecycle Management For Docker UI

FINAL REPORT (SEMESTER 2)

Stephen Coady

20064122

Supervisor: Dr. Brenda MULLALLY

BSc (Hons) in Applied Computing

## **Plagiarism Declaration**

Unless otherwise stated all the work contained in this report is my own. I also state that I have not submitted this work for any other course of study leading to an academic award.

# Contents

<b>1</b>	<b>Introduction</b>	<b>6</b>
1.1	Problem Statement . . . . .	6
1.2	Aims and Objectives . . . . .	7
1.3	Semester One Summary . . . . .	7
<b>2</b>	<b>Technologies</b>	<b>9</b>
2.1	Docker . . . . .	9
2.2	Node JS . . . . .	9
2.3	Angular JS . . . . .	9
2.4	Travis CI . . . . .	10
2.5	SonarQube . . . . .	10
2.6	Vagrant . . . . .	10
<b>3</b>	<b>Design</b>	<b>12</b>
3.1	System Architecture Overview . . . . .	12
3.2	Front End Design . . . . .	13
3.3	Enterprise Level Considerations . . . . .	14
<b>4</b>	<b>Methodology</b>	<b>17</b>
4.1	Agile . . . . .	17
4.2	Jira . . . . .	17
4.3	Gitflow . . . . .	18
4.4	Testing . . . . .	19
4.5	Code Quality/Coverage . . . . .	21
4.6	Continuous Integration/Deployment . . . . .	21
4.7	Documentation . . . . .	22
<b>5</b>	<b>Implementation</b>	<b>25</b>
5.1	Sprint 1 . . . . .	25
5.2	Sprint 2 . . . . .	26
5.3	Sprint 3 . . . . .	27
5.4	Sprint 4 . . . . .	29
5.5	Sprint 5 . . . . .	30
5.6	Sprint Metrics . . . . .	31
<b>6</b>	<b>Summary</b>	<b>33</b>
6.1	Review . . . . .	33
6.2	Learning Outcomes . . . . .	34
6.3	Project Direction . . . . .	35
	<b>Appendices</b>	<b>36</b>
A	Application Repository . . . . .	36
B	Travis Repository . . . . .	36
C	SonarQube Repository . . . . .	36
D	DockerHub Repository . . . . .	36
E	Staging Server . . . . .	36

F	Dockerode . . . . .	36
G	Report Source Code . . . . .	36
H	Formal System Models . . . . .	37
I	Wireframes . . . . .	40
<b>Bibliography</b>		<b>44</b>

## Glossary

- API** Application programming interface. A set of endpoints which lead to functions and application logic. Allows developers to expose application functionality without directly exposing the code within the application. [6](#), [8](#), [19](#)
- Bootstrap** A front end css framework designed to give developers more power with less work when creating html pages. Makes use of a standard 12-width grid system to provide an easy-to-use css styling method. [13](#)
- CLI** Command Line Interface. A means of interacting with a computer program where a user can only enter commands in the form of successive lines of text. [6](#), [7](#)
- Code Coverage** Refers to the percentage of code which has been executed by tests. Not an indication of test quality but instead can be used to identify pieces of code which has been missed by test cases. [21](#), [22](#)
- Code smell** A piece of code which may perform as expected in some or all cases but that introduce a possibility of an unexpected result. Should be avoided. They are normally decided upon by the community. [10](#), [21](#)
- Continuous Deployment** The act of continuously deploying software which has passed acceptance tests to a live system. [21](#)
- Continuous Integration** The act of continuously merging newly created software with the current working version, validated by automatic build and testing tools allowing for early detection of faults. [10](#), [16](#), [21](#), [25](#), [27](#), [28](#)
- CRUD** Create, Read, Update, Delete. CRUD defines the four cornerstones of API functionality. An API should provide these functions to any user using the API. [8](#)
- CSS** Cascading Style Sheet. Used for applying styles to markup text primarily displayed on web pages. [13](#), [15](#)
- Docker** An application which manages containers running on a host. [6](#), [9](#), [15](#)
- Docker container** An isolated package which bundles everything required to run an application within a container. The application can then be run within this container without regard to the underlying architecture. [7](#), [9](#), [12](#), [13](#), [16](#), [27](#)
- Docker daemon** The server-side component of the Docker Engine. [6](#)
- Docker host** The computer, server or virtual machine on which the Docker application is installed. One user may manage several Docker host's, depending upon how many computers they have installed it on. [7](#), [9](#), [13](#)
- Docker image** A template from which many containers can be started. Can be pushed an pulled to/from a remote Docker registry. [7](#), [9](#), [14](#), [22](#)
- Dockerfile** A template from which a Docker image can be built. Defined in plaintext and interpreted by the Docker Engine. Can define which commands should be run etc. [30](#)

**DockerHub** An online platform to store Docker images. Can be pulled from by anyone once the repository is public. Essentially a way to share any built Docker images. [21](#), [22](#)

**Git** A version control system which allows source code to be tightly controlled and stored in a central repository. [8](#), [15](#), [18](#), [21](#), [24](#)

**Github** An online platform to store git repositories. Allows for multi-developer collaboration on projects. [8](#), [18](#), [21](#)

**HTML** Hypertext Markup Language. A means of tagging text using “markup” to allow them to be positioned, styled and linked on web pages. [13](#)

**JWT** JSON Web Tokens. A means to provide authentication over the internet using a simple string of characters. [14](#)

**REST** Representational state transfer. A means of providing communication between computers across the internet. RESTful web services allow systems interact with each other using completely stateless operations. [7](#)

**SonarQube** A tool to scan source code. It can inform developers of coding best-practices and highlight “code smells”, which are essentially when best practices are not adhered to. Also highlights technical debt. Code is deemed either ‘passing’ or ‘failing’, meaning the code has been deemed either sufficient or insufficient in the following categories: Code Test Coverage, Bugs, Vulnerabilities and Technical Debt Ratio. [8](#), [10](#), [21](#), [25](#)

**Sprint** A short cycle of development - normally one or two weeks long. Allows for rapid change of development direction if project requirements change. [7](#), [8](#), [17](#), [25](#)

**Staging Server** A computing unit exposed on the network which typically runs an incomplete or demo version of a piece of software. Generally used to show the in progress development to any product stakeholders. [21](#), [22](#)

**Technical Debt** The extra development work which arises as a result of implementing an easier but less robust solution. [10](#), [21](#), [26](#)

**Travis** A website which allows for automatic builds of code and feedback of results. Can be used to automatically deploy code dependent on test results also. [8](#), [10](#), [21](#)

**UI** User Interface. A graphical view towards an application which exposes functionality by using buttons or other components. Typically utilised using a computer mouse. [6](#)

**Vagrantfile** A template file which provides Vagrant with all the instructions required to create the desired environment. Written in the Ruby programming language. [11](#)

**Virtual Machine** An abstracted virtual version of a computer. Normally runs on another host with a dedicated piece of software to manage it. Appears to the user as a real computer, however all or most components are defined by software. [9](#), [10](#)

# 1 Introduction

This report will aim to guide the reader through the planning and development of the Lifecycle Management for Docker UI application. After reading this report the reader should have a clear idea of why the application was built, what was used to build it and how the process was carried out.

This project is being undertaken with a local company, Red Hat Mobile, acting as product owners. Red Hat have a vested interest in solving the problem discussed in Section 1.1 and so will act as product owners in the development of this product. This will ensure that the initial requirements will accurately shape the project and the delivered solution passes a product review by Red Hat Mobile.

This application will be built using open source principles and best practices, enabling it to be maintained and improved by any developer who wishes to contribute. For this reason many of the decisions made and processes employed were done so with an open source final product in mind.

## 1.1 Problem Statement

Currently the Docker application does not ship with any bundled UI. When installed, it is comprised of a client and a server side component (Docker, 2017a). The server side exposes itself through an API and is ultimately responsible for controlling all aspects of Docker on the host such as containers, images, networks and volumes etc. The API exposed by the server-side application of the Docker Engine is consumed by the Docker CLI which is the client side application. A graphical representation of the complete Docker engine can be seen in Figure 1.

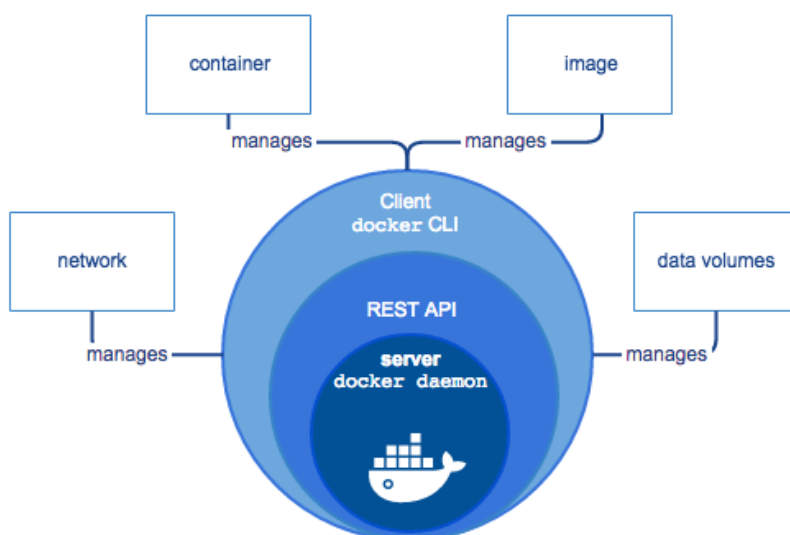


Figure 1: *Docker Engine Components*. Credit: (Docker, 2017a)

This model is extremely versatile as it allows the developer to control any Docker daemon (the server-side component of a Docker installation) once they have access to the command line of the

host Docker is running on. In fact, if the API exposed by the Docker daemon is exposed remotely then the developer does not need access to the host's command line, instead they can directly access the API remotely.

While the [CLI](#) gives developers full control over the server-side component of a [Docker host](#) it also has its drawbacks.

- Learning curve - the person using the command line must be familiar with typical commands used to achieve certain tasks. This precludes anybody without these skills from using Docker.
- Vast set of Docker commands - there are a vast number of commands available to use from the Docker CLI. This is also a learning curve as even a developer who is familiar with a CLI must first learn the Docker commands to be able to use the client-side application.
- User friendliness - The command line does not produce content that is easily readable and can often format the data it is trying to present in an odd fashion depending on things like screen size etc.

## 1.2 Aims and Objectives

The aim of this project is to address all of these problems while also trying to increase the functionality available to anybody who wishes to use Docker.

At a high level the primary objectives of this project are:

- Fully functional server-side application
- Expose this application through a [RESTful](#) API.
- A fully functional front-end application
- A [Docker image](#) built to allow easy distribution of the application

These objectives will then provide the following functionality:

- A UI which will
  - allow users to manipulate images, containers etc on the host with the same capabilities as the command line
  - allow them to do this remotely
- A [Docker container](#) which has no external dependencies. The benefit of this is that the user does not need to install the application in the traditional sense. This will be discussed further in [Section 2](#).
- An independent API which can be consumed by any front end application
  - This will provide flexibility if the front end framework needs to be changed further down the line

## 1.3 Semester One Summary

As this is the second of 2 reports detailing the progress of this project it is important to provide a summary of report one. The work completed in semester one was achieved in the form of 2 [sprints](#), the first lasting 2 weeks and the second taking place over 3 weeks.



### 1.3.1 Sprints

Sprint 1:

- The developer environment was set up (Vagrant + Docker installation)
- A basic Express [API](#) was created and run on test endpoints with no functionality
- A basic Dockerfile was created to run the application within a Docker container
- The Dockerode third party module was added to the application to provide [CRUD](#) functionality to the container and image endpoints

Sprint 2:

- The prototype application was improved to include further and more complicated [CRUD](#) calls
- A [Travis](#) account was created and linked with the public [Github](#) repository of the application. Both of these can be seen in Appendices [A](#) and [B](#).
- A `travis.yml` file was created which details the steps to be followed when building the application. The Travis repository in Appendix [B](#) will now build the application and run the unit tests every time a [Git](#) commit is made.
- A [SonarQube](#) account was associated with the Github repository and incorporated in the build pipeline. This can be viewed in Appendix [C](#).

To gain a complete understanding of the process and what was achieved semester one report is available in Appendix [G](#).

The final product of these 2 [sprints](#) was a prototype application which provided a proof of concept. It also validated the technology decisions which were discussed in detail in report 1 and which we will discuss further in Section [2](#). While it was not a functionally complete application it did prove useful when reflecting on semester one.

### 1.3.2 Reflection

Once the prototype application had been built it offered valuable insight which could be used when moving forward into semester two.

- More time should be spent making the test suite robust. While complex tests cases require initial investment that outlay can save time in the long run.
- Creating a large section of the CI/CD pipeline was a good investment also as it meant a better development process was in place for semester two.
- Running the application at all times within a container is good practice as it means testing the application in the environment it will ultimately run in.
- The decision to use Agile methodologies was a good one as it allowed for a flexible and fast development cycle. This is ideal when the project span is short at 12 weeks.

## 2 Technologies

In this section of the report the technologies used to create the application will be examined and explained in detail.

### 2.1 Docker

[Docker](#) is a platform which allows developers to package their applications into isolated containers which contain only the software dependencies required by the application. A container is different to a [virtual machine](#) in that a container does not contain a full operating system ([Docker, 2016](#)).

Since a primary objective of this application is to manage a [Docker host](#) it makes sense to leverage the capabilities of Docker and run this application within a [Docker container](#). This provides several benefits over distributing source code, such as:

- Portability - If a [Docker image](#) can be built and uploaded to a public repository then it makes it easier for other developers to pull and run the application.
- Ease of use - As the application will be running in a container a developer does not need to install any third party components on their system to use the application. They do not need to worry about their environment at all, once their system has Docker installed it will run the application.
- Ephemeral - Docker containers are designed to be ‘throw-away’. This means that if this application needs to be quickly stopped and restarted then containers are the perfect vehicle to do this.

### 2.2 Node JS

Node JS is a server-side JavaScript runtime, it is built on the same V8 engine that powers the popular Chrome browser. It uses an event-driven, non-blocking I/O model that makes it lightweight, efficient and very fast. Node JS’ package ecosystem, NPM, is the largest ecosystem of open source libraries in the world. ([Nodejs.org, 2016](#)). Node JS provides an excellent way to build highly scalable network application which are non-blocking and extremely performant ([Griffin et al., 2011](#)). This means that if the application was adapted in the future to deal with large numbers of servers then the technology choice will be able to deal with that.

Node JS was also deemed a good fit for this project as it has a large and extremely active online community. Since this is an open source project this will increase the likelihood of other developers taking part in the project and contributing. We can see in [Figure 2](#) that there are currently (as of November 2016) more node modules available through the node package manager (NPM) than any other of the large package managers such as the ones used by Go, PHP, Python and Ruby.

### 2.3 Angular JS

Angular JS is a web framework for building dynamic web applications using Javascript as a controller. It uses HTML as its template language to display the information passed to it from the application controller ([AngularJs, 2017](#)).

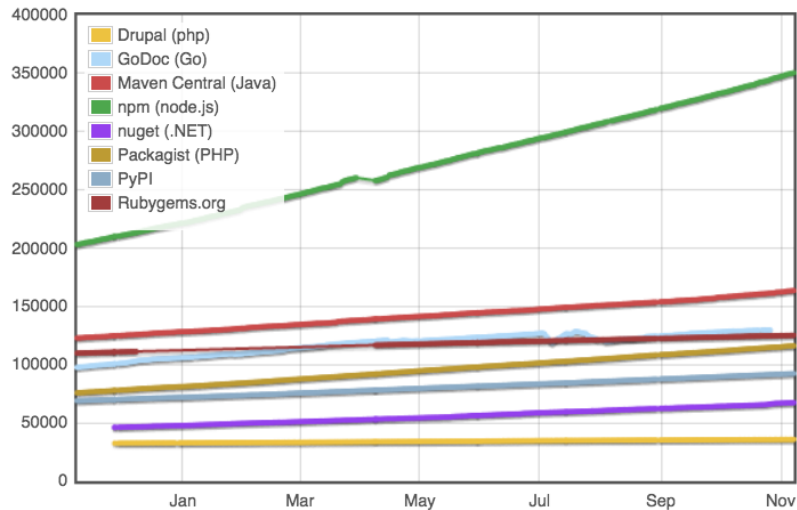


Figure 2: *Various Module Counts (Credit: modulecounts.com)*

For this application the front end requirements were relatively low. Once the framework provided a mechanism to show dynamic content then it was a candidate. For this reason several were evaluated and Angular was chosen as it had the lowest barrier to entry. The front-end application will be discussed further in Section 3.

## 2.4 Travis CI

Since this project was developed as an open source project it made sense to have a transparent and fully automated build process integrated into the project. For this reason [continuous integration](#) in this project is handled by [Travis CI](#). It is a feature-rich service free to use for open source projects and has a large user base. The set up used in this project for testing and continuous integration will be explored further in Section 4.

## 2.5 SonarQube

All code in this project should be held to a high standard. Since this project is open source it is important to ensure all code is bug free and follows current best practices. While this is important it also ensures more educational value for the writer.

To achieve this an open source tool [SonarQube](#) will be used ([SonarQube, 2016](#)). This tool analyses the output of tests to give detailed information about test coverage and also scans the code to find possible bugs and [code smells](#). It can also give useful information such as the current amount of [technical debt](#). SonarQube will be discussed in further detail in Section 4.5. The SonarQube repository for this project can be seen in Appendix C.

## 2.6 Vagrant

Vagrant is a technology to create configurable, reproducible and portable environments by using a set of programmable steps to produce a [virtual machine](#) which the developer can use to develop in ([Vagrant, 2017](#)). While this is just one use-case of Vagrant it is the main reason it was used in this project.

Since this project is open source it is useful to have one standardised VM within which all development can take place. This virtual machine can then be shared (either as its own separate repository or included in the main application repository). This is useful as it enables any developer who wishes to contribute to the project to instantly have the required environment. For instance, a developer can contribute to this project by using the [Vagrantfile](#) supplied without requiring them to first install Docker or Node JS.

### 3 Design

The formal information modelling of the system remains unchanged from Report 1 and is available in Appendix H. However in this section we will examine the system overview and all aspects of design will be discussed.

#### 3.1 System Architecture Overview

To gain a better understanding of the system we will now look at it from a high-level architectural view. This will give the reader an idea of how all major components fit together.

A diagram showing each major component of the application can be seen in Figure 3 below.

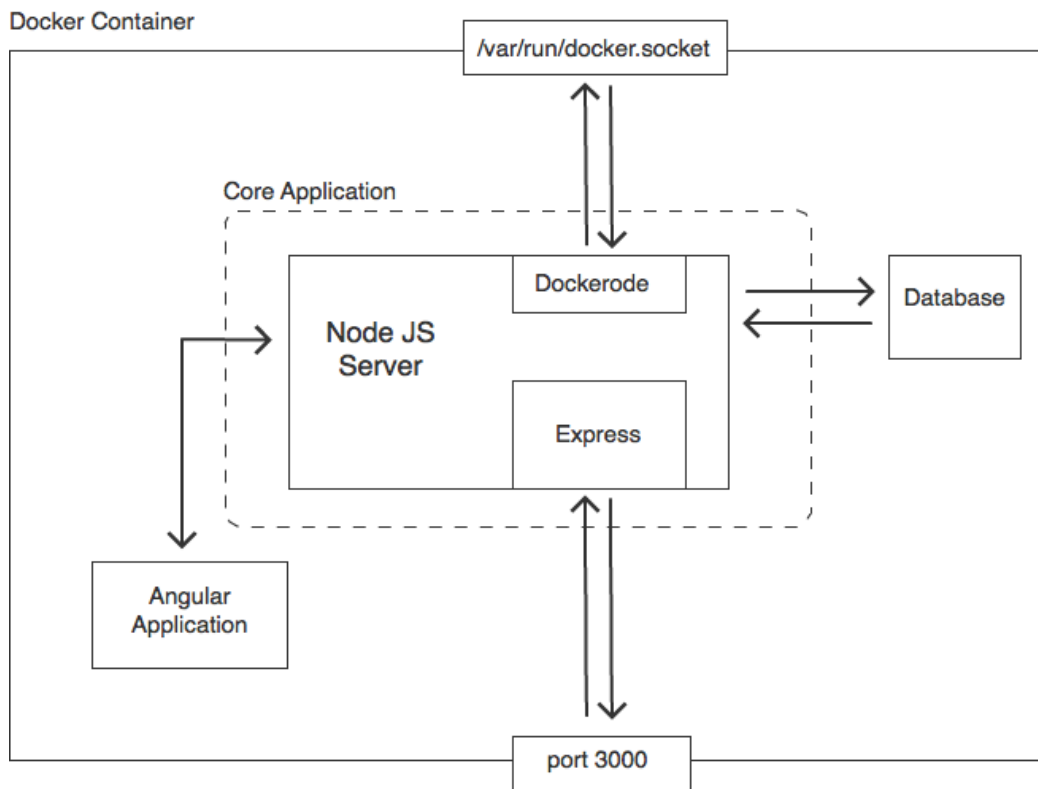


Figure 3: *System Architecture*

The whole application is bundled in a [Docker container](#). This is represented in Figure 3 and means the architecture will never vary across different systems.

Most of the application's logic is in the Node JS server. It is the most important component as all others are built around it. It provides a mechanism to access the application through an Express API while also communicating with the Docker API using Dockerode as an external library. It also performs all communication with the database and front end application.

It is important to note that the design of this application is deliberately modular. This means a low cohesion between each component of the application which in turn means that any one component can be swapped for any another which provides the same functionality. For instance, if in the future it was decided that a different front end framework was required then Angular could easily

be replaced. Everything in Figure 3 outside of the dashed rectangle can be easily swapped for a different technology in this same fashion.

The Node JS application ‘listens’ on port 3000 within the [Docker container](#) which in turn maps to port 3000 on the host it is running on. It also maps the Docker unix socket ‘/var/run/docker.socket’ as a volume on the Docker container.

## 3.2 Front End Design

As previously discussed the requirements for the front-end application are relatively low. They are:

- The application should allow for dynamic content.
- It should allow for re-use of code to keep the codebase small and manageable, i.e. ‘templating’.
- As this project is open source it should be a relatively well known framework, meaning low barrier to entry for potential contributors.
- The application would have a clean, minimalistic interface using a sidebar to navigate all available pages.
- It would be responsive - meaning it would scale well on smaller devices such as mobile phones and tablets.

Therefore it was decided Angular was the best choice as it satisfied all of these conditions.

### 3.2.1 Wireframes

With these design decisions in mind an initial batch of wireframes were created which would be used when writing the front end code. One of these, the containers view, can be seen below in Figure 4 while the rest are available in Appendix I.

### 3.2.2 Mobile Web Application

Instead of creating a dedicated mobile application on a proprietary platform it was decided that a web application would be better. This is mainly because:

- Since the application would also need to be installed it would not make sense to require the user to install another application just to manage the first one.
- Not restricting users to certain devices was a major factor in deciding to create a web application as any user with a web browser can manage their [Docker host](#).

[Bootstrap](#) was therefore decided as the best method of delivering a fully functional mobile web application. Bootstrap gives the developer full flexibility in terms of choosing the arrangement of content on different sized devices. For example, on a large device the developer can decide to have a 2 column 2 row grid of items. If the size of the screen then shrinks to mobile-size it can rescale to a 1 column 4 row grid. To do this simply means adding [CSS](#) classes to the [HTML](#) code and then Bootstrap will handle the layout.

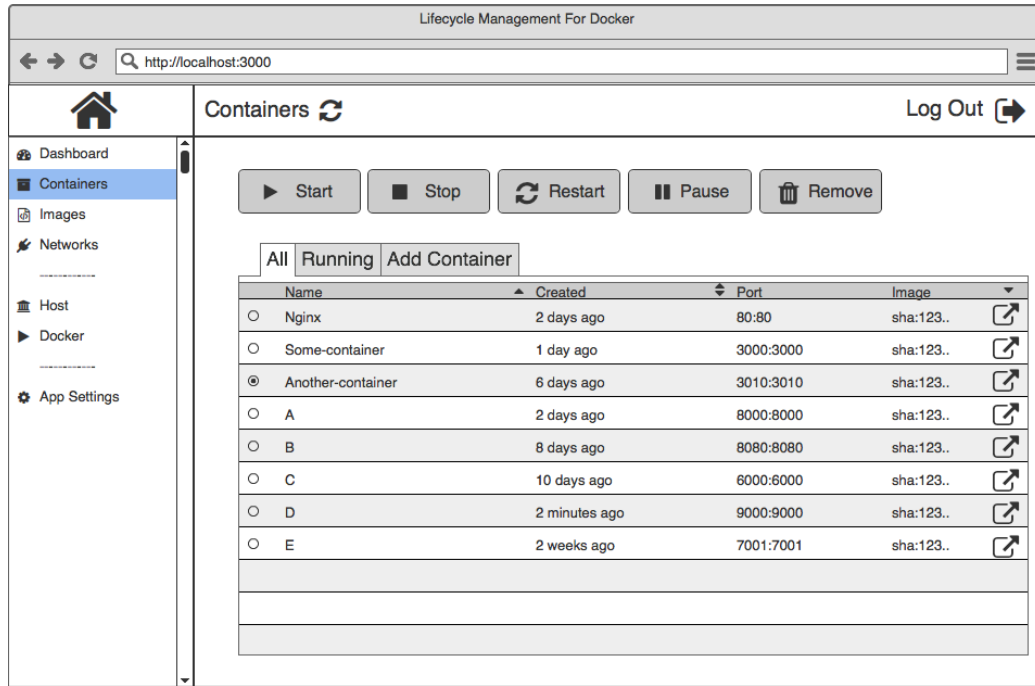


Figure 4: *Containers Mockup*

### 3.3 Enterprise Level Considerations

When developing any application that will potentially be used in a production environment it is important to consider this in the design phase. There are several headings under which careful consideration must be given to ensure the application performs as it should while also being usable.

**Scalability** On a system which will potentially be used by many different users at the same time, how it scales and adapts to an increase in usage is important. To ensure that any user has complete flexibility in this regard this application is distributed using a [Docker image](#), and therefore it can easily be used in a system which natively supports scaling such as Docker swarm or Kubernetes ([Kubernetes, 2017](#); [Docker, 2017b](#)).

**Performance** A number of previously mentioned technology choices significantly increase the performance of the application.

- Node JS - Node JS has been shown to have significant performance benefits due to its asynchronous non-blocking event-driven model ([Tilkov and Vinoski, 2010](#)).
- Docker - Since this application will run in a container it is designed to be lightweight. It will only contain the third party modules it absolutely needs and it should minimise the risk of memory issues on the host it is running on.

**Security** To secure an application the Express endpoints will be secured using JSON web tokens ([JWT](#)). The front end application will authenticate itself with the Node JS server and will then use the returned JWT token to access all Express endpoints.

**Distribution** To make distribution a simple process it has already been described how [Docker](#) will be the vehicle of choice. It makes downloading and running the application extremely easy for any developer who wishes to do so. Once the developer has Docker installed on their system all they need to do is run one command to download and begin using the application.

### 3.3.1 12 Factor Application

A recent methodology has emerged regarding web applications and the development best practices associated with creating and deploying them. This methodology is known as ‘The Twelve-Factor App’ and dictates the guidelines to follow for an application to be easily setup, portable and suitable for deployment on various architectures ([Wiggins, 2017](#)). We will now examine how each of these twelve factors influenced the design of this application.

#### 1. Codebase

*‘One codebase tracked in revision control, many deploys’*

This application is tracked in a single [Git](#) repository. It is not a deployable application in the traditional sense as each developer must deploy their own version of this application.

#### 2. Dependencies

*‘Explicitly declare and isolate dependencies’*

All external dependencies in this project such as NPM modules, [CSS](#) files and external libraries are bundled within the application. The application can even be run without an internet connection and only external API calls will fail.

#### 3. Config

*‘Store config in the environment’*

While there is very little config in this application it is isolated to a config file and is not hard-coded within the application.

#### 4. Backing Services

*‘Treat backing services as attached resources’*

The only backing service within this application is the Nedb database and it is treated as a modular service which satisfies this factor.

#### 5. Build, Release, Run

*‘Strictly separate build and run stages’*

As this application uses Docker as both a build and deployment vehicle there is a clear separation by default here. The image is built and the container is deployed and they are both separate entities.



## 6. Processes

*‘Execute the app as one or more stateless processes’*

Again Docker solves this problem as it completely isolates the environment and therefore the process.

## 7. Port Binding

*‘Export services via port binding’*

This whole application is exposed via a single port listening on the host.

## 8. Concurrency

*‘Scale out via the process model’*

This factor is not applicable to this application as the process to run this application is already a single unit and cannot be broken down any further. This factor deals with applications which may have multiple instances of themselves running across several hosts.

## 9. Disposability

*‘Maximize robustness with fast startup and graceful shutdown’*

Due to the ephemeral nature of [Docker containers](#) this constraint is also satisfied. Containers can be stopped and removed and quickly started again without affecting the next instance’s startup and shutdown procedures.

## 10. Dev/Prod Parity

*‘Keep development, staging, and production as similar as possible’*

This factor is implemented by using Vagrant as discussed in Section 2.6 for the development environment to replicate the Docker engine environment. The [continuous integration](#) server Travis is then used with the same Docker engine. As any user running the application will also be using the Docker engine it ensures the application will always have the same environment available to it.

## 11. Logs

*‘Treat logs as event streams’*

This application exports all application logs directly to the web application. This ensures they are always available to the user if required.

## 12. Admin Processes

*‘Run admin/management tasks as one-off processes’*

This application does not provide the facility to run any administrative tasks.

We can see that by choosing to use Docker as a build and deployment vehicle many of these twelve factors have been automatically satisfied with minimal input from the developer.

## 4 Methodology

This section aims to give the reader an insight into the process used to build the application. After reading this section the reader should have a clear understanding of all methodologies used and how they benefited the project.

### 4.1 Agile

The Agile movement helps teams develop in unpredictable circumstances by using incremental, iterative units of work. It provides a mechanism by which feedback is not only facilitated but actively encouraged, promoting greater transparency along the development cycle ([Agile Methodology, 2016](#)).

Agile was chosen as the development methodology for this project for the following reasons:

**Quality Testing** Testing is integrated into the development cycle, enabling the developer to continuously monitor the functionality and performance of the application. In Waterfall testing is not carried out until the very end when development is finished. This can lead to problems for a single developer as testing coverage and quality may not be as high.

**Visibility** Agile provides a great environment to see how expectations are managed effectively. It provides a clear view into the project scope and the current track it is on. With Waterfall all expectations and deliverables need to be forecast before any development has begun. This can be difficult to do and can mean increased overhead of work.

**Risk Management** Incremental development cycles allow the developer to accurately assess any challenges early on and make it easier to respond and adapt. In Waterfall there is very little room for adapting to unforeseen challenges.

**Flexibility** Agile allows for change natively. Instead of setting a rigid time plan up front the timescale is set and each [sprint](#) allows for the requirements to change and even for more to emerge as development continues.

Agile uses time-boxed units called [sprints](#) throughout the development cycle ([Agile Methodology, 2016](#)). These are short development cycles designed to give the developer achievable goals while also allowing for change at short intervals.

The Agile implementation used in this project will be discussed further in [Section 5](#).

### 4.2 Jira

The project management tool Jira was used to aid with Agile implementation and to track all project activity ([Atlassian, 2016](#)). Jira is a professional grade project management software which is currently used by Red Hat Mobile. It provides functionality to graphically manage the product backlog and each [sprint](#). The developer is presented with a dashboard which allows them to create and edit tasks by assigning descriptions, estimation of work and subtasks.

Granular control over backlog items is important in an Agile environment as change is expected and so being able to have fine-grain control over everything makes this process much easier.

## 4.3 Gitflow

As this project will be developed in an open source environment there will also be well defined procedures followed when using [Git](#) as a version control tool. This ensures that should any other developers wish to contribute to the project in the future then a set of guidelines will ensure all code is merged in a clean way which will in turn ensure complete transparency. This set of guidelines is referred to as a ‘Gitflow’. The Gitflow used for this project can be seen below in [Figure 5](#).

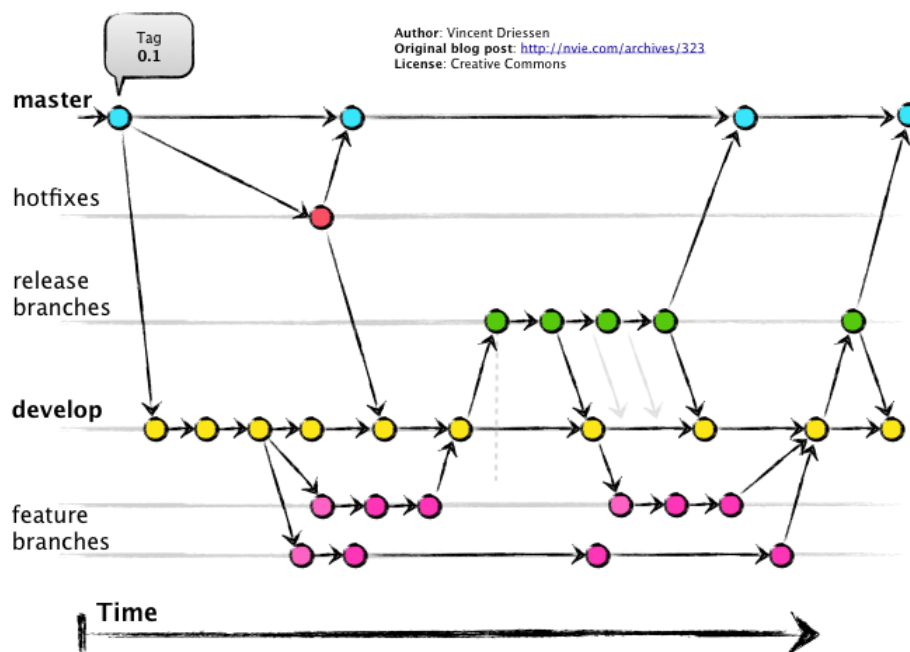


Figure 5: *Gitflow* (*Driessen, 2017*)

Using a well-defined Gitflow provides many benefits. Namely:

## Tagged Versions

Tagging versions at release intervals means it is easy to see a desired version if the developer wishes to do so. For example if someone wishes to download a version 0.6.0 of software then they can navigate to the versions pane in [Github](#) and easily download that specific version. An example of this for this project can be seen in Figure 6. Here we can see how a developer can easily download a specific version.

## Safe Merges

When using multiple branches it can become difficult to safely merge code from two branches. Having a well-defined process to do this minimises this risk while also creating a clearer picture in the developer's mind about what code is being merged and to where it is being merged.

## Easier Troubleshooting

In the case where something has gone wrong if there is a reproducible set of steps which were followed

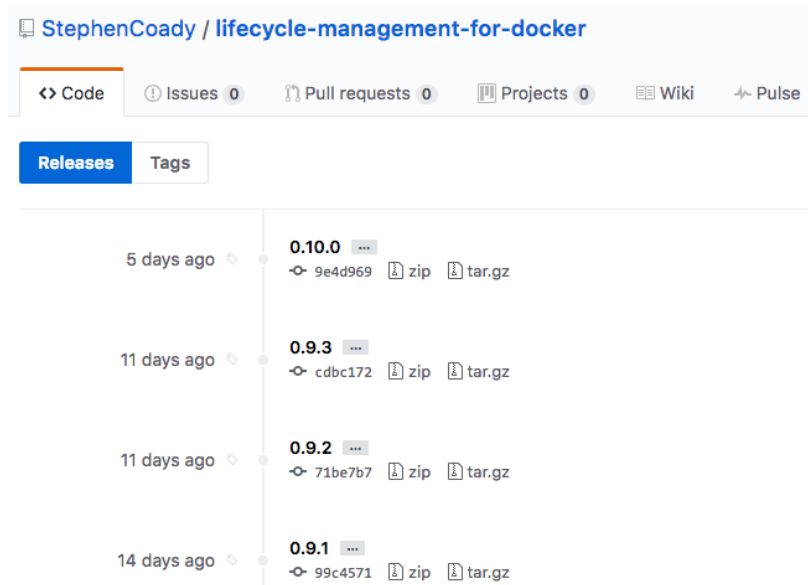


Figure 6: *Git Tagged Versions*

then troubleshooting the Git environment becomes easier. It also makes it easier for novice developers who may be inexperienced with Git to contribute to the project if every step is documented.

## 4.4 Testing

Testing is a vital aspect of software development and it is for that reason great consideration was given to the test plan for this application. Software testing in this project can be broken up into 4 distinct headings, namely:

- Unit Testing
- Integration Testing
- System Testing
- Acceptance Testing

Unit, integration and system testing in this project is all automated while acceptance testing is a manual process. We will now look at each of these and how they are implemented in this project in detail.

### Unit Testing

Unit tests are the most basic form of automated testing and occur when one unit of a program is tested. This unit may be a basic variable or it can also be some function belonging to a module of software. Unit tests on a function for example may call that function and compare the returned value with the expected output. It is a simple, standalone test which does not rely on any other test within the test suite (STF.com, 2017d). An example of a unit test for this project can be seen in Figure 7.

We can see on line 8 of Figure 7 that this unit test simply makes an API call and compares the result to the expected result. While this is powerful it is also too simple for modern day applications.

```

1  it('should list specific container', (done) => {
2    request(app)
3      .get('/api/containers/' + testContainer)
4      .set('x-access-token', token)
5      .expect('Content-Type', /json/)
6      .end(function(err, res) {
7        expect(res.status).to.be.equal(200);
8        assert.equal(testContainer, res.body.container.Id);
9        done();
10     });
11  });

```

Figure 7: *A Simple Unit Test*

Instead, we must test how several different functions acting in sequence behave, as this gives a more realistic simulation of an application being used by a real user.

## Integration Testing

We therefore naturally arrive at integration tests as a means to increase testing potency. Integration tests are essentially a sequence of unit tests. This sequence is carried out with the express intent of exposing defects in software as a result of the interaction between multiple components (STF.com, 2017b).

```

1  it('container should be stopped', (done) => {
2    request(app)
3      .get('/api/containers/' + testContainer)
4      .set('x-access-token', token)
5      .expect('Content-Type', /json/)
6      .end(function(err, res) {
7        expect(res.status).to.be.equal(200);
8        assert.equal("exited", res.body.container.State.Status);
9        done();
10     });
11  });
12
13  it('container should restart', (done) => {
14    request(app)
15      .post('/api/containers/' + testContainer + '/restart')
16      .set('x-access-token', token)
17      .expect('Content-Type', /json/)
18      .end(function(err, res) {
19        expect(res.status).to.be.equal(200);
20        expect(res.body.message).to.equal("Container restarted successfully");
21        done();
22     });
23  });
24
25  it('container should be started', (done) => {
26    request(app)
27      .get('/api/containers/' + testContainer)
28      .set('x-access-token', token)
29      .expect('Content-Type', /json/)
30      .end(function(err, res) {
31        expect(res.status).to.be.equal(200);
32        assert.equal("running", res.body.container.State.Status);
33        done();
34     });
35  });

```

Figure 8: *A Simple Integration Test*

We can see a trivial example of integration testing in this project in Figure 8. In this test case, we first stop the container and then restart it before checking that the container is actually started.

This is to ensure that the act of stopping the container does not interfere with restarting.

### System Testing

System testing is the act of testing a system in its entirety and in the same environment on which it will run (STF.com, 2017c). We will discuss this further in Section 4.6 but for the purposes of this system testing refers to the process of all tests being in sequence and those tests should cover the complete application. This is referred to as [code coverage](#) and will again be discussed further in Section 4.5.

### Acceptance Testing

Acceptance testing is the process of manually using an application to ensure it meets requirements and performance expectations (STF.com, 2017a). Since this project has a product owner in the shape of Red Hat Mobile they acted as the user. At the end of each sprint this involved the product owner using a staged version of the application to ensure it met all of their initial requirements for the newly developed feature(s).

## 4.5 Code Quality/Coverage

For an open source project it is vital to keep code quality at a high standard. If the project wishes to attract other developers to contribute then a good codebase with current best practices implemented and few bugs will help. To do this the tool SonarQube will be used, as discussed in Section 2.5. SonarQube will scan the codebase and inform the developer of any [code smells](#) present and will also perform calculations such as [technical debt](#) and [code coverage](#).

As we will see in the next section SonarQube is embedded in the [continuous integration](#) pipeline for this project. This will ensure that code is consistently monitored which in turn ensures code quality and test coverage is always at the forefront of the developers mind.

## 4.6 Continuous Integration/Deployment

In software development, [continuous integration](#) is the act of continuously ensuring software is of a suitable standard to be integrated into the current software package. This will ensure that any changes made to the code base will receive immediate test-feedback (Fowler, 2006). Even though this application was not built in a production environment having a continuous build cycle ensured maximum quality code and also reduced the risk of a “bug bottleneck”. [Continuous deployment](#) is the act of making an application available for use as soon as it has passed all tests contained in the integration section of the build pipeline.

For this project, a complete pipeline was built to facilitate a full continuous integration & deployment environment build and release process. This pipeline consists of the following:

- [Git](#) repository to house the code (stored remotely on [Github](#))
- [Travis](#) CI build server to execute tests and carry out post-test tasks
- [SonarQube](#) Server to analyse and advise of improvement to code, based on best-practices
- [DockerHub](#) repository which the built image is pushed to
- A [staging server](#) which the built image is deployed to and then run on

This pipeline can be seen in Figure 9 and will work as follows:

- Git commit is made
- Travis CI build is triggered which runs all tests and [code coverage](#) reports
- If successful a SonarQube push is triggered and the code is sent for evaluation
- Once this is complete a Travis then builds a [Docker image](#) from the newly passed code
- This image is then pushed to the associated [DockerHub](#) repository to be made public
- Once the push is complete Travis then deploys the application (by running a container) on the [staging server](#).

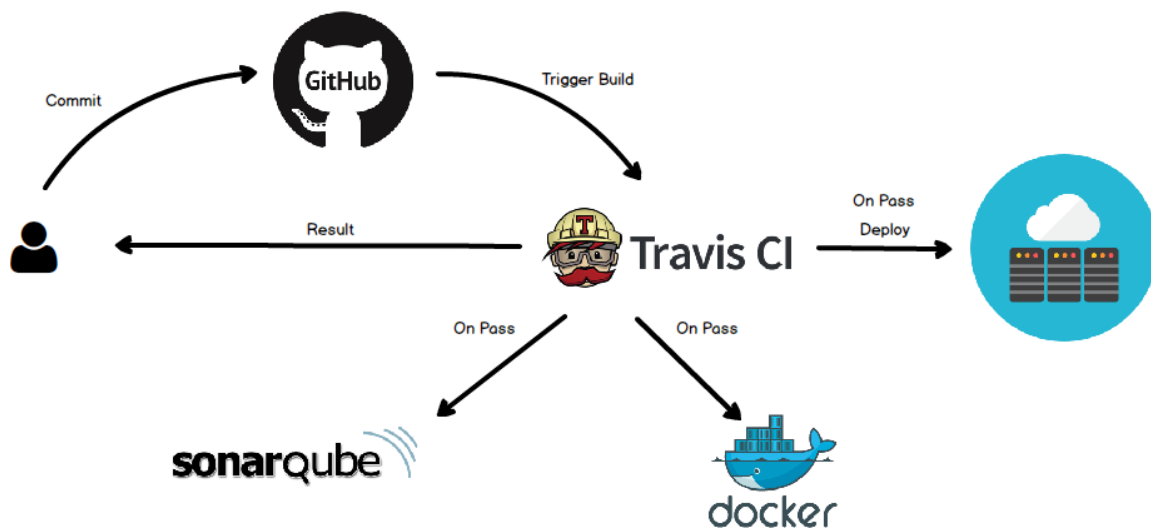


Figure 9: *Continuous Integration and Deployment Pipeline*

There are several advantages to this method of integration and deployment which are additional to those mentioned previously. These are:

- The process is completely automated, meaning one git push is all that is required to completely build the application and make it ready for deployment.
- Using SonarQube will mean that code quality does not drop at any iteration of development
- Automatically releasing to DockerHub will also mean that the application is rapidly updated between software releases.
- Staging the application provides immediate feedback for anybody wishing to evaluate the current iteration of the project and whether or not it has met the requirements for the sprint.

## 4.7 Documentation

This section will discuss the tools used to document the entire process of building this application and also the document which accompanies it.

### 4.7.1 User Documentation

Since the project comes in two parts, the standalone API and the user web application there are technically two separate user guides. The first user guide is relatively short and can be seen in Appendix A. It is the form of the README file associated with the repository. In the open source community it is common practice to include everything in the README which the user requires to being using the application.

The second set of user documentation uses a standalone application called Swagger UI to document the API (Swagger.io, 2017). Swagger allows any user to interact with the API through the documentation. For example, anyone with access to the documentation can make calls to the real API by filling in data and pushing buttons. It shows the user all current API endpoints and what each accepts as parameters and returns as a result. A screenshot of this can be seen in Figure 10. We can also see how one individual API endpoint is shown in swagger in Figure 11.

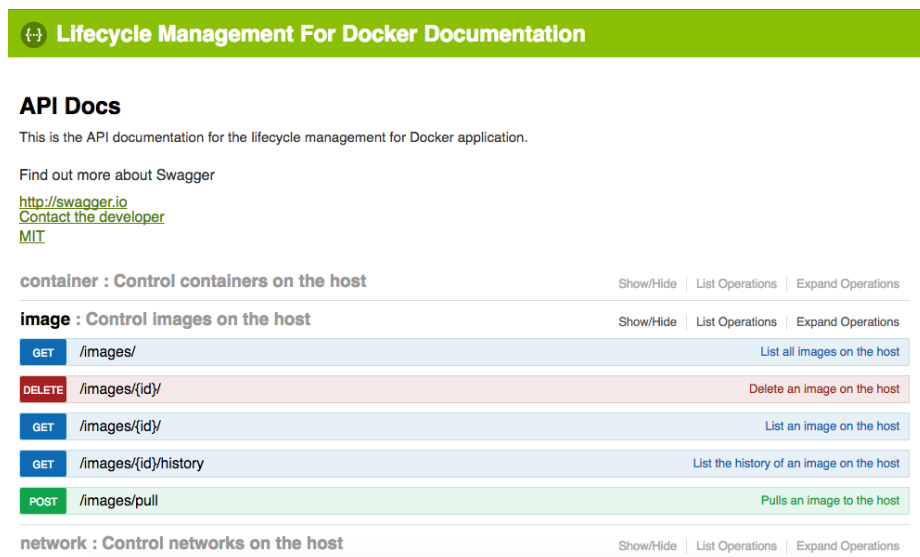


Figure 10: *Swagger Overview*



Figure 11: *A Single Swagger Endpoint*

### Making it accessible

To make the documentation easily accessible to anybody who wishes to view it it has been embedded as part of the application. When the user runs the project the node application automatically serves



the documentation up on the same host as the application. This can be seen by following the documentation link in [Appendix E](#).

#### 4.7.2 LaTeX

Latex is a software package which is used to write academic, high-quality papers. It is written using plain text with some markup which is then used to format. The plain text documents are compiled and Latex produces a pdf file ([The Latex Project, 2017](#)).

In this project Latex was used exclusively to write this document. This offered a number of clear benefits over traditional office-based software packages.

- Plain text - since Latex only uses plain text to create its documents the writer is free to concentrate on the important aspects of writing documentation.
- Source controlled - again as Latex is plain text it can be easily stored in a version control system such as [Git](#).
- Powerful compilation engine - The compilation engine behind Latex offers huge benefits such as auto-referencing all sections and figures etc. It also can auto-create sections such as glossaries and tables of contents.

The source code used to create this report can be seen in [Appendix G](#).

## 5 Implementation

This section will detail all technical work carried out in this project. It will use the project [sprints](#) to build a timeline for the reader.

While following the Agile methodology, this project also employs some Scrum techniques to better manage development. The complete process can be seen in Figure 12. We will use these planning, review and retrospective sessions to guide the implementation.

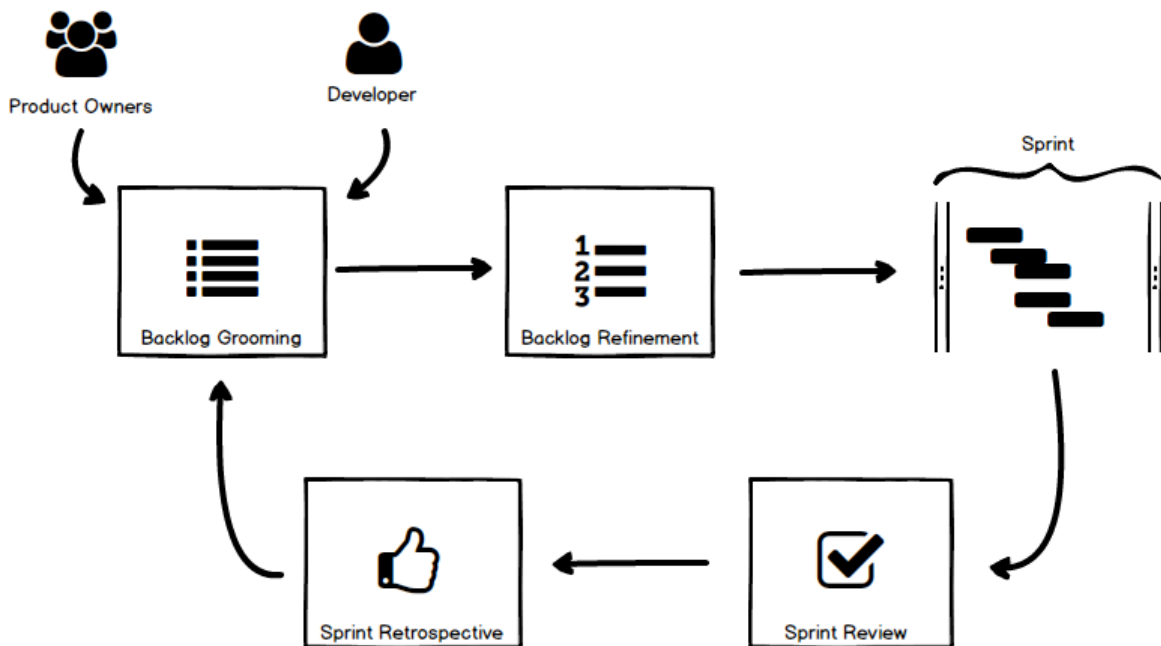


Figure 12: *Agile/Scrum Process*

- Backlog Grooming - Each [sprint](#) has a sprint planning session to initially scope the product backlog and to inform the total scope of the project. This typically involves the product owners who will help to shape the overall project direction by providing their priorities for the project.
- Backlog Refinement - Refining the backlog to break large development tasks into smaller tasks which will fit better in a sprint. This also helps to identify similar tasks which can be grouped together and reduce duplication.
- Sprint Review - After a sprint is completed a sprint review is then performed which will evaluate goals achieved versus goals planned and the backlog is then re-prioritised accordingly.
- Sprint Retrospective - A retrospective will then analyse sprint performance and help to highlight areas where improvement can be made. This will also enhance the accuracy of the following sprint.

### 5.1 Sprint 1

#### Sprint Planning

The planning session for this sprint identified that it would be best to have a functional API developed early in the project and so those tasks associated with this were prioritised and refined. It was also deemed important to have [SonarQube](#) integrated in the [continuous integration](#) pipeline early in the

project. This ensured **technical debt** was minimised from the beginning. For the same reason it was decided that the continuous integration pipeline should be finalised in this sprint to maximise its effectiveness throughout the project. Without working tests in place the value of this pipeline is minimal and so the testing tickets in the backlog were refined and placed in the sprint.

### **Sprint Review**

#### **Goals achieved:**

- Large subset of necessary API endpoints created.
- SonarQube integration completed
- Continuous integration pipeline finalised
- Full test suite for all current API endpoints implemented

This sprint delivered on all initial goals and with the experience gained the product backlog was re-prioritised accordingly.

### **Sprint Retrospective**

Date: 01 Feb 2017

Participants: Leigh Griffin, Stephen Coady

#### **What did we do well?**

- Already had prototype in place to accelerate development
- 3rd party module knowledge accelerated development
- Guidance from Red Hat really helped focus the sprint
- Scope on tickets well understood from Red Hats perspective

#### **What should we have done better?**

- Story points were inflated because domain knowledge was higher than anticipated
- Testing strategy needs to be revised, very time consuming

#### **Actions:**

- Stephen Coady review backlog for story point accuracy based off of current domain knowledge
- Stephen Coady add a ticket to review / spike testing strategies, feel free to consult David Martin and Leigh Griffin on specifics
- Stephen Coady add a ticket for UI frameworks investigations and spikes, end result should be an Epic that we can triage and prioritise

## **5.2 Sprint 2**

### **Sprint Planning**

While reviewing the backlog after Sprint 1 several API endpoints were identified as missing and so were added to the backlog. It was decided that these would be developed in Sprint 2. Since the API should be a standalone component it is vital to have documentation available for any developer wishing to use it. For this reason a documentation tool investigation ticket was added to the sprint.

## **Sprint Review**

### **Goals achieved:**

- Express API made considerably larger by adding multiple end points
- Documentation investigation resulted in Swagger being decided on as the best method of writing documentation ([Swagger.io](https://swagger.io), 2017)
- Swagger implemented for existing API endpoints

### **Issues encountered:**

- Testing method was found to be laborious and was impacting development speed

## **Sprint Retrospective**

Date: 15 Feb 2017

Participants: Leigh Griffin, Stephen Coady, David Martin

### **What did we do well?**

- We performed a backlog review and set the priority for the remaining 3 sprints
- Progression of the sprint was excellent, good pace to it and good story pointing
- Comms was pretty good
- Smooth sprint, story points and tickets were well scoped
- Sprint Planning revisited the story points so very little surprises
- Team (Stephen) came to the Stakeholders (Dave & Leigh) with the plan for the next Sprint

### **What should we have done better?**

- Sprint started at a bad time college wise, with other assignments due
- Not keeping in touch with the sprint day to day (Dave & Leigh)

### **Actions:**

- Stephen Coady to share wireframes as a mid sprint review asynchronously. Would recommend emailing that to us both.
- Stephen Coady metrics spike insight when you get to it (this sprint possibly)

## **5.3 Sprint 3**

Since the application was now well-formed from a server-side perspective it was decided that the front-end application should be started. This would mean a more visual component for the project stakeholders to view which would provide more useful feedback moving forward. To start this process tickets were created relating to the system wireframes. Also, since it was intended that the application would have a front-end component by the end of this sprint then it would be practical to build this into the [continuous integration](#) pipeline ensuring it was automatically deployed upon each build. As a result of the Sprint 2 retrospective it was decided that tests should be implemented on the staging server within a [Docker container](#).

## **Sprint Review**

### **Goals achieved:**

- Continuous deployment implemented using bash scripts and Travis CI. Staging server can be seen in Appendix [E](#)
- Wireframes created and passed to stakeholders for review. Following feedback they were revised and improved
- Front end application was then built using these wireframes

#### **Issues encountered:**

- Containerised testing was not implemented on the [continuous integration](#) server.

#### **Sprint Retrospective**

Date: 28 Feb 2017

Participants: Leigh Griffin, Stephen Coady

#### **What did we do well?**

- The UI is very usable, lots of nice feedback and functionality visible now
- Consistency in the velocity at 20 points
- Got the wireframe relationship, it really helped with my front end skills which I was not confident in
- Wireframe feedback was excellent, really helped scope the work
- Got to demo to my supervisor which gave her a lot of insight
- Overall work pace was judged well for the most part, consistent delivery

#### **What should we have done better?**

- The story pointing on the skeleton was completely off, it could have derailed the entire sprint
- Velocity last sprint was off
- you should have de-scoped when you realised how big the UI was
- you should have re story pointed the UI mid sprint to allow a controlled de-scope
- Tickets are not descriptive enough, need to add more metadata
- Didn't de-scope the testing in a container ticket, should have done that when the UI became so big

#### **Actions:**

- Stephen Coady to review the backlog with a view to WHAT and WHY being evolved in the tickets as well as story points
- Stephen Coady to define the critical path through the project, 80 story points left with a 60 story point burn predicted
- Stephen Coady to add some investigative tasks around KeyCloak SSO for future work i.e. out of scope of this project

## 5.4 Sprint 4

Front end application - images, containers, networks and volumes views created based on wireframes  
- creation of volume, network - addition of volumes to containers - view a container's log

Investigation of metrics tools Addition of API endpoints

### Sprint Planning

For this sprint the general direction was aimed at creating a more complete front-end application. Therefore the backlog was groomed and re-prioritised accordingly. Metrics tools and a means of collecting them was also identified as a desirable outcome of this sprint. Further API endpoints were identified and added to the sprint.

### Sprint Review

#### Goals achieved:

- Front-end application:
  - images, containers, networks and volumes views created
  - creation of volumes and networks
  - addition of volumes to containers
  - view a container's log
- Investigation of metrics tools
- Further API endpoints added

### Sprint Retrospective

Date: 13 Mar 2017 Participants: Stephen Coady, Leigh Griffin

#### What did we do well?

- Better scoping of story points as a result of last retrospective
- Re-scoped mid sprint which I hadn't done before - leads to more accurate metrics
- Tickets were made more descriptive before this sprint. This meant less time spent before starting a task figuring out what was needed
- The velocity of this sprint was much higher than previous sprints, this is a combination of not having as many college commitments during this sprint and also as a result of better re-scoping mid-sprint.
- Agile methodology maturity is clear to see now. Tickets are more accurate, estimates are accurate and a mastery of the methodology is really clear from my side (Leigh)

#### What should we have done better?

- Getting container logs had not been researched properly as the data was a stream but could also be requested as a JSON object, missed this flag which wasted a lot of time parsing streams to JSON.
- Should have looked at the Docker remote API documentation in detail sooner. Would have saved time instead of relying on third party module 'Dockerode' which has little to no documentation.

## Actions

- Stephen Coady align defined critical path with remaining backlog so that 'nice-to-haves' are separated from 'must-haves'
- Stephen Coady to send naming conventions is it LifeCycle Management for Docker, or UI or LCMS or something random!

## 5.5 Sprint 5

Implemented searching docker hub feature Dockerfile upload feature added Implemented database Created Login page and server-side components Created User settings page Implemented JWT security once user logged in

### Sprint Planning

Since this would be the last sprint of the project there were a number of core features remaining unimplemented. These were:

- Allowing the user to search images instead of requiring them know the image name beforehand
- Drag and drop image building using a [Dockerfile](#)
- Implementation of a database which should provide user details and therefore security
- Login features to make use of the database

### Sprint Review

Goals achieved:

- Search feature implemented
- Database integrated into application along with startup script
- Security in the form of JSON web tokens put in place. This feature secures the front end application and also all API routes
- Dockerfile upload and build implemented behind a drag and drop user interface
- Created a page to allow the user to change their password

### Sprint Retrospective

Date: 01 Apr 2017 Participants: Stephen Coady, David Martin, Jason Madigan

#### What did we do well?

- Majority of story pointing was very accurate. Lead to a very predictable sprint
- Used previous knowledge of JWTs to decrease the time taken to implement them
- Design choice of not using breadcrumbs was a good one, as validated by user acceptance testing
- Managed to close out the last of the college project deliverables

#### What should we have done better?

- JWT implementation impeded by forgetting to include re-writing of tests in the ticket
- Sprint retrospective not carried out immediately after sprint ended, made it a more laborious task

## 5.6 Sprint Metrics

### 5.6.1 Sprint Velocity

Using JIRA we can view the velocity for each sprint, which shows the story points completed in each sprint compared to the initial commitment for that sprint. This gives the developer an indication as to their performance but also maturity from an Agile perspective. The velocity for this project can be seen below in Figure 13.

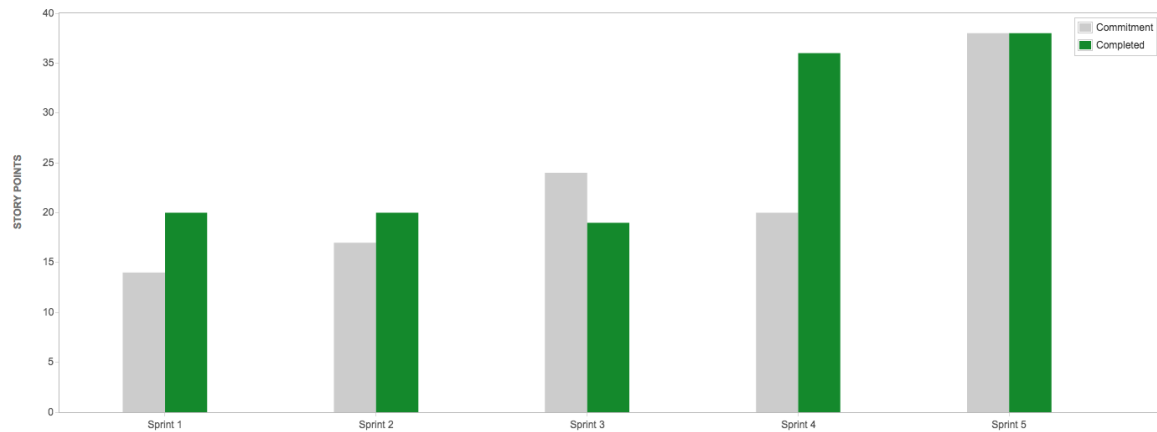


Figure 13: *Sprints Velocity*

### 5.6.2 Sprint Burndowns

The burn down report for each sprint can be seen below in Figure 14. The burn down chart shows the pace of development on a sprint. The red line on each graph is the development and the grey line is the recommended pace if the sprint is to be completed by the deadline set. Burn down charts can be used to highlight problems if they exist. For example, on Sprint 1 we can see that the initial scoping of the tasks may not have been accurate as the red line peaks within 4 days, indicating either missed story points or tasks.



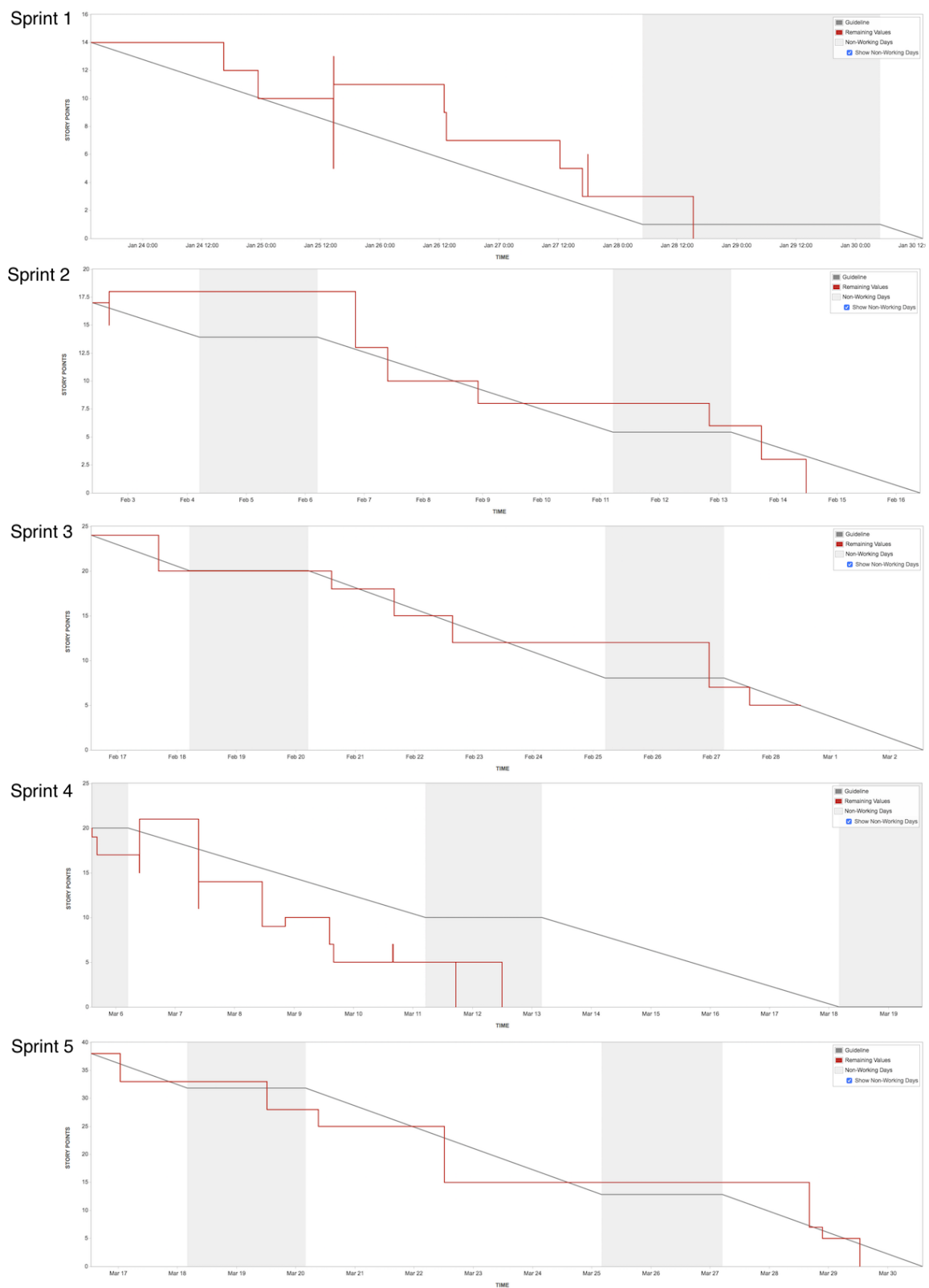


Figure 14: *Sprint Burn Downs*

## 6 Summary

In this Section we will aim to dissect the project and examine its proposed deliverables and compare them to the components it actually delivered. This will determine the overall success of the project. We will also look at the direction of the project going forward in terms of the product backlog and the work which is still outstanding.

### 6.1 Review

At the beginning of the project all stakeholders decided on the core and stretch goals of the system - these would then form the initial requirements. This list was then broken down further and was the basis for the initial product backlog. This high-level list can be seen below in Figure 15.

Type	Initial Requirement	Status
Core	Fully functional UI	Complete
	Control Images	Complete
	Control Containers	Complete
	Server Side Application	Complete
	Containerise the whole application	Complete
	Full RESTful API	Complete
Stretch	Implement security	Complete
	Connection to multiple hosts	Incomplete
	Drag and Drop Dockerfiles	Complete
	Business Intelligence	Complete

Figure 15: *Initial Project Requirements*

We can see that all core requirements were delivered and only one stretch goal was not delivered. However as this is now an open source project the tasks associated with this feature have been created and added to the product backlog.

We will now look at the main three components this project has delivered. As the system is loosely coupled each component can be completely recycled in any other project or indeed be replaced within this project by a comparable component.

#### Server Side Application

The server side of this application is a node module which communicates with the Docker API by using the third party module, Dockerode, previously mentioned in Section 3.

#### Independent API

The Express JS API has been designed to be independent of any server side or front end code. While it is run by the node module it is not constrained by it. An API written in any other language could easily be placed in front of the node module also.

#### Front End Application

The front end application written using Angular is probably the most weakly coupled component delivered. It is a web application which consumes API endpoints and could just as easily be written using another front end framework.

## 6.2 Learning Outcomes

The learning outcomes of this project can be categorised under technical and non-technical.

### 6.2.1 Technical

As a result of developing this application many technical skills were gained. These include:

- Gained a deep understanding of container technologies, both on the command line and by using the APIs exposed by services such as Docker.
- Learned how to use open source software effectively. i.e while using a package it may be necessary to git clone the software and run it locally. Once software has been run locally it makes it much easier to interact with the community by asking questions.
- Developing an application which has some elements of all modern applications - i.e a server side component, a database, an API and a front end - has resulted in valuable experience of developing the 'full-stack'.
- Using current best practices by creating a fully-functional continuous integration and deployment pipeline has enforced strict coding practices which is invaluable when working as part of a multi-developer team.
- Using code quality tools such as SonarQube has meant code quality is no longer an afterthought when developing applications. This ultimately means a better and more reliable software developer.

### 6.2.2 Non-Technical

- Working as part of an agile team, even as a lone developer, has meant increased awareness of the overall goal within a project and therefore a more focused method of development.
- Working with a scrum master has also enforced the ideology of performance and code reviews, again contributing to a better overall development experience and therefore a higher quality end product.
- Having input throughout the project from product owners Red Hat mobile has been instrumental to professional development. It has lead to a more focused and organised process. Therefore the quality of the end product has also increased exponentially as a result.
- Communication skills have been greatly improved as a result of constant contact with both the product owner and scrum master.

## 6.3 Project Direction

As this product was developed from the very beginning under the open source software ethos it is currently still being developed. The current direction can be categorised under the following headings.

### 6.3.1 Continued Development

Currently the product backlog is as follows:

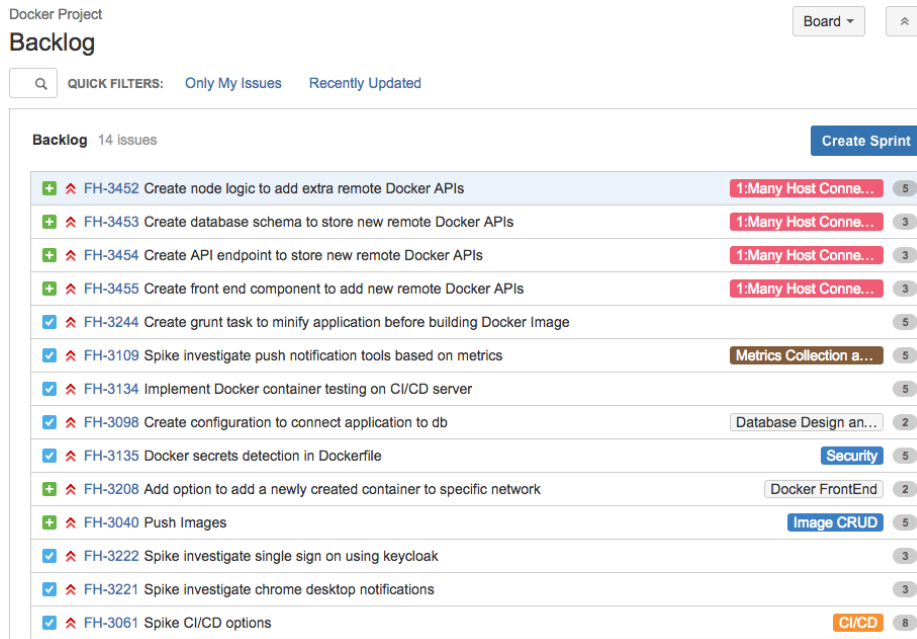


Figure 16: *Current Backlog*

This backlog contains approximately two sprints. It will implement several features which will improve the overall usability of the application.

### 6.3.2 Encourage Developer Contributions

As Docker grows in popularity so too will the interest in peripheral tools and so this project may gain interest due to this. However, to raise its profile further things like posting on developer community message boards or using social media to attract developers may be viable.

### 6.3.3 Increase the Feature Set

While the current feature set is large it could be increased further to provide users with more power from the UI. The Docker remote API is extremely large, therefore the amount of possible actions is only limited by the functionality provided by this remote API.

## Appendices

### A Application Repository

<https://github.com/StephenCoady/lifecycle-management-for-docker>

### B Travis Repository

<https://travis-ci.org/StephenCoady/lifecycle-management-for-docker>

### C SonarQube Repository

<https://sonarqube.com/dashboard/index?id=lifecycle-management-for-docker>

### D DockerHub Repository

<https://hub.docker.com/r/scoady2/lifecycle-management-for-docker/>

### E Staging Server

application: <http://87.44.18.55:3000/>

documentation: <http://87.44.18.55:3000/docs>

default username: admin

default password: admin

### F Dockerode

<https://github.com/apocas/dockerode>

### G Report Source Code

<https://github.com/StephenCoady/fyp-documentation>

## H Formal System Models

Visual Paradigm Standard(Waterford Institute of Technology)

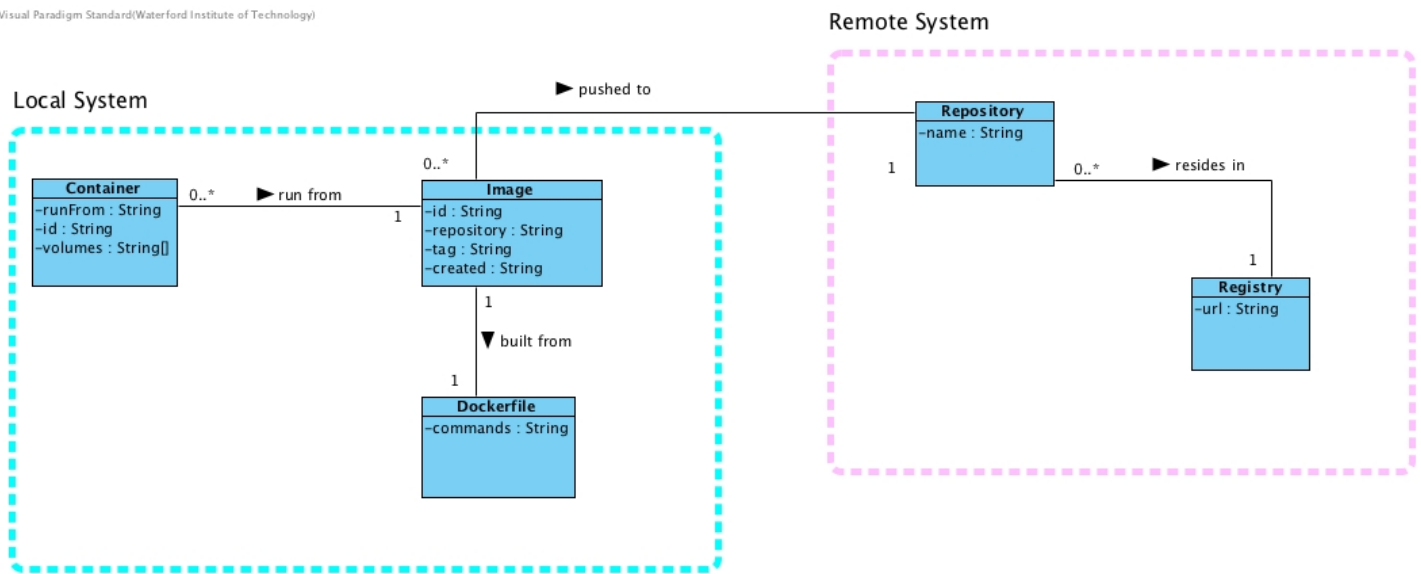


Figure 17: *Class Diagram*

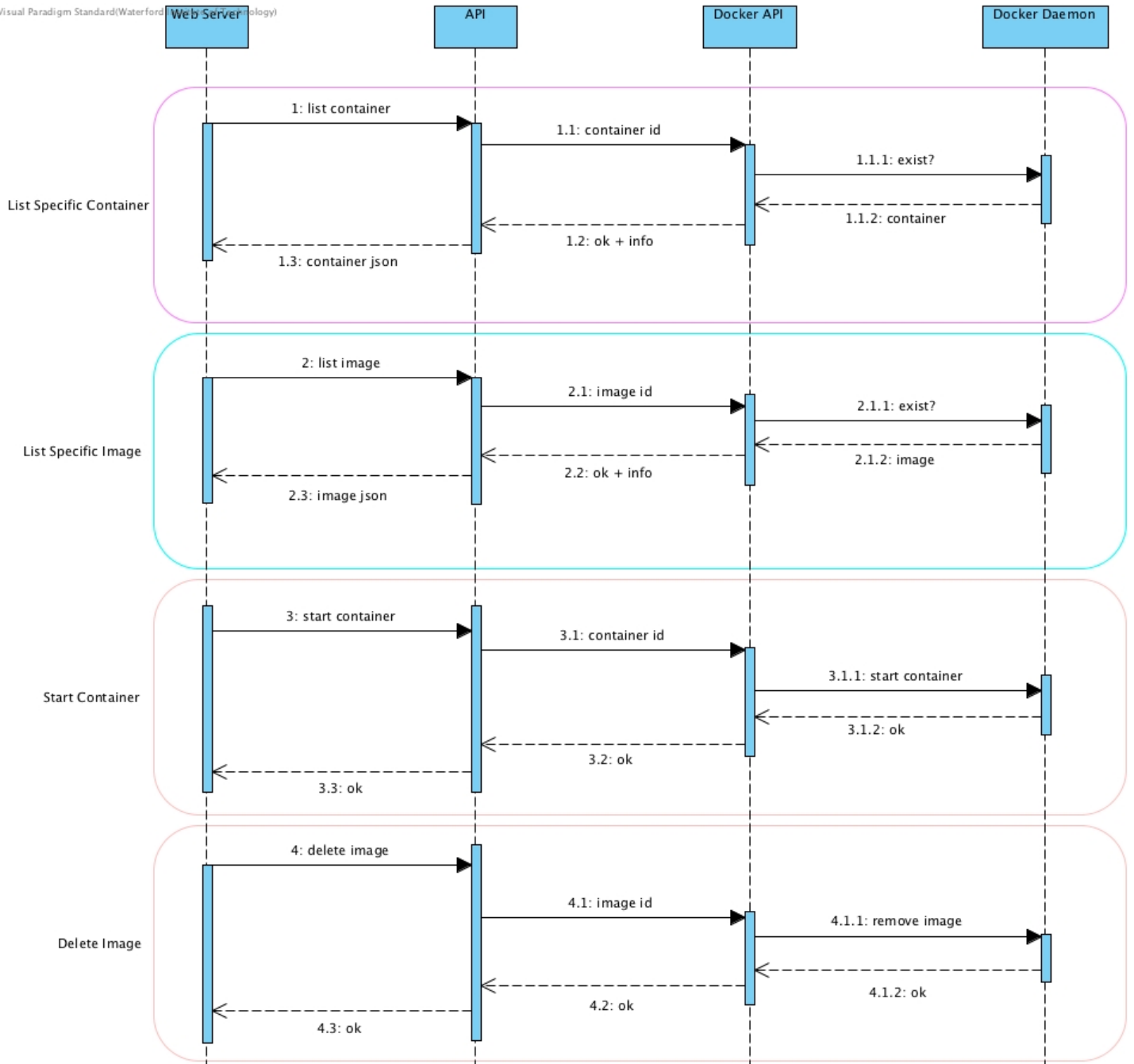


Figure 18: Sequence Diagram

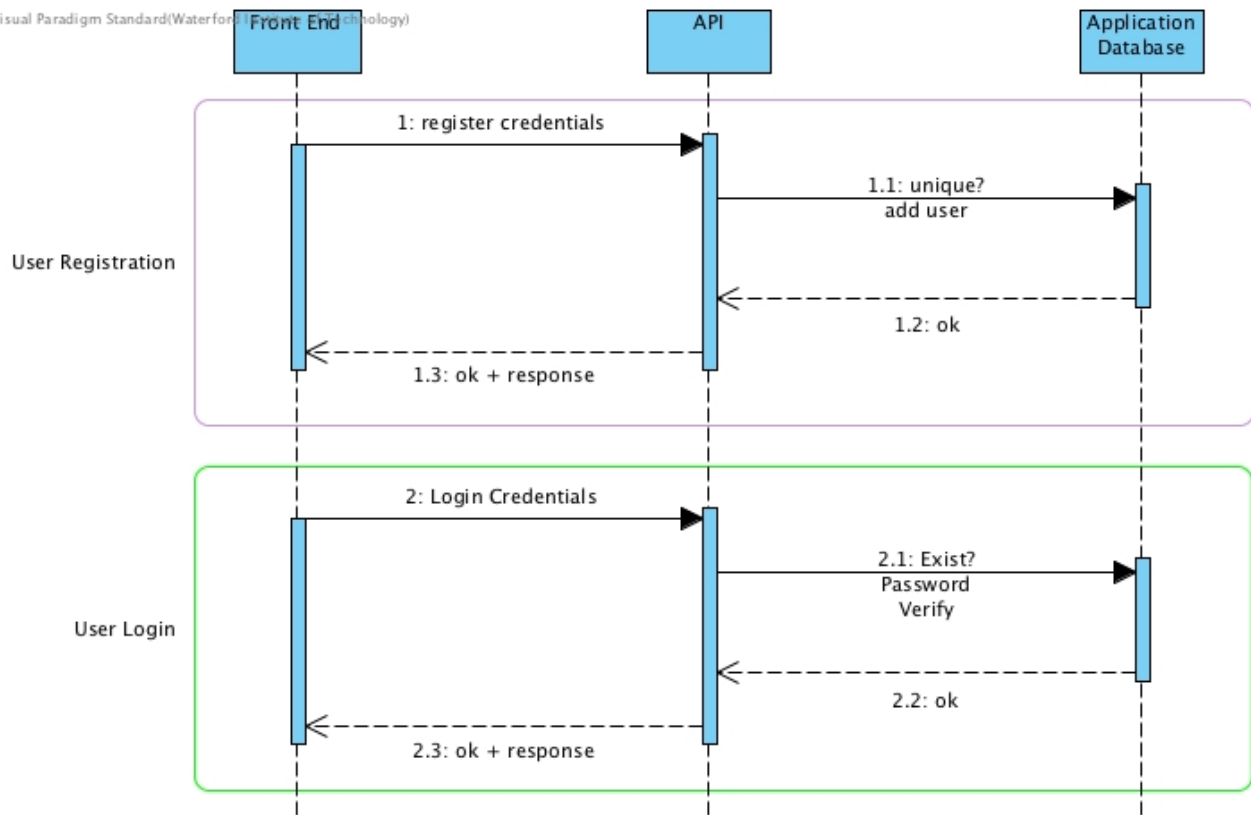


Figure 19: User System Sequence Diagram

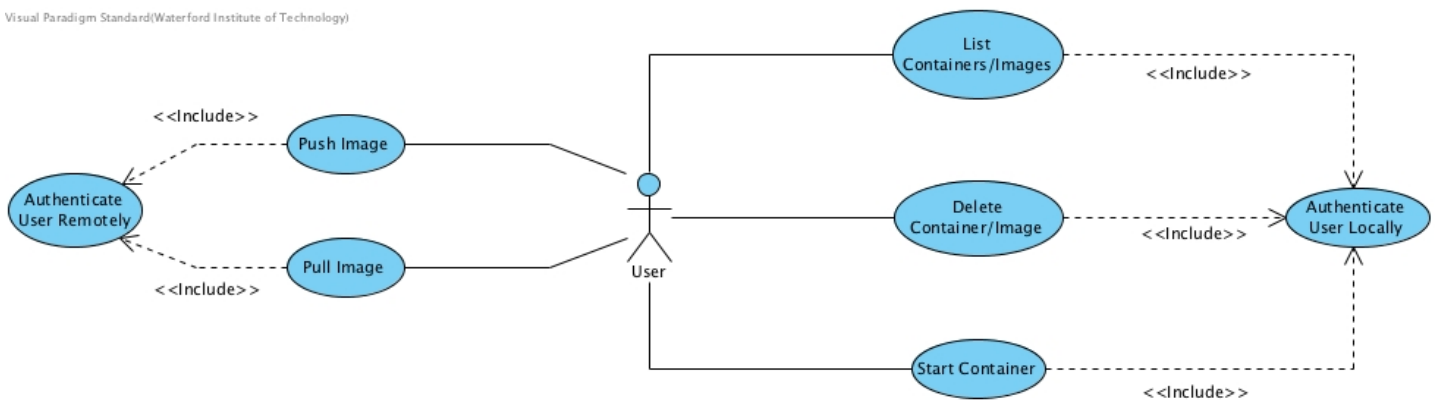


Figure 20: Use Case Diagram



## I Wireframes

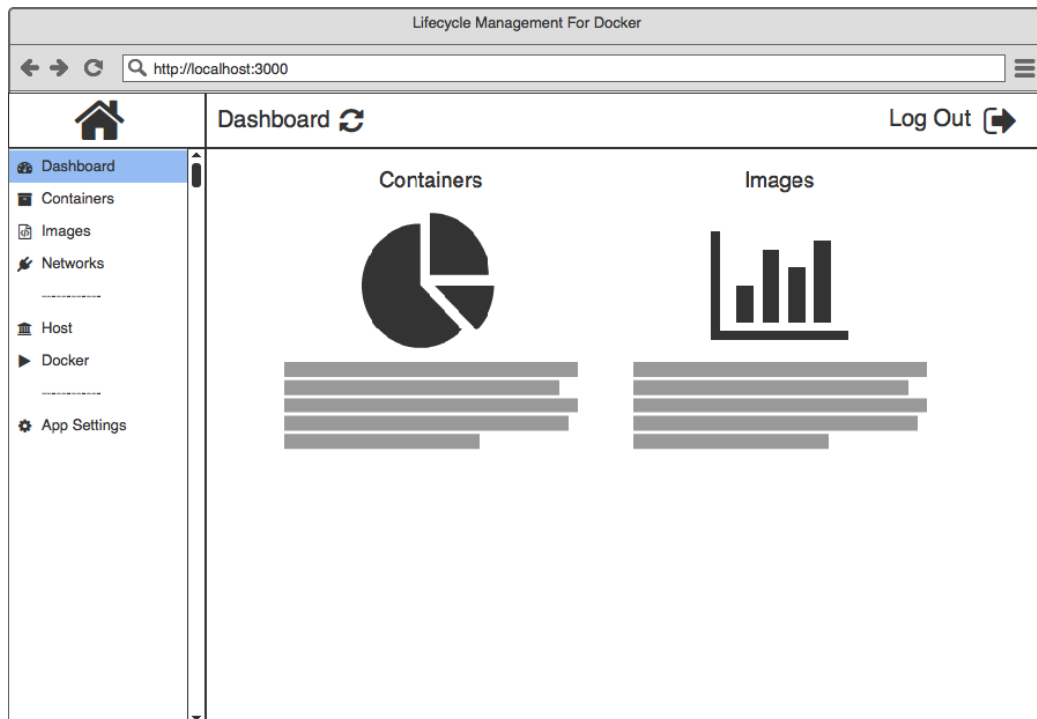


Figure 21: *Dashboard Mockup*

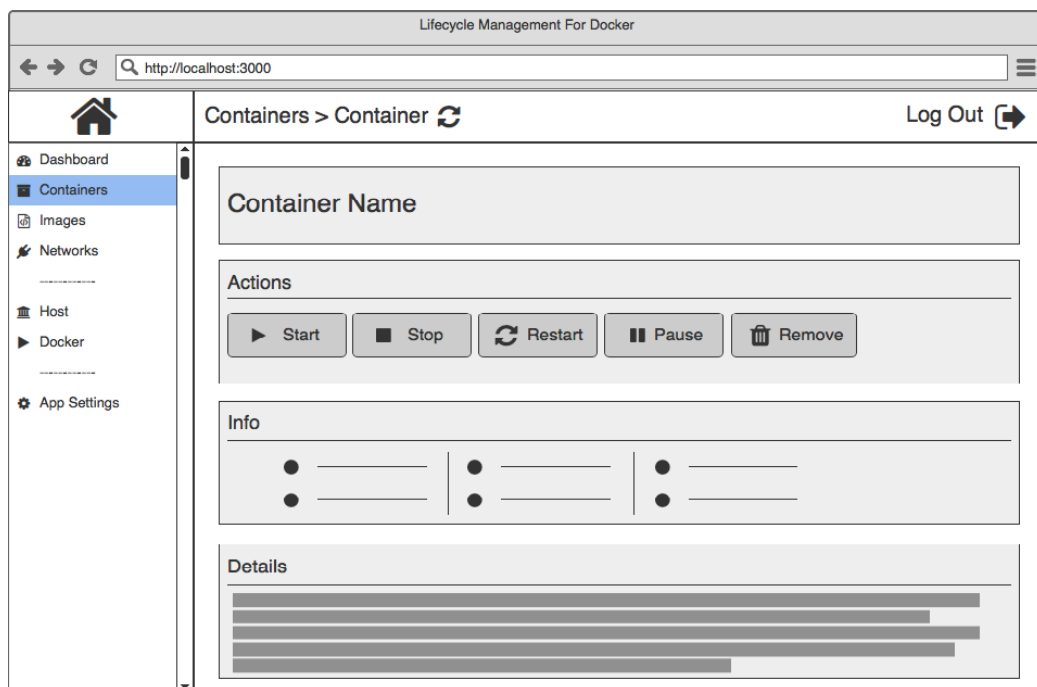


Figure 22: *Container Mockup*

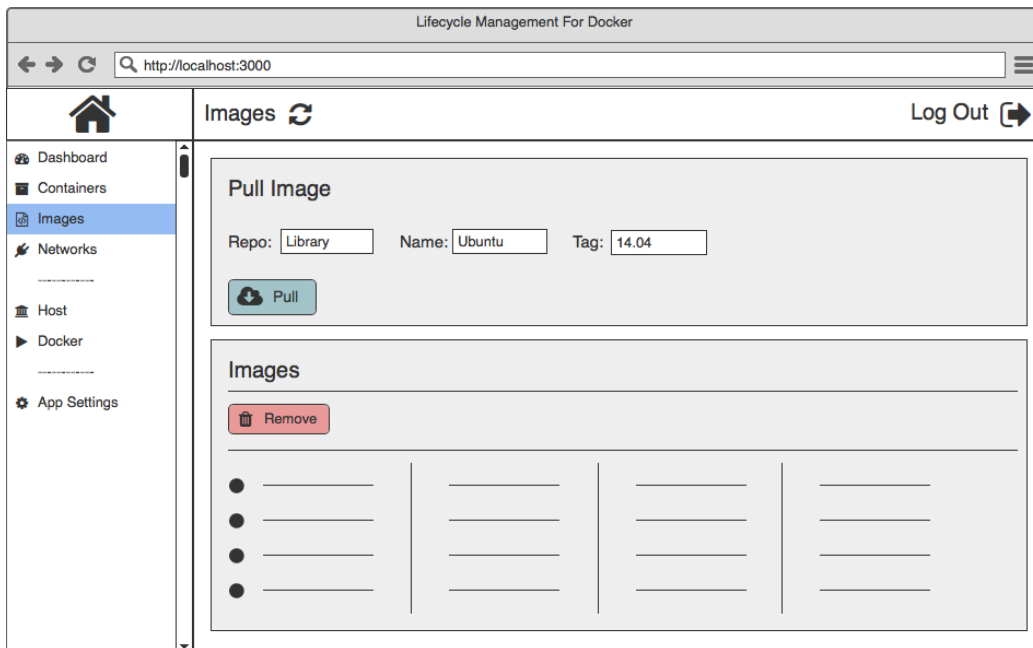


Figure 23: *Images Mockup*

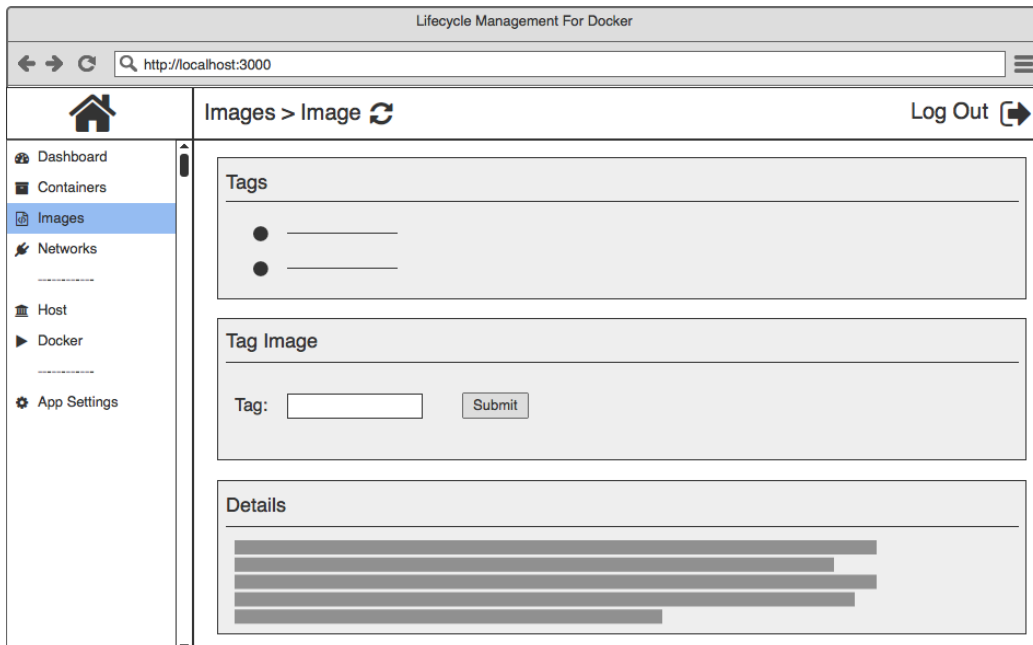


Figure 24: *Image Mockup*

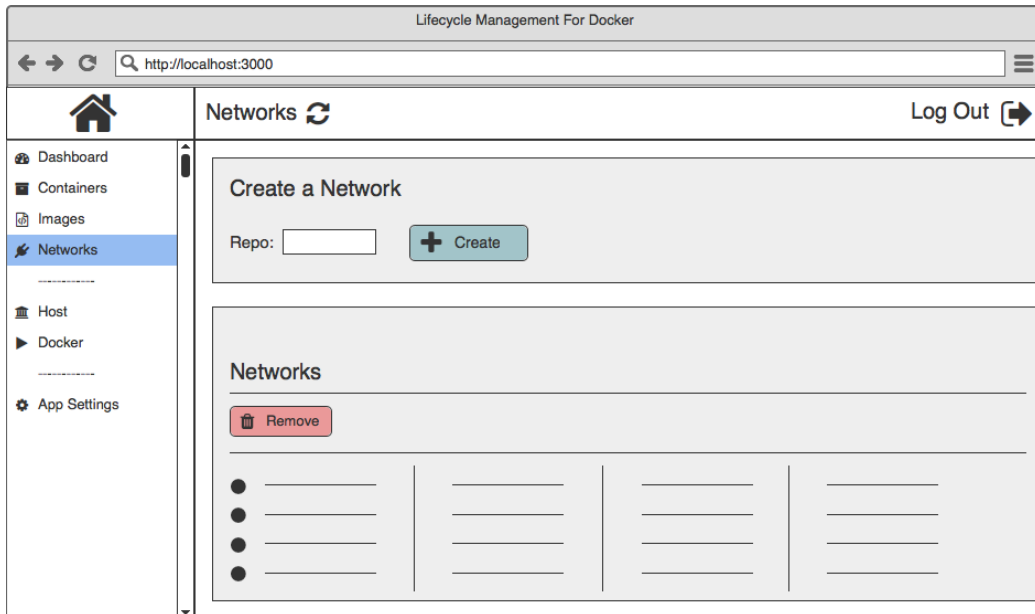


Figure 25: *Networks Mockup*

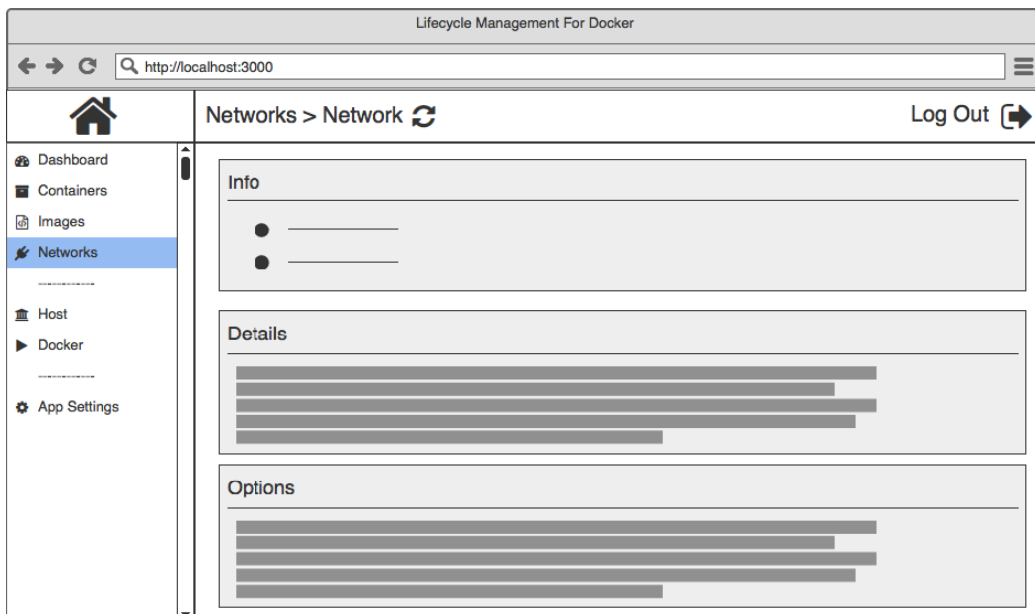


Figure 26: *Network Mockup*

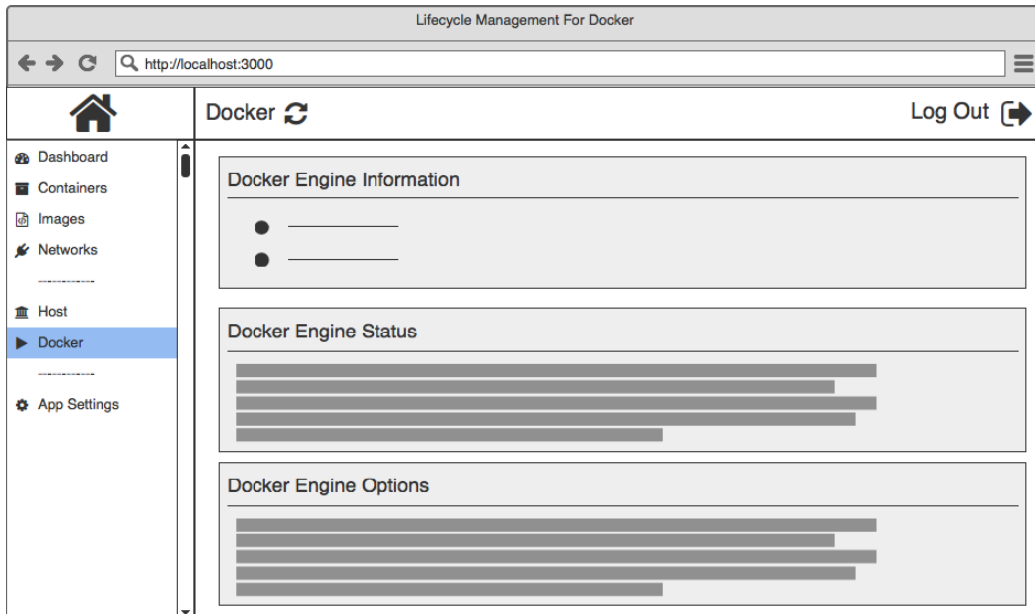


Figure 27: *Docker Mockup*

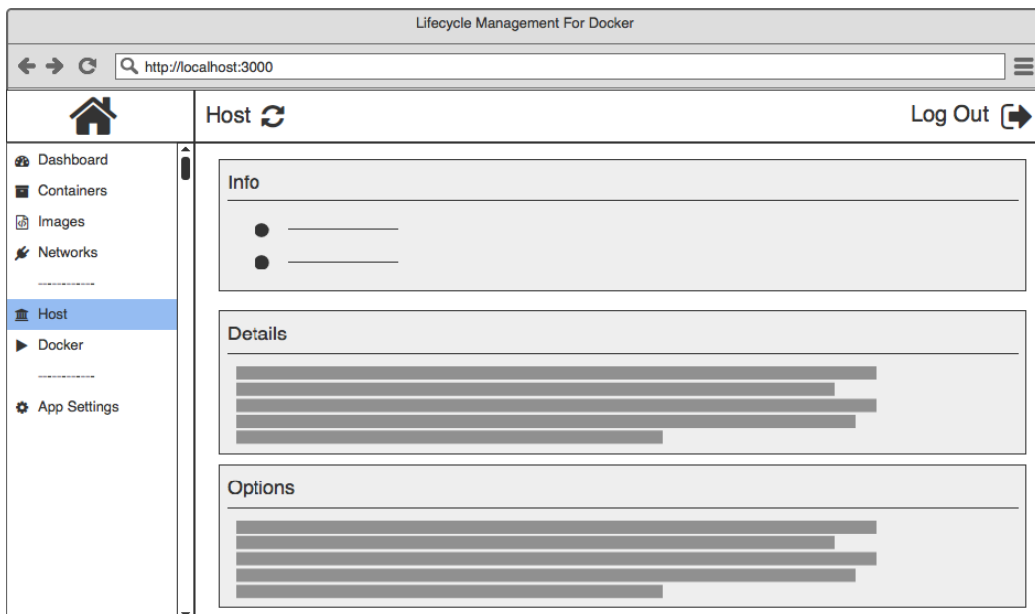


Figure 28: *Host Mockup*

## Bibliography

- Agile Methodology (2016), ‘The Agile Movement’. [online] Accessed: 27/11/2016.  
**URL:** <http://agilemethodology.org/>
- AngularJs (2017), ‘What is angularjs?’. [online] Accessed: 10-03-2017.  
**URL:** <https://docs.angularjs.org/guide/introduction>
- Atlassian (2016), ‘Jira Software’. [online] Accessed: 27/11/2016.  
**URL:** <https://www.atlassian.com/software/jira>
- Docker (2016), ‘What is Docker’. [online] Accessed: 27/11/2016.  
**URL:** <https://www.docker.com/what-docker>
- Docker (2017a), ‘Docker overview’. [online] Accessed: 08/03/2017].  
**URL:** <https://docs.docker.com/engine/understanding-docker/>
- Docker (2017b), ‘Swarm mode key concepts’. [online] Accessed: 19-03-2017.  
**URL:** <https://docs.docker.com/engine/swarm/key-concepts/>
- Driessen, V. (2017), ‘A successful git branching model’. [online] Accessed: 27-03-2017.  
**URL:** <http://nvie.com/posts/a-successful-git-branching-model/>
- Fowler, M. (2006), ‘Continuous Integration’. [online] Accessed: 27/11/2016.  
**URL:** <http://martinfowler.com/articles/continuousIntegration.html>
- Griffin, L., Ryan, K., de Leastar, E. and Botvich, D. (2011), ‘Scaling instant messaging communication services: A comparison of blocking and non-blocking techniques’. [online] Accessed: 10-03-2017.  
**URL:** <http://repository.wit.ie/1636/>
- Kubernetes (2017), ‘What is kubernetes?’. [online] Accessed: 19-03-2017.  
**URL:** <https://kubernetes.io/docs/concepts/overview/what-is-kubernetes/>
- Nodejs.org (2016), ‘Node.js’. [online] Accessed: 27/11/2016.  
**URL:** <https://nodejs.org/en/>
- SonarQube (2016), ‘SonarQube’. [online] Accessed: 27/11/2016.  
**URL:** <http://www.sonarqube.org/>
- STF.com (2017a), ‘Acceptance testing fundamentals’. [online] Accessed: 27-03-2017.  
**URL:** <http://softwaretestingfundamentals.com/acceptance-testing/>
- STF.com (2017b), ‘Integration testing fundamentals’. [online] Accessed: 27-03-2017.  
**URL:** <http://softwaretestingfundamentals.com/integration-testing/>
- STF.com (2017c), ‘System testing fundamentals’. [online] Accessed: 27-03-2017.  
**URL:** <http://softwaretestingfundamentals.com/system-testing/>
- STF.com (2017d), ‘Unit testing fundamentals’. [online] Accessed: 27-03-2017.  
**URL:** <http://softwaretestingfundamentals.com/unit-testing/>
- Swagger.io (2017), ‘Swagger ui’. [online] Accessed: 28-03-2017.  
**URL:** <http://swagger.io/swagger-ui/>

The Latex Project (2017), ‘An introduction to latex’. [online] Accessed: 28-03-2017.

**URL:** <https://www.latex-project.org/about/>

Tilkov, S. and Vinoski, S. (2010), ‘Node.js: Using javascript to build high-performance network programs’, *IEEE Internet Computing* **14**(6), 80–83.

Vagrant (2017), ‘Why vagrant?’. [online] Accessed: 10-03-2017.

**URL:** <https://www.vagrantup.com/docs/why-vagrant/>

Wiggins, A. (2017), ‘The twelve-factor app’. [online] Accessed: 28-03-2017.

**URL:** <https://12factor.net/>