



Lido for Polygon Smart Contracts Security Audit Report

March 10, 2022

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1 Executive Summary

This report consists of the audit results performed by [Oxorio team](#) on the Lido for Polygon project, at the request of the [Lido team](#). The audited code can be found in the public [Lido for Polygon Github Repository](#). Moreover, we used multiple versions to compose this report according to relevant commits. Versioning methodology is explained in the [Methodology](#) part.

The main goals of this audit are:

- to review Lido for Polygon's solidity implementation for its decentralized staking model,
- to study potential security vulnerabilities, its general design and architecture,
- to uncover errors and bugs that could compromise the software in production.

We make observations on specific areas of the code that present concrete problems, as well as general observations which could improve its quality as a whole.

1.1 Disclaimer

Note that as of the date of publishing, the contents of this document reflect the current understanding of investigated security patterns and the state of art regarding smart contract security. Given the size of the project, the findings detailed here are not to be considered exhaustive. Further testing and auditing are recommended after the covered issues would be fixed.

1.2 Methodology

On the methodology part, we do the following audit steps:

1. Manual code study

Manually code study to find out the errors and bugs.

2. Check the code against the list of known vulnerabilities

Verification process of the code against the constantly updated list of already known vulnerabilities maintained by the company.

3. Architecture and structure check of the security model

Study project documentation and its comparison against the code including the study of

the comments and other technical papers.

4. Result's cross-check by different auditors

Normally the research of the project is made by more than two auditors. After that, there is a step of the mutual cross-check process of audit results between different task performers.

5. Report consolidation

Consolidation of the audited report from multiple auditors.

6. Reaudit of new editions

After the client's review and fixes, the founded issues are being double-checked. The results are provided in the new audit version.

7. Audit report publication on the official website

The final audit version is provided to the client and also published on the official website of the company.

1.3 Structure of the Document

This report contains the list of issues and comments divided by version and also by their [severity](#) and [status](#) levels. Each issue is aligned with the code file that it is represented in for the readability of the report. For an easy way of navigation, a table of contents is provided at the beginning of the report.

1.4 Documentation

For this audit, the following sources of truth about how the Lido for Polygon smart contracts should work were used:

- main [GitHub repository](#) of the project
- [Almanac documentation](#) provided by the client.

These were considered the specification, and when discrepancies arose with the actual code behaviour, there were consultations directly with the Lido team.

1.5 About Oxorio

Oxorio is a young but rapidly growing audit and consulting company in the field of the blockchain industry, providing consulting and security audits for organizations from all over the world. Oxorio has participated in multiple blockchain projects where smart contract systems were designed and deployed by the company.

Oxorio is the creator, maintainer, and major contributor of several blockchain projects and employs more than 5 blockchain specialists to analyze and develop smart contracts.

Clients include Lido, among others.

More info at: oxor.io

2 Audit Scope

Audit includes 6 revisions which are presented in the following Table:

Table: Six Revisions

Revision №	Hash Commit	Date
Revision 1	05bff82670a76eb2ccf1c66d5cb242bbb375d40d [PR#33]	10/12/2021
Revision 2	431300f0ebcad04376c2a90609519eb2ba410b70	11/01/2022
Revision 3	0f50eebbc3d36a77d0b166963427c576fd5a3765 [PR#36]	18/01/2022
Revision 4	bda8645bff4916a12d21fff38df8379e036724fd [PR#42]	28/01/2022
Revision 5	511da0d53549e29145689f09a6666d3bd3c6c224 [PR#49]	04/02/2022
Revision 6	6e2ac6a5b93cecfcbd77f2a0c4e5021e30533741 [PR#56]	16/02/2022

Besides this, the next commits including pull requests with minor fixes were checked as well. No issues were found.

- [0b1ce58cce24cbc6d5b5ad48cde2c765ba2e544a](#) [PR#57]
- [F4e7f53ac6b3a38197f6153b3b3e1b23f4f074cd](#) [PR#58]
- [Ea33825882c188943d3f85b552e33322842406e2](#) [PR#59]
- [C383ab54802816d7a0ba516728d269c9028a35e4](#) [PR#60]
- [2f4d94b116ba4a160c1c007a8e3870c3ad8aba1e](#) [PR#61]
- [5be86d9700201397b2fcff13daaaf9549cfe0272](#) [PR#62]

3 Severity Level Reference

Every issue in this report was assigned a severity level from the following:

CRITICAL

Critical severity issues need to be fixed as soon as possible. Can result in loss of funds by the usage of the project's contract(s).

MAJOR

Bugs that can contribute to contracting failure or other major operational issues.

WARNING

High severity issues will probably bring problems and should be fixed. Can expose contracts to various attacks.

INFO

Low severity issues are minor details and warnings that can remain unfixed but would be better fixed at some point in the future.

4 Status Level Reference

Every issue in this report was assigned a status level from the following:

FIXED

This indicates that the issue was fixed by the client.

ACKNOWLEDGED

This indicates that the issue was acknowledged by the client.

DISMISSED

This indicates that the issue was dismissed by the client.

5 Revision 1: Findings

5.1 CRITICAL

5.1.1 Withdrawal of Less Matic Than Their stMatic Value

SEVERITY	CRITICAL
STATUS	FIXED

Description

Steps to reproduce the error:

1. User calls `requestWithdraw`
(`totalDelegated` > `currentAmount2WithdrawInMatic`) &&
(`amount2WithdrawFromValidator` < `totalAmount2WithdrawInMatic`)
If these conditions are true we are in the while loop [#L178](#) at least twice;
2. From the second and larger iterations, `token2WithdrawRequest[tokenId]` would be overwritten [#L224](#);
3. User waits and then calls `claimTokens`;
4. A user gets `amount2WithdrawFromValidator` only from the last iteration less than `stMatic` value.

Recommendation

To rewrite the logic so `token2WithdrawRequest[tokenId]` is not rewritten.

5.1.2 Delegation and Distribute Rewards with Decrease of totalBuffered

SEVERITY	CRITICAL
STATUS	FIXED

Description

Steps to reproduce the error:

1. User calls submit function, `totalBuffered` increases by `_amount`;

2. User calls the `delegate` function, and in the worst case, `totalBuffered` is not changed. In addition to that, the same error occurs in cases where only some tokens are not delegated. For example:
 - a user submits 1,000,000 MATIC
 - there are 10 validators
 - `maxDelegateLimit` is default, 10 MATIC
 - `reservedFunds` = 0
 - a. `availableAmountToDelegate` = 1000000 MATIC;
 - b. `maxDelegateLimitsSum` = 100;
 - c. `totalToDelegatedAmount` = 100;
 - d. `remainder` = 1000000 - 100 = 999900;
 - e. `totalBuffered` = 999900;
 - f. Matic balance of this contract is 999,900 MATIC;
3. User calls `requestWithdraw` function
 - a. (`totalDelegated` > `currentAmount2WithdrawInMatic`) we go in the while loop [#L178](#).
NOTE: there is a critical bug with `token2WithdrawRequest[tokenId]` in this while loop, it's ignored in this example;
 - b. `token2WithdrawRequest[tokenId]` is saved with `validatorAddress != address(0)` [#L224](#);
4. User waits and calls `claimTokens` function
 - a. We are inside if statement on [#L347](#), `totalBuffered` is not changed, but MATIC sent to the user [#L371](#). So Matic balance of this contract is 0, but `totalBuffered` = 999900;
 - b. `totalBuffered` is invalid now, it's more than the MATIC balance of the contract. And it can be overwritten only in the `delegate` function;
5. `delegate` function is called:
 - a. require (`totalBuffered` > `delegationLowerBound`) false [#L256](#)
`availableAmountToDelegate` incorrect, > MATIC balance of this contract (`availableAmountToDelegate`=990000, balance is 0) [#L268](#) `totalToDelegatedAmount` = `availableAmountToDelegate` most of the times (`totalToDelegatedAmount`=990000) [#L276](#);
 - b. `stakeManager` gets the approve;
 - c. `amountToDelegatePerOperator` is incorrect. It is greater than needed;
 - a. `maxDelegateLimit` by default is 10 MATIC, recall that in our example there are 10 validators `amountToDelegatePerOperator` = 10 * 990k / 10 * 10 = 99k;
 - b. In our example any `amountToDelegatePerOperator` > 0 will lead to revert;
 - c. In a general case any (`totalBuffered` - `reservedFunds`) > balance of MATIC will lead to a revert;
 - d. `buyVoucher` transfers too many MATIC and reverts when this contract's balance of MATIC is insufficient (`buyVoucher` -> `ValidatorShare.buyVoucher` -> `stakeManager.delegationDeposit` -> `token.transferFrom`).

Results:

- `delegate` is locked

- `distributeRewards` is locked - overflow at [#L389](#).

Recommendation

To rewrite the logic so `totalBuffered` is always in sync with the real buffered value.

5.1.3 Function Lock due to Validator's Slash

SEVERITY	CRITICAL
STATUS	FIXED

Description

Validator's slash between `requestWithdraw` and `claimTokens` calls leads to the function lock.
Steps to reproduce the error:

1. User calls `requestWithdraw(Y)`
 - a. We calculate `allowedAmount2Withdraw = X` based on `Y` value and save it in a `token2WithdrawRequest[tokenId].amountToClaim`;
2. Validator was slashed [contracts/staking/validatorShare/ValidatorShare.sol #L195](#)
 - a. In slash method `withdrawPool` value is decreased;
3. User calls `claimTokens`
 - a. `unstakeClaimTokens_new` is called [#L348](#);
 - b. The calculated amount in `ValidatorShare._unstakeClaimTokens` (L304) would be lower than the original amount `X`, saved at step 1.a because `withdrawPool` was decreased due to slashing;
 - c. `LidoMatic` contract receives less than `X` tokens.
4. `LidoMatic` tries to transfer `X` tokens, which may fail, the contract may not have enough balance [#L371](#);
5. If it does not fail the user receives funds that s/he should not have;
6. `totalDelegated` value is out of sync [#L353](#) with the contract balance now, it might be more than the contract's balance
 - a. `delegate` function will fail, incorrect calculations of `availableAmountToDelegate` at [#L268](#) will lead to reverts on `buyVoucher` call or tokens that is not supposed to be;
 - b. `totalPooledMatic` is incorrect [#L138](#) => `amountToMint` incorrect => submitter receives less than he should;
 - c. `distributeRewards` will fail or too many rewards will be distributed.

Recommendation

To rewrite the logic so slashing is handled appropriately.

5.1.4 Incorrect Usage of approvalExists Mapping

SEVERITY	CRITICAL
STATUS	FIXED

Description

[#L58](#)

`approvalExists` mapping should use `tokenId` as a keys, but now it uses array indexes which leads to incorrect contract behavior and transaction reverts during approvals.

Recommendation

To use `tokenId` as key for `approvalExists` mapping.

5.2 WARNING

5.2.1 Division by Zero if maxDelegateLimit is Zero

SEVERITY	WARNING
STATUS	FIXED

Description

If all operators have zero `maxDelegateLimit` then `maxDelegateLimitsSum` would be zero ([LidoMatic.sol#L273](#)). This leads to division by zero at [LidoMatic.sol#L290](#).

Recommendation

Make sure `maxDelegateLimit` is never equal zero for all operators or make a check before division.

5.2.2 Possible Overflow if maxDelegateLimit is Too Large

SEVERITY	WARNING
STATUS	FIXED

Description

[#L288](#)

If `operatorShares[i].maxDelegateLimit` set too high an overflow is possible. For example, errors can happen when there is no limit.

Recommendation

To make sure `maxDelegateLimit` is never too high. A check in `nodeOperator.setMaxDelegateLimit` could be added.

5.2.3 Possible Denial of Service if the Number of Operators is Too High

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

LidoMatic uses a lot of loops through operator shares. If the number of operators would be significant it can potentially lead to out of gas errors.

Recommendation

To decrease the number of loops and optimize gas consumption or limit the possible number of operators.

5.2.4 Potential Reentrancy Attack

SEVERITY	WARNING
STATUS	FIXED

Description

[#L371](#)

State is changed after an external call. It can lead to potential reentrancy attacks.

Recommendation

To use Checks Effects Interactions pattern to prevent possible reentrancy attacks. It's better to place external calls after state modification at [L373](#) to prevent reentrancy in the future. (Verification is in line [L337](#))

5.2.5 Empty Slots in operatorShares Array.

SEVERITY	WARNING
STATUS	FIXED

Description

[#L942](#)

The resulting array `operatorShares` will contain empty slots if some operators have non `STAKED` status. It may lead to bugs in further usage of this function in external contracts. For example `LidoMatic` doesn't checks `operatorShares` for empty values when calling `nodeOperator.getOperatorShares()`.

Recommendation

To use an extra counter for filling `operatorShares` array without empty slots.

5.2.6 index Variable is Unused

SEVERITY	WARNING
STATUS	FIXED

Description

[#L991](#)

`index` is only incremented but not used. Should be used at line [L985](#).

Recommendation

To use the index counter while filling an array of `rewardAddresses`.

5.2.7 Auth Modifier is a Copy of AccessControlUpgradeable.onlyRole

SEVERITY	WARNING
STATUS	FIXED

Description

Functional auth modifier copies `onlyRole` inherited from OpenZeppelin's `AccessControlUpgradeable` contract.

Recommendation

To remove the auth modifier and use `onlyRole` from OpenZeppelin.

5.2.8 Subtraction with Overflow

SEVERITY	WARNING
STATUS	FIXED

Description

[#L372](#)

The only place where `totalTimesValidatorsSlashed` is updated is subtraction. This will lead to overflow and empty revert messages.

Recommendation

To redesign `totalTimesValidatorsSlashed` usage.

5.2.9 Usage of `_mint` instead of `_safeMint`

SEVERITY	WARNING
STATUS	DISMISSED

Description

[#L44](#)

Usage of `_mint` instead of `_safeMint`.

According to OpenZeppelin's documentation usage of `_mint` method is discouraged, `_safeMint` should be used whenever possible.

Recommendation

To use `_safeMint` instead of `_mint`.

5.2.10 Contract Without Constructor

SEVERITY	WARNING
STATUS	DISMISSED

Description

[#L7](#)

Contract has no constructor. There is no way the `state` variable would be initialized. It is used in `isOperator` modifier and is required for all methods that update state. No contract that inherits `Validator.sol` found and it's unclear how it will work.

Recommendation

To initialize `state` variable properly.

5.3 INFO

5.3.1 Multiple Initialization Problem

SEVERITY	INFO
STATUS	FIXED

Description

[#L94](#)


```
__ERC20_init("Staked MATIC", "StMATIC");
```

Recommendation

To use `***_init_unchained` functions for initialization as [suggested](#) by OpenZeppelin.

5.3.2 Missing notPaused Modifier

SEVERITY	INFO
STATUS	FIXED

Description

Missing `notPaused` modifier (`isStoped` in docs) in the majority of functions, except `requestWithdraw`.

Recommendation

To add `notPaused` modifier if needed.

5.3.3 Incorrect Functions Visibility

SEVERITY	INFO
STATUS	FIXED

Description

Examples: [#L650](#) and [#L591](#)

Recommendation

Functions that are not used inside the contract should be declared as external to explicitly show that it's not used inside the contract. Moreover, this will optimize gas consumption in some cases.

5.3.4 Commented Code

SEVERITY	INFO
STATUS	FIXED

Description

Example in [#L42](#).

Recommendation

The best practice is to remove all commented code.

5.3.5 No Tight Variable Packing in FeeDistribution Struct

SEVERITY	INFO
STATUS	FIXED

Description

[#L65](#)

Tight packing can be applied to a struct [FeeDistribution](#) - now it uses uint256 for its members, but the maximum value for them is only 100 because it's a percentage value. See [tight variable packing pattern](#).

Recommendation

To use uint8 instead of uint256 for FeeDistribution members.

5.3.6 No Zero Address Checks in the Initializer

SEVERITY	INFO
STATUS	DISMISSED

Description

[#L97](#)

Potential brick of the contract in the initializer.

Recommendation

To add a check that addresses are not 0 to not accidentally brick the contract in the initializer, at least for DAO.

5.3.7 Contradiction with the Docs in Access Roles Distribution

SEVERITY	INFO
STATUS	FIXED

Description

In the [documentation](#) there is the following roles description
MANAGE_FEE: fee manager role (initially set to msg.sender)

...

SET_TREASURY: treasurer role (initially set to msg.sender)

GOVERNANCE: DAO role (initially set to msg.sender)

But in fact MANAGE_FEE and SET_TREASURY are set to _dao, GOVERNANCE is changed to DAO and set to _dao [#L99](#)

Recommendation

To update the docs or change the code accordingly.

5.3.8 Contradiction with the Docs in claimTokens Function

SEVERITY	INFO
STATUS	FIXED

Description

[#L338](#)

According to the documentation it should be:

`block.timestamp > userRequests.requestTime + stakeManager.withdrawalDelay()`

Recommendation

To update the docs or change the code accordingly.

5.3.9 Equality Instead of Subtraction

SEVERITY	INFO
STATUS	FIXED

Description

May use just == instead of subtraction and comparing with zero.

Recommendation

To replace to `if(currentAmount2WithdrawInMatic == amount2WithdrawFromValidator)` for code readability.

5.3.10 Unused Variable validator2Nonce

SEVERITY	INFO
STATUS	FIXED

Description

Unused variable in [#L47](#):

```
mapping(address => uint256) public validator2Nonce; // DELETE before deploying to production
```

Recommendation

To remove the unused variable.

5.3.11 Writing to the Storage in a Loop

SEVERITY	INFO
STATUS	FIXED

Description

[#L298](#) writing to storage in the loop.

Recommendation

To use a local variable in the loop to calculate the total `amountToDelegatePerOperator` value and use it after to update the storage only once. Writing to storage in most cases is a very expensive operation.

5.3.12 Missing Version Function

SEVERITY	INFO
STATUS	FIXED

Description

LidoMatic doesn't have a version function while contracts **NodeOperatorRegistry.sol**, **Validator.sol** and **ValidatorFactory.sol** have.

Recommendation

To add version function to LidoMatic contract.

5.3.13 Usage of array.length in Loops

SEVERITY	INFO
STATUS	FIXED

Description

Reading the length of a storage array costs more than reading a memory variable, e.g.:

[NodeOperatorRegistry.sol#L360](#)

[NodeOperatorRegistry.sol#L691](#)

[NodeOperatorRegistry.sol#L939](#)

Recommendation

To use `uint256 length = array.length;` in loop `for (uint i = 0; i < length; i++){}`

5.3.14 No Events Usage in LidoMatic Contract

SEVERITY	INFO
STATUS	FIXED

Description

LidoMatic doesn't emit any events.

Recommendation

To consider adding events for at least such important actions as pausing/unpausing contract or user interactions for better logging and monitoring.

5.3.15 Multiple Initialization Problem

SEVERITY	INFO
STATUS	FIXED

Description

[#L35](#)

Multiple initialization problem in the line.

Recommendation

To use `***_init_unchained` functions for initialization as [suggested](#) by OpenZeppelin.

5.3.16 Unnecessary Reads of tokenIdIndex Variable From the Storage

SEVERITY	INFO
STATUS	FIXED

Description

[#L43](#)

Unnecessary reads of tokenIdIndex variable from storage in the line.

Recommendation

To use local variable to prevent expensive reading from storage:

```
function mint(address _to) external isLido returns (uint256) {  
    uint256 newTokenIdIndex = ++tokenIdIndex;  
    _safeMint(_to, newTokenIdIndex);  
    return newTokenIdIndex;  
}
```

5.3.17 Redundant Storage Variable indexExists

SEVERITY	INFO
STATUS	FIXED

Description

[#L19](#)

Storage variable `indexExists` is never read and only written.

Recommendation

To remove `indexExists` variable if it's not used.

5.3.18 Implicit Usage of ERC721PausableUpgradeable Functional

SEVERITY	INFO
STATUS	FIXED

Description

[#L81](#)

Implicit usage of ERC721 [PausableUpgradeable](#) functional.

Recommendation

To inherit from ERC721PausableUpgradeable contract to use it's functional explicitly.

5.3.19 Duplicating Code of Resetting Approvals

SEVERITY	INFO
STATUS	FIXED

Description

[#L105](#)

Duplicating code of resetting approvals.

Recommendation

To move resetting approvals to a separate **method** and to use it in [approve](#) and [_beforeTokenTransfer](#) methods.

```
function _resetApprovals(uint256 tokenId, bool resetIndex) internal {
    uint256 approvedIndex = approved2Index[tokenId];
    if (approvalExists[approvedIndex]) {
        address lastApprovedAddress = getApproved(tokenId);
        uint256[] storage lastApprovedTokens = address2Approved[
            lastApprovedAddress
        ];

        delete lastApprovedTokens[approvedIndex];
        if (resetIndex) {
            approved2Index[tokenId] = 0;
            approvalExists[approvedIndex] = false;
        }
    }
}
```


5.3.20 Unnecessary Reads of approvedTokens Variable from Storage

SEVERITY	INFO
STATUS	FIXED

Description

[#L94](#)

`approvedTokens` is used only if approval exists, so it's better to move the declaration of `approvalExists` in this block.

Recommendation

To read `approvalExists` value from storage only if it's needed.

5.3.21 Missing Version Function

SEVERITY	INFO
STATUS	FIXED

Description

`LidoNFT` does not have a version function while contracts `NodeOperatorRegistry.sol`, `Validator.sol` and `ValidatorFactory.sol` have.

Recommendation

To add a version function.

5.3.22 Extra Calls of External “getPolygonERC20” Method

SEVERITY	INFO
STATUS	FIXED

Description

[#L214](#)

`operator.getPolygonERC20()` is called 3 times in a row in `unstakeClaim` function.

Recommendation

To save this external call result to a stack variable once and reuse it for gas saving.

5.3.23 Debug Import in Validator.sol

SEVERITY	INFO
STATUS	FIXED

Description

[Validator.sol#L7](#)

Import of hardhat/console.sol.

Recommendation

To remove debug import.

5.3.24 Mis-usage of Structure State

SEVERITY	INFO
STATUS	FIXED

Description

[#L24](#)

The reason why the structure `state` is used for storing the `operator` and `validatorImplementation` variables is not clear.

Recommendation

To store `operator` and `validatorImplementation` variables in the storage directly.

5.3.25 Debug Import in ValidatorFactory.sol

SEVERITY	INFO
STATUS	FIXED

Description

[ValidatorFactory.sol#L5](#)

Recommendation

To remove debug import.

5.3.26 isOwner modifier is a Copy of OwnableUpgradeable.onlyOwner

SEVERITY	INFO
STATUS	FIXED

Description

[#L44](#)

Functional of `isOwner` modifier copies `onlyOwner` inherited from OpenZeppelin's `OwnableUpgradeable` contract.

Recommendation

To remove the `isOwner` modifier and to use `onlyOwner` instead.

5.3.27 Unused SetValidatorImplementation Event.

SEVERITY	INFO
STATUS	FIXED

Description

[#L37](#)

Recommendation

To remove `SetValidatorImplementation` event or emit it.

5.3.28 Unused Storage Variable Operator.

SEVERITY	INFO
STATUS	FIXED

Description

[#L12](#) It is unclear how `operator` variable should be used. It is never read and only written to.

Recommendation

To store operator and validatorImplementation variables in the storage directly.

5.3.29 No Verification for whenNotPaused modifier

SEVERITY	INFO
STATUS	FIXED

Description

Functions `setOperatorName`, `setOperatorRewardAddress`, `setDefaultMaxDelegateLimit`, `setMaxDelegateLimit`, `setSlashingDelay` can be called when the contract is on pause.

Recommendation

To add `whenNotPaused` modifier if it is required.

5.3.30 No Checks for `_defaultMaxDelegateLimit` Argument

SEVERITY	INFO
STATUS	FIXED

Description

[#L643](#)
`_defaultMaxDelegateLimit` might be equal to zero.

Recommendation

To check at least that `_defaultMaxDelegateLimit` is not equal to zero.

5.3.31 No Checks for `_maxDelegateLimit` argument

SEVERITY	INFO
STATUS	FIXED

Description

[#L653](#)

Needs checks that variables are not equal to zero.

Recommendation

To check at least that `_maxDelegateLimit` is not equal to zero. Otherwise, it can lead to division by zero in [L273](#).

5.3.32 Redundant check `_amount > 0`

SEVERITY	INFO
STATUS	FIXED

Description

[#L441](#)

No need to verify that `_amount > 0` because it will be automatically applied by the usage of `checkStakeAmount` modifier.

Recommendation

To remove excess verification `require(_amount > 0, "Amount is ZERO");`.

5.3.33 Nonoptimal Gas Consumption in removeOperator Function

SEVERITY	INFO
STATUS	FIXED

Description

[#L343](#)

This line could be re-written in order to reduce gas consumption.

Recommendation

It might be better to place no.status to stack variable and use it, since using sload opcode twice consumes more gas than using it once and pushing value to stack for further usage

5.3.34 Nonoptimal Gas Consumption in withdrawRewards Function

SEVERITY	INFO
STATUS	FIXED

Description

[#L685](#)

Nonoptimal gas consumption.

Recommendation

It might be better to place [totalStakedNodeOperator](#) to a stack variable and use it since using SLOAD opcode twice consumes more gas than using it once and pushing the value to the stack for further usage.

5.3.35 Not Updated “slashed” Variable

SEVERITY	INFO
STATUS	FIXED

Description

[#L288](#)

The only place where `slashed` is updated is its initialization with 0. Later it is used in subtraction in line [#L372](#).

Recommendation

To redesign logic of `slashed` usage

5.3.36 Not Updated “`slashedTimestamp`” Variable

SEVERITY	INFO
STATUS	FIXED

Description

[#L289](#)

The only place where `slashedTimestamp` is updated is its initialization with 0.

Recommendation

To redesign the logic of `slashedTimestamp` usage.

5.3.37 Nonoptimal Gas Consumption in `getOperatorShares` function

SEVERITY	INFO
STATUS	FIXED

Description

[#L945](#)

Gas consumption might be reduced in this line.

Recommendation

It might be better to place `totalTimesValidatorsSlashed` to a stack variable and use it since using load opcode twice consumes more gas than using it once and pushing the value to stack for further usage.

5.3.38 Nonoptimal Gas Consumption in getOperatorRewardAddresses function

SEVERITY	INFO
STATUS	FIXED

Description

[#L988](#)

In the line gas consumption can be reduced.

Recommendation

It might be better to place [slashingDelay](#) to a stack variable and use it since using sload opcode twice consumes more gas than using it once and pushing the value to stack for further usage.

5.3.39 No Events Usage

SEVERITY	INFO
STATUS	DISMISSED

Description

LidoNFT doesn't emit any events.

Recommendation

To consider adding events for any important actions or user interactions for better logging and monitoring.

5.3.40 Inconsistent Naming of _newImplementation Variable

SEVERITY	INFO
STATUS	FIXED

Description

[#L20](#)

Recommendation

To rename `_newImplementation` to `_implementation`.

5.4 Revision 1 Summary

Issue Type	Number of Founded Issues
CRITICAL	4
MAJOR	0
WARNING	10
INFO	40
Total	55

6 Revision 2: Findings

6.1 CRITICAL

6.1.1 Possible Incorrect Contract State - “reservedFunds” Variable May Become Greater than “totalBuffered”

SEVERITY	CRITICAL
STATUS	NO ISSUE

Description

Using the issue from section 6.2.5 [allowedAmount2RequestFromValidators](#) will be changed by `minValidatorBalance`, which will be less than real. [StMATIC.sol#L157](#)

An attack example for `StMATIC.requestWithdraw`: there are 20 validators; all validators have minimal balance (10 Matic), `minValidatorBalance` manipulated to be 9:

- call `requestWithdraw(uint256 _amount)` with `_amount = 50` - `totalDelegated = 10*20 = 200`

- `totalBuffered = 0`

- first require right side = $10 + 9*20 = 190$, does not revert [StMATIC.sol#L150-L156](#)

```
require(
    (totalDelegated + totalBuffered) >=
        currentAmount2WithdrawInMatic +
            minValidatorBalance *
                operatorShares.length,
    "Too much to withdraw");
```

- `allowedAmount2RequestFromValidators = 200 - 180 = 20 - 30`
- 30 will be reserved even if there is not enough money on the contract.

Results:

1. `reservedFunds > totalBuffered`
2. `delegate` will revert on the first requirement for everyone, the claim will not work for this user

Using an attack above it is possible to manipulate `convertStMaticToMatic`, when `reservedFunds` set too big, `getTotalPooledMatic` will be less; Hence, balance in Matic will be bigger.

The attack example:

1. make `reservedFunds > totalBuffered`
2. `getTotalPooledMatic` will be < than it should

3. `convertStMaticToMatic` will return $>$ than it should

Results:

1. `requestWithdraw` will allow withdrawing more than it should
2. `submit` will return less than it should

Moreover, it might be used to front-run and block a whale withdrawal:

1. An attacker sees a whale withdrawal
2. Calls `requestWithdrawal` using this bug in that way that when the attacker calls `claimTokens` in will decrease `totalBuffered` to 0 but leaves some in `reservedFunds`
3. Wait for `stakeManager.epoch() == usersRequest.requestTime`
4. An attacker calls `claimTokens`
5. A whale call will revert because there are not enough buffered to withdraw

Recommendation

To fix logic related with `minValidatorBalance` parameter to avoid manipulations possibilities

6.2 MAJOR

6.2.1 Incorrect Contract State in Case of Slashed Validator Becomes Unstaked

SEVERITY	MAJOR
STATUS	FIXED

Description

Slash may lead to unstake of [StakeManager.sol#L703](#)

Moreover, polygon governance may `forceUnstake` [StakeManager.sol#L198](#)

Another option: `StakeManager.dethroneAndStake` is called [StakeManager.sol#L405](#)

These cases are not handled properly.

Results:

1. The operator will not be able to exit until DAO calls `stopOperator`. `NodeOperatorRegistry` still marks it as active, however, a call to `NodeOperatorRegistry.unstake` will revert because it calls `StakeManager.unstake` [StakeManager.sol#L417](#) that checks `deactivationEpoch` that is updated to non-zero value in `StakeManager_unstake` [StakeManager.sol#L1111](#)

2. Any call to `StMATIC.delegate` will fail because:

1. `NodeOperatorRegistry.getOperatorInfos` will return this operator as active => `StMATIC.delegate` will be called for this operator
2. `StMATIC.buyVoucher` for this operator will fail because
 1. It calls `ValidatorShare.buyVoucher` that calls `ValidatorShare_buyShares` [ValidatorShare.sol#L115](#) that has only `WhenUnlocked` modifier [ValidatorShare.sol#L374](#); lock is called in
 - `StakeManager_unstake` [StakeManager.sol#L1118](#) that is called in:
 - `StakeManager.forceUnstake` [StakeManager.sol#L198](#)
 - `StakeManager.slash` [StakeManager.sol#L703](#)
 - `StakeManager.dethroneAndStake` [StakeManager.sol#L405](#)
 - `StakeManager.unstake` [StakeManager.sol#L411](#)
 - `StakeManager_jail` that is called in `StakeManager.slash` [StakeManager.sol#L705](#)
3. `StMATIC.distributeRewards` will revert because an operator does not generate any rewards, and `stakeManager.withdrawRewards` has `require(rewards >= minAmount, "Too small rewards amount")`; [ValidatorShare.sol#L163](#)
4. In `StMATIC.requestWithdraw` `allowedAmount2RequestFromValidators` will be less (because `minValidatorBalance * operatorShares.length` counts the unstaked operator) In the worst case, for example when all validators has `minValidatorBalance + (minValidatorBalance / active operators count)`, it will be impossible to withdraw `minValidatorBalance` because of underflow in `allowedAmount2RequestFromValidators` calculation.

Recommendation

To handle a case when a validator slash leads to his/her unstake.

6.2.2 An Unstaked Operator may join

SEVERITY	MAJOR
STATUS	FIXED

Description

Call to `addOperator` [NodeOperatorRegistry.sol#L209](#) and `joinOperator` do not check if an operator has a stake. So an unstaked operator may be added. Or they can be unstaked after they are added.

Results:

The same as in the issue from section 6.2.1.

Recommendation

To add check that an operator has a stake.

6.2.3 Incorrect Contract State in Case of Validator without validatorShare joins

SEVERITY	MAJOR
STATUS	FIXED

Description

Steps:

1. DAO adds a node operator without `validatorShare`
2. The node operator's owner call join
3. `sm.getValidatorContract` will return 0, `no.validatorShare` will be 0 ([NodeOperatorRegistry.sol#L320](#))

Also StakeManager's governance can set validatorContract to a broken address ([StakeManager.sol#L268](#))

Results:

1. `stopOperator` will fail for this node operator on `IStMATIC(stMATIC).withdrawTotalDelegated(no.validatorShare);` ([NodeOperatorRegistry.sol#L267](#))
Because [StMATIC.sol#L415](#) will fail
2. `unstake` for the operator will fail for the same reason [NodeOperatorRegistry.sol#L477](#)
3. `validatorShare2OperatorId` will be incorrect, especially if 2 operators without `validatorShare` will join
It will break exit/wait stats (see `claimFee`)
4. `stMatic.requestWithdraw` will fail because it calls `getTotalStakeAcrossAllValidators` which calls `getTotalStake` which calls `_validatorShare.getTotalStake`. However, `_validatorShare` might have 0 addresses or not a `validatorShare` address.
`delegate`, `claimTokens`, `withdraw TotalDelegated`, `distributeRewards` and `getTotalStakeAcrossAllValidators` will also fail for similar reasons
5. `stMatic.claimTokens` won't work for the operator

This situation is unfixable without contracts redeployment.

Recommendation

To add a check that a joining validator has a `validatorShare` that `!= 0`. To handle a case when the Polygon government will set `validatorShare` for a broken address.

6.2.4 Reentrancy in NodeOperatorRegistry.migrate

SEVERITY	MAJOR
STATUS	FIXED

Description

If there are ≥ 2 `totalStoppedNodeOperator` including an attacking one and reward address of an attacker will transfer an NFT back and then reenter migrate in `onERC721Received` it's possible to get invalid state, `totalStoppedNodeOperator` too small and `totalWaitNodeOperator` too big

Note that reward address can be changed anytime by an operator in `setOperatorRewardAddress`

Results:

1. Invalid `getState` that is impossible to fix after the attack
2. Another stopped operator will not be able to migrate
3. Events may be in incorrect order which may lead to errors in 3rd parties

Recommendation

To use CEI pattern or `nonReentrant` modifier from OpenZeppelin's `ReentrancyGuard` or similar.

6.2.5 `minValidatorBalance` Variable May be Manipulated

SEVERITY	MAJOR
STATUS	FIXED

Description

[StMATIC.sol#L289](#)

```
(uint256 validatorShare, ) = IValidatorShare(
    operatorShares[i].validatorShare
```

```
).getTotalStake(operatorShares[i].validatorShare);
```

`getTotalStake` is called for the `validatorShare` itself. It should not have any balance because any tokens sent to it will be locked.

Because of that `minValidatorBalance` may be manipulated by sending validator shares to itself

Results:

1. `requestWithdraw` will fail (because `minValidatorBalance` is always `type(uint256).max`) until one of `validatorShare` contract has some balance
2. After the manipulation `requestWithdraw` allow to withdrawal a validator to almost 0, it's riskier (slashing takes a bigger part of stake) and may lock `distributeRewards` for a long time, see 'Call to `distributeRewards` will revert if any validator has < 1 Matic in rewards'
3. An attacker may lock withdrawals temporary for this example:
 1. `totalDelegated` + `totalBuffered` = 1kk
 2. there are 20 validators, each has 50k delegated to it

Steps for a griever:

1. From one `validatorShare` buy 500k of Matic
2. Send it to the `validatorShare` contract
3. `minValidatorBalance` will be 50k, because others are 0
4. `requestWithdraw`: $(\text{totalDelegated} + \text{totalBuffered}) \geq \text{currentAmount2WithdrawInMatic} + \text{minValidatorBalance} * \text{operatorShares.length}$
 - a. $(\text{totalDelegated} + \text{totalBuffered}) = 1\text{kk}$
 - b. $\text{currentAmount2WithdrawInMatic} = X$
 - c. $\text{minValidatorBalance} * \text{operatorShares.length} = 50\text{k} * 20 = 1\text{kk}$

Result:

all withdrawals are locked until someone sends any amount of shares to any other `validatorShare` contract.

Recommendation

To replace [StMATIC.sol#L289](#) with
`getTotalStake(IValidatorShare(operatorShares[i].validatorShare))`

6.2.6 A Slashed Validator May Lock delegate Method

SEVERITY	MAJOR
STATUS	FIXED

Description

When a validator gets slashed, it may become locked, so `StMATIC.buyVoucher` won't work (reverted because of `onlyWhenUnlocked` in `_buyShares`). [StakeManager.sol#L705](#)

[StakeManager.sol#L1046](#)

`NodeOperatorRegistry.slashOperators` does not account for that. So a malicious operator (or just a random one) may get slashed and paralyze delegation. In the case of a malicious operator, it can be fixed only by the DAO (which may take a lot of time depending on DAO implementation). And a slashed operator can't do anything, only unstake, unjail will not work because of `require(validators[validatorId].status == Status.Locked, "Not jailed");` [StakeManager.sol#L717](#)

Recommendation

To fix `NodeOperatorRegistry.unjail` function

6.2.7 A Node Operator Signer May Lock delegate Function

SEVERITY	MAJOR
STATUS	FIXED

Description

Node operator signer may call `StakeManager.updateValidatorDelegation` and set `validatorShare.delegation` to false - => `validatorShare._buyShares` will revert on first require - => `validatorShare.restake` and `validatorShare.buyVoucher` will revert - => `StMATIC.delegate` will stop working until DAO do stop

Recommendation

To add code to handle cases when delegation is set to false.

6.2.8 Revert of distributeRewards Function In Case Some Validator Has Less Than 1 Matic in Rewards

SEVERITY	MAJOR
STATUS	FIXED

Description

Call to `distributeRewards` will fail if some validator has less than 1 Matic in rewards. See [ValidatorShare.sol#L163](#) Because of that slashed operators may not get penalty because this function is always called after the penalty period has ended

Recommendation

To add handling of a case when an operator has < 1 Matic in rewards so `distributeRewards` won't fail and make sure it's called often enough. Possibly using a keeper.

6.2.9 A Slashed Operator may not Suffer any Reduction in Rewards

SEVERITY	MAJOR
STATUS	FIXED

Description

1. An operator gets slashed
2. `NodeOperatorRegistry.slashOperators` is called
3. `NodeOperatorRegistry.slashingDelay` has passed (~2.5h), `StMATIC.distributeRewards` is not called or reverts because of bug 'Call to `distributeRewards` will revert if any validator has < 1 Matic in rewards'.
4. `slashOperators` is called again, `no.slashedTimestamp` is set to 0
[NodeOperatorRegistry.sol#L1037](#)
5. `distributeRewards` is called, a slashed operator gets 100% of the rewards

Recommendation

To add handling of a case when an operator has < 1 Matic in rewards so `distributeRewards` won't fail and make sure it's called often enough. Possibly using a keeper.

6.3 WARNING

6.3.1 Impossibility of Restaking Rewards

SEVERITY	WARNING
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L455](#) `_stakeRewards` parameter for `IValidator(no.validatorProxy).restake` is always false

Recommendation

To replace `false` with `_restakeRewards`

6.3.2 Impossibility to Change Node Operator Status from “WAIT”

SEVERITY	WARNING
STATUS	FIXED

Description

Because `exitOperator` is never called, an operator with WAIT status will have this status forever. If there are too many operators with WAIT status `ValidatorFactory` will start to fail with 'out of gas' when `setValidatorImplementation/setOperator` is called.

Recommendation

To add a call to `exitOperator`

6.3.3 Failure of `unjail` Method in Case it is Called by an Unstaked but Unslashed Operator

SEVERITY	WARNING
STATUS	FIXED

Description

1. An operator calls `unstake`
2. An operator changes their mind and calls `unjail`
3. Call to `unjail` fails L520
`IValidator.unjail` calls `StakeManager.unjail` which has `require(validators[validatorId].status == Status.Locked, "Not jailed");`
`Status.Locked` may be set only in `_jail => slash`

Recommendation

To update the docs or fix the `unjail` function

6.3.4 Incorrect Return Value of getValidatorStake Method for msg.sender

SEVERITY	WARNING
STATUS	FIXED

Description

Because of typo, == instead of =, at [NodeOperatorRegistry.sol#L968](#) will return the balance of `address(0)` when `address(0)` is passed, not of `msg.sender`. It may lead to errors with 3rd parties.

Recommendation

To replace with single =.

6.3.5 A Slashed Operator Will Get Incorrect Share of Rewards

SEVERITY	WARNING
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L1090](#)

```
uint256 t = _slashedTimestamp - block.timestamp;
uint256 penalty = ((t / slashingDelay) + (t == slashingDelay ? 0 : 1)) *
    10;
```

`t / slashingDelay` is 0 starting from the next block after the slash because both `t` and `slashingDelay` are units and `t < slashingDelay`.

That means that `penalty = (0+1)*10=10` at the next block and `(1+0)*10=10` at the same block the operator was slashed. But according to docs, the penalty should be 20.

Recommendation

To add precision constant for calculation using integer division or update the docs

6.3.6 The Risk of getApprovedTokens Getting out of Sync with getApproved

SEVERITY	WARNING
STATUS	FIXED

Description

In PoLidoNFT, if a user transfers to themselves `_tokenApprovals[tokenId]` will be set to `address(0)`, but `address2Approved` will still contain the token. If someone will use `getApprovedTokens` as the source of truth they may think that they are approved, but they are not.

Recommendation

To handle a case when from `==` to in `PoLidoNFT._beforeTokenTransfer`

6.3.7 entityFees are not in Sync with Documentation

SEVERITY	WARNING
STATUS	FIXED

Description

Docs say: "90% gets restaked, 5% goes to the treasury, 5% ... among all active node operators."

But actually it's 2,5% to DAO, 2,5% to insurance and 5% to operators

`entityFees = FeeDistribution(25, 50, 25);` [StMATIC.sol#L105](#)

Recommendation

To update the docs or the code

6.3.8 Risk of Centralization

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

Centralization leads to a single point of failure. The initializer of [NodeOperatorRegistry](#) has all the rights to steal tokens from the contract. Or break the contracts.

The same goes for [StMATIC](#) and [ValidatorFactory](#) initializers.

Recommendation

To make sure it's a DAO or a multi-sig.

6.3.9 Possible Out of Gas if a lot of Operators Were Added and Removed

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

As times go by, validators are added and removed and the biggest operatorId may become so big that for-loop will run out of gas. [NodeOperatorRegistry.sol#L988](#)

Recommendation

To consider adding a way to request in bundles. Or rewrite in such a way that the [operators](#) array does not grow.

6.3.10 Potential No Penalties For Second Operator Slash

SEVERITY	WARNING
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L1029](#)

1. the first slash happens
2. `slashOperators` is called
3. `slashingDelay` has passed, `no.slashedTimestamp < block.timestamp`
4. no one has called `slashOperators`
5. some more time has passed
6. The second slash happens
7. `slashOperators` is called

Depending on how much time step 5 will take a slashed operator may not receive any penalties for the second slash because `no.slashedTimestamp + slashingDelay` may be in the past

Recommendation

To set `no.slashedTimestamp` to `block.timestamp + slashingDelay` if `no.slashedTimestamp` is in the past.

6.3.11 Possible to DOS `getApprovedTokens` and `getOwnedTokens`

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

1. `owner2Tokens[someAddress]` size is never decreased. It's possible to increase the gas cost a lot for contracts that call `getApprovedTokens` for a certain user by calling `approve` a lot of times with 'to' set to a victim address May effectively DOS any calls to that function for that user (in another contract)
2. `address2Approved[someAddress]` size is never decreased. If an attacker receives a lot of empty/cheap tokens in StMatic he/she can then send it all to a victim and it may cause DOS in another contract that will read `getOwnedTokens`.

Recommendation

To add information about it to the docs or rewrite that an array size is decreased

6.3.12 Potential Unexpected Delegation Ratios

SEVERITY	WARNING
STATUS	FIXED

Description

[StMATIC.sol#L269](#) Operators that were added earlier will get more in total than their ratio ($\text{maxDelegateLimit}/\text{maxDelegateLimitsSum}$) and operators with a high ratio that was added later will get less.

Recommendation

This behavior may be unexpected. A possible solution here would be to add that information to the docs or rewrite the logic.

6.3.13 Potential Too Many Rewards for Just Joined Operator

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

It may be significant depending on a period with which [StMATIC.distributeRewards](#) is called [StMATIC.sol#L349](#)

Recommendation

Make sure it's called often enough or don't add rewards for the first call to [distributeRewards](#) for new operators

6.3.14 Potential No Incentive to Call slashOperators Depending on Gas Cost

SEVERITY	WARNING
STATUS	FIXED

Description

Depending on the slash amount and gas cost, it may take a long time before it will make sense to call this function. Even for a system as a whole. E.g. calling it costs \$1000 and slash was \$300. There will be no motivation to call it even for a PoLido keeper. Any other operator has even less motivation because they get only a fraction of rewards from a slashed operator.

It's especially bad when a slash happens twice or more because only one slash will be recorded.

Recommendation

To consider rewriting the logic so no matter how often the function is called an operator will be slashed fairly.

6.4 INFO

6.4.1 "wait" Status Description is Wrong

SEVERITY	INFO
STATUS	FIXED

Description

Docs say WAIT: when the operator's owner claimed his tokens or migrated his NFT but the LidoMatic has not yet withdrawn the delegated Matics. In fact, the delegated Matics are withdrawn in [stopOperator](#). [NodeOperatorRegistry.sol#L477](#)

Recommendation

To update the docs

6.4.2 Unreachable Statement

SEVERITY	INFO
STATUS	FIXED

Description

Condition in if is unreachable [NodeOperatorRegistry.sol#L611](#)

```
if (validatorShare2OperatorId[no.validatorShare] != 0)
```

It can be changed to 0 in `exitOperator` but `exitOperator` is never called. And we can't get here after deleting in `else` because of status EXIT

Recommendation

To add call to `exitOperator`

6.4.3 StMATIC does not extend IStMATIC interface

SEVERITY	INFO
STATUS	FIXED

Description

`NodeOperatorRegistry` uses `IStMATIC` but `StMATIC` does not extend it.

Recommendation

To make `StMATIC` extend `IStMATIC`

6.4.4 User's claim Loss in Case of StakeManager.drainValidatorShares is Called by StakeManager Governance

SEVERITY	INFO
STATUS	FIXED

Description

1. User calls `StMATIC.requestWithdraw`
 2. `StakeManager.drainValidatorShares` is called
 3. User calls `StMATIC.claimTokens` and gets nothing
- The same goes for `withdrawTotalDelegated` & `claimTokens2StMatic`

Recommendation

To reflect it in the docs

6.4.5 Wrong Description for rewardAddress

SEVERITY	INFO
STATUS	FIXED

Description

/// @param `rewardAddress` Validator public key used for access control and receive rewards.
[NodeOperatorRegistry.sol#L34](#)

Recommendation

To update the description

6.4.6 Unspecified Unit for maxDelegateLimit Parameter

SEVERITY	INFO
STATUS	FIXED

Description

/// @param maxDelegateLimit max delegation limit that StMatic contract will delegate to this operator each time delegate function is called.

[NodeOperatorRegistry.sol#L43](#)

Recommendation

Consider adding units used

6.4.7 Inconsistent naming of rewardAddress and operatorOwners variables

SEVERITY	INFO
STATUS	FIXED

Description

rewardAddress and **operatorOwner** are the same entity, they are updated and cleared in sync. It will be much easier to read and understand the code if the terms would be the same [NodeOperatorRegistry.sol#L47](#), [NodeOperatorRegistry.sol#L121](#)

Recommendation

To consider renaming rewardAddress to operatorOwner or vice versa

6.4.8 Unconventional Modifier Name

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L164](#)

Usually modifiers revert if a checked condition is false, e.g. `userHasRole` will revert if the user does not have the role. `checkIfRewardAddressIsUsed` reverts if the condition is true which is a little bit misleading. It may also be unexpected that this modifier checks for zero address.

Recommendation

To consider renaming to `rewardAddressIsNotUsedNorZero/notUsedAsRewardAddressNorZero` or similar

6.4.9 The Usage of non-self-explaining Modifier Names

SEVERITY	INFO
STATUS	DISMISSED

Description

It's not clear what some modifiers will do until its code or its comment is read, e.g. `checkStakeAmount` [NodeOperatorRegistry.sol#L140](#), `checkHeimdallFees`, `checkMaxDelegationLimit`

Recommendation

Consider renaming `checkStakeAmount` to `stakeAmountIsInAllowedBounds` or similar, etc.

6.4.10 Missing Recommended Zero Address Checks in “initialize” Function and Setters

SEVERITY	INFO
STATUS	DISMISSED

Description

Zero address checks does not cost a lot of gas and may help in case of a mistake.

Recommendation

To consider adding zero address checks in initialize and setters

6.4.11 Non-use of “ether” Keyword for Units

SEVERITY	INFO
STATUS	DISMISSED

Description

It's best to replace magic numbers with constant/keyword for readability and clearness of intentions [NodeOperatorRegistry.sol#L187](#)

```
minAmountStake = 10 * 10**18;  
minHeimdallFees = 20 * 10**18;
```

Recommendation

To use ether instead of 10**18

6.4.12 The Usage of Magic Number Instead of Constant or Comment

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L189](#)

```
slashingDelay = 2**13;
```

Recommendation

It would be better to replace magic numbers with constant or units (hours, minutes) for readability and clearness of intentions or at least add a comment

6.4.13 Different Levels of Abstraction in the Same Function

SEVERITY	INFO
STATUS	DISMISSED

Description

It's best for readability to keep a function at the same level of abstraction.

- [NodeOperatorRegistry.sol#L317](#)

```
for (uint256 idx = 0; idx < operatorIds.length - 1; idx++) {  
    if (_operatorId == operatorIds[idx]) {  
        operatorIds[idx] = operatorIds[operatorIds.length - 1];  
        break;  
    }  
}  
operatorIds.pop();
```
- [NodeOperatorRegistry.sol#L356](#)

```
address(uint160(uint256(keccak256(no.signerPubkey))))),
```

Recommendation

To consider moving low-level “get address from pub key” and “remove from an array” to a separate functions

6.4.14 Non-Use of Constant for getOperator

SEVERITY	INFO
STATUS	DISMISSED

Description

In `getOperator(0)` it's not 100% clear why 0 is used.

Recommendation

It might be more clear to use a constant, e.g. `getOperator(OPERATOR_ID_FOR_MSG_SENDER)`

6.4.15 Typos

SEVERITY	INFO
STATUS	FIXED

Description

1. [NodeOperatorRegistry.sol#L468](#) - “quite” instead of “quit”

```
/// @dev when the operators's owner wants to quite the PoLido protocol he can call
```

2. [NodeOperatorRegistry.sol#L1013](#) - “slahed” instead of “slashed”

```
checkCondition(length == operatorIds.length, "slahed operators length");
```

Recommendation

To fix typos

6.4.16 An Operator's Exit without a Stop from DAO Leads to Unstaking and Losing a Slot

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L476](#)

It may be inconvenient for a validator to join if an exit costs them a slot.

Recommendation

To recheck that it's a desired logic or change it

6.4.17 Ambiguity in setCommissionRate natspec

SEVERITY	INFO
STATUS	DISMISSED

Description

/// @notice Allows to set the commission rate used.

[NodeOperatorRegistry.sol#L741](#)

It's not clear that the commission rate will only be used for new operators

Recommendation

To add a clarification that it will set a new commission rate only for new validators, old ones will keep an old commission rate

6.4.18 Unnecessary Storage Read

SEVERITY	INFO
STATUS	DISMISSED

Description

[NodeOperatorRegistry.sol#L1035](#)

You can save gas by reading from memory, slashedTimestamp

```
else if (  
    slashedTimestamp != 0 &&  
    no.slashedTimestamp < block.timestamp  
)
```

Recommendation

To replace `no.slashedTimestamp` with `slashedTimestamp`

6.4.19 Uninitialized Local Variables

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L1058](#), [NodeOperatorRegistry.sol#L884](#)

uint256 index;

[StMATIC.sol#L147](#)

unit256 allowedAmount2RequestFromValidators;

Recommendation

To explicitly set them to zero in order to improve code readability. To use slither to detect them.

6.4.20 checkCondition is Redundant

SEVERITY	INFO
STATUS	DISMISSED

Description

[NodeOperatorRegistry.sol#L1100](#). It will be easier to read code with `requires` than with `checkConditions`

Recommendation

To replace `checkCondition` with `require`

6.4.21 Missing Checks-Effects-Interactions pattern

SEVERITY	INFO
STATUS	DISMISSED

Description

It's a best practice to always use CEI. Several places don't use it. Not all of them lead to reentrancy now, but this may lead to in the future when some of your or polygon contracts are changed. It can be found with slither.

Recommendation

To consider always using CEI pattern

6.4.22 PoLidoNFT Does Not Extend IPoLidoNFT interface

SEVERITY	INFO
STATUS	FIXED

Description

PoLidoNFT does not extend IPoLidoNFT

Recommendation

Add IPoLidoNFT to parents of IPoLidoNFT

6.4.23 PoLidoNFT.tokenId2ApprovedIndex Does Not Include Ones From setApprovalForAll

SEVERITY	INFO
STATUS	FIXED

Description

It may be unexpected because there is no information about it in the documentation.

Recommendation

To add the information about this topic to the docs.

6.4.24 Non external visibility for PoLidoNFT.initialize, StMATIC.initialize and ValidatorFactory.initialize

SEVERITY	INFO
STATUS	FIXED

Description

To save gas and to explicitly show that it will not be called inside the contract

Recommendation

To set visibility to external

6.4.25 “_name” and “_symbol” Shadow Ones From ERC721Upgradeable

SEVERITY	INFO
STATUS	FIXED

Description

[PoLidoNFT.sol#L35](#) Best practice is to not shadow existing variables.

Recommendation

To rename shadow variables ‘name’ and ‘symbol’. To use slither to detect shadowing.

6.4.26 No Token Existence Checks in PoLidoNFT.burn function

SEVERITY	INFO
STATUS	FIXED

Description

[PoLidoNFT.sol#L67](#)

There are no checks that given tokenId exists. Right now it’s impossible to call it because of checks in StMATIC, but it may change in the future and it’s better to check arguments inside [burn function](#). Burning non-existing token will lead to [Minting](#) path inside [_beforeTokenTransfer](#).

Recommendation

To check that a [_tokenId](#) exists inside [burn](#)

6.4.27 Misleading Naming of “lastApprovedTokens” Variable

SEVERITY	INFO
STATUS	FIXED

Description

[PoLidoNFT.sol#L198](#)

Recommendation

To rename the variable to `approvedTokens`

6.4.28 Redundant Writing to storage of approvedTokens for address(0)

SEVERITY	INFO
STATUS	FIXED

Description

[PoLidoNFT.sol#L84](#)

You may save a little bit of gas by not writing for 0 address and it will also help to keep storage clean from unused data

Recommendation

To check for `address(0)` and do not write to storage for it

6.4.29 Potential Gaps and Incorrect Length of PoLidoNFT.getOwnedTokens and getApprovedTokens Arrays

SEVERITY	INFO
STATUS	DISMISSED

Description

Array that is returned from `getOwnedTokens/getApprovedTokens` may have gaps (0s), length

may be incorrect (e.g. when someone calls approve/removeApproval or burn a token)

Recommendation

To make sure it's accounted for in front-end and is described for 3rd parties. Or to rewrite in order to decrease the length of the arrays.

6.4.30 Non external visibility for PoLidoNFT.getOwnedTokens and getApprovedTokens functions

SEVERITY	INFO
STATUS	FIXED

Description

[PoLidoNFT.sol#L172](#), [PoLidoNFT.sol#L185](#)

To save gas and to explicitly show that it will not be called inside the PoLidoNFT those functions can be declared as external.

Recommendation

To declare these functions with external visibility

6.4.31 Misleading Naming of “requestTime” Variable

SEVERITY	INFO
STATUS	FIXED

Description

It stores epoch, not time.

[StMATIC.sol#L64](#)

Recommendation

To rename to `requestEpoch`

6.4.32 Misleading Naming of “nodeOperator” Variable

SEVERITY	INFO
STATUS	FIXED

Description

It stores node operator registry, not just an operator

[StMATIC.sol#L97](#)

Recommendation

To rename to `nodeOperatorRegistry`

6.4.33 Incorrect IStakeManager.withdrawRewards Return Type

SEVERITY	INFO
STATUS	FIXED

Description

[IStakeManager.sol#L57](#)

function withdrawRewards(uint256 validatorId) external returns (uint256);

[StakeManager.sol#L516](#)

```
function withdrawRewards(uint256 validatorId) public onlyStaker(validatorId) {
```

Recommendation

To remove returns (uint256)

6.4.34 DOS in Case of the Delegation is Disabled by Stakemanager

SEVERITY	INFO
STATUS	FIXED

Description

if `StakeManager.delegationEnabled` is false a user will be able to call `StMATIC.submit` but not withdraw and almost all the other functions (`restake`, `requestWithdraw`, `delegate`, `withdrawTotalDelegated`) will revert.

Recommendation

To make sure it's highly unlikely that `delegationEnabled` will be false. One more possible option is to add information to the docs

6.4.35 Redundant Variable “totalAmount2WithdrawInMatic”

SEVERITY	INFO
STATUS	FIXED

Description

[StMATIC.sol#L142](#)

```
uint256 totalAmount2WithdrawInMatic = convertStMaticToMatic(_amount);  
uint256 currentAmount2WithdrawInMatic = totalAmount2WithdrawInMatic;  
may be replaced with
```

```
uint256 currentAmount2WithdrawInMatic = convertStMaticToMatic(_amount);
```

Recommendation

To remove redundant intermedia variable.

6.4.36 Out of Gas Exception in StMATIC, ValidatorFactory in Case of too Many Validators are Added

SEVERITY	INFO
STATUS	DISMISSED

Description

It was discussed earlier that there should not be more than 20 however, there are no such limits in code.

Recommendation

To consider limiting validators in code

6.4.37 Magic Number for minValidatorBalance Calculation

SEVERITY	INFO
STATUS	DISMISSED

Description

[StMATIC.sol#L292](#)

It's not clear in the code why $*10/100$ is used. It may be replaced with $/10$. It may also be extracted to a variable or constant.

Recommendation

To replace the magic variable with a constant or a named variable

6.4.38 Unnecessary Multiplication by 1

SEVERITY	INFO
STATUS	FIXED

Description

[StMATIC.sol#L359](#)

Multiplication by 1 does not change anything.

Recommendation

To remove unnecessary operation

6.4.39 Unnecessary Complexity in Calculation

SEVERITY	INFO
STATUS	FIXED

Description

[StMATIC.sol#L400](#)

totalBuffered += (currentBalance - totalBuffered);
Might be replaced with totalBuffered = currentBalance

Recommendation

To remove unnecessary complexity.

6.4.40 Incorrect Term in natspec

SEVERITY	INFO
STATUS	FIXED

Description

[StMATIC.sol#L406](#)

* @notice Only NodeOperator can call this function

Recommendation

Replace [NodeOperator](#) with [NodeOperatorRegistry](#)

6.4.41 Nonoptimal Gas Usage in claimTokens2StMatic and claimTokens Functions

SEVERITY	INFO
STATUS	FIXED

Description

It won't be used anymore so it can be deleted.

[StMATIC.sol#L441](#), [StMATIC.sol#L310](#)

Recommendation

To delete lidoRequest/usersRequest at the end of claimTokens2StMatic/claimTokens function.

6.4.42 StMATIC.restake Function is Unused

SEVERITY	INFO
STATUS	FIXED

Description

[StMATIC.sol#L511](#)

Recommendation

To remove unused function

6.4.43 Unexpected Result for a User in Case of Withdrawn Value is Less than it was Requested

SEVERITY	INFO
STATUS	FIXED

Description

ValidatorShare.unstakeClaimTokens_new use the same variables for all withdrawals

[ValidatorShare.sol#L87](#)

function withdrawExchangeRate() **public** view returns (uint256) {

```
...
    return _withdrawShares == 0 ? precision :
withdrawPool.mul(precision).div(_withdrawShares);
}
```

[ValidatorShare.sol#L305](#)

withdrawShares = withdrawShares.sub(shares);

withdrawPool = withdrawPool.sub(_amount);

Thus, if a user requests a withdrawal, then a slash happens, then someone else requests a withdrawal a user will receive less than he/she requested

Recommendation

To add that information to the docs

6.4.44 Comments Without Meaning

SEVERITY	INFO
STATUS	FIXED

Description

[Validator.sol#L123](#)

// stakeManager

[Validator.sol#L181](#)

// polygonERC20

// stakeManager

Recommendation

To remove useless comments.

6.4.45 Non-Needed Approval

SEVERITY	INFO
STATUS	FIXED

Description

Approval is not used and is cleared by calling `safeTransferFrom`

[Validator.sol#L257](#)

```
erc721.approve(_rewardAddress, _validatorId);  
erc721.safeTransferFrom(address(this), _rewardAddress, _validatorId);
```

Recommendation

To remove `erc721.approve(_rewardAddress, _validatorId);`

6.4.46 Lack of Information Regarding the Obligatory Implementation of EIRC721Receiver for rewardAddress Contract in Case of Migration

SEVERITY	INFO
STATUS	ACKNOWLEDGED

Description

`safeTransferFrom` will fail if `_rewardAddress` is not IERC721Receiver.

```
erc721.safeTransferFrom(address(this), _rewardAddress, _validatorId);
```

[Validator.sol#L258](#)

Recommendation

To add that information to the docs

6.4.47 Misleading Use of onERC721Received

SEVERITY	INFO
STATUS	DISMISSED

Description

[Validator.sol#L287](#) onERC721Received should be removed because [Validator.sol](#) doesn't know how to handle other NFTs and you don't want them to be sent to the contract. Someone may accidentally call [safeTransferFrom](#) function with the parameter [to](#) equal to this contract address, and an NFT will be stuck. It will also help to save on deployment cost.

[Validator.sol#L276](#) After that replace [safeTransferFrom](#) with [transferFrom](#) in `erc721.safeTransferFrom(_rewardAddress, address(this), _validatorId);`

Recommendation

To remove onERC721Received and use transferFrom

6.4.48 Redundant require Statement

SEVERITY	INFO
STATUS	FIXED

Description

No need for this check because isOperator modifier implicitly checks it and this error will never be triggered

```
require(operator != address(0), "Operator contract not set");
```

[ValidatorFactory.sol#L41](#)

Recommendation

To remove redundant require

6.4.49 Usage of += Operator instead of =

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L418](#)

```
no.amountStaked += _amount;
```

An operator can call stake only after [addOperator](#) is called where [amountStaked](#) is set to 0

Recommendation

To replace += with =

6.4.50 Non-Use of Events for Critical Setters

SEVERITY	INFO
STATUS	FIXED

Description

E.g. [NodeOperatorRegistry.setRestake](#), [setUnjail](#), [setStMATIC](#), [setValidatorFactory](#), etc.

Recommendation

To add events for critical setters so your user and you can track those changes

6.4.51 No Verification for Zero Amount in Function Input

SEVERITY	INFO
STATUS	FIXED

Description

At the line [StMATIC.sol#L137](#) function `requestWithdraw(uint256)` has `_amount` argument which has no verification for not being zero. If it's zero, the function will be executed for no reason

Recommendation

To verify that `_amount` argument is not zero

6.4.52 Unnecessary State Write

SEVERITY	INFO
STATUS	FIXED

Description

At the line [StMATIC.sol#L420](#) if there is no amount to be withdrawn, the function still mints `poLidoNFT` and consumes gas.

Recommendation

To replace `return` with `revert`.

6.4.53 Usage of array.length in Loops

SEVERITY	INFO
STATUS	FIXED

Description

At the lines: - [StMATIC.sol#L250](#) - [StMATIC.sol#L288](#) - [StMATIC.sol#L353](#) - [StMATIC.sol#L380](#) - [StMATIC.sol#L386](#) - [StMATIC.sol#L586](#)

loops use `array.length` as high bound, which consumes more gas than it's separation to variable and using this variable

Recommendation

To create a stack variable to store an `array.length` value and use it as a loop bound.

6.4.54 Multiple Consecutive Calls

SEVERITY	INFO
STATUS	FIXED

Description

Starting at the line [Validator.sol#L64](#) there are 3-4 consecutive calls to [stakeManager](#).

Recommendation

To save gas, we would recommend changing/expanding the interface of [IStakeManager](#) by adding a method that aggregates the functionality of these 3-4 methods.

6.4.55 The Difference of totalPooledMatic Formula in Different Parts of Docs

SEVERITY	INFO
STATUS	FIXED

Description

[Lido for Polygon Architecture Docs](#)
[StMATIC Docs](#)

Recommendation

To update the docs

6.5 Revision 2 Summary

Issue Type	Number of Founded Issues
CRITICAL	0
MAJOR	9
WARNING	14
INFO	55
Total	78

7 Revision 3: Findings

7.1 WARNING

7.1.1 Possible Front-Run of setStMATIC, setFxRootTunnel, setFxChildTunnel

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

setStMATIC is not protected, anyone can call it. It's possible to front-run a deployer. This will require redeployment because it will lead to DoS of **StMatic**. It's better to set **stMATIC** in the constructor.

[FxStateRootTunnel.sol#L21](#)

Because there is no zero address check it's possible to set **stMatic** to **address(0)** by mistake which will also allow an attacker to DoS **StMatic**. Moreover, **setFxRootTunnel** and **setFxChildTunnel** are not protected from the same attack.

Recommendation

To set **stMATIC** in the constructor. Consider calling **setFxRootTunnel**, **setFxChildTunnel** in the constructor.

7.2 INFO

7.2.1 The Rule Of FxStateChildTunnel.getReserves Consideration

SEVERITY	INFO
STATUS	ACKNOWLEDGED

Description

It should be kept in mind that **StMatic** may become out of sync with data sent via fx-portal and it's quite easy to manipulate that by depositing/withdrawing funds. Also adding/removing a validator,

changing its state, slashing, calling [distributeRewards](#), etc. will change balances but will not trigger events and leads to out-of-sync data.

Recommendation

To add a note in the documentation that [FxStateChildTunnel.getReserves](#) shouldn't be considered as a reliable source of data.

7.2.2 Unnecessary Use of Assembly

SEVERITY	INFO
STATUS	DISMISSED

Description

Assembly significantly decreases code readability. It's error-prone and it's better to avoid it when possible.

[FxStateChildTunnel.sol#L34](#)

Recommendation

To use [abi.decode\(latestData, \(uint256, uint256\)\)](#).

7.2.3 Commented Code

SEVERITY	INFO
STATUS	FIXED

Description

[FxStateChildTunnel.sol#L41](#)

Unused code should be removed because it decreases readability.

Recommendation

To remove commented code.

7.2.4 The Option of Copy-Paste Code Replacement With npm Package

SEVERITY	INFO
STATUS	DISMISSED

Description

Contracts added to lib and tunnel directories may be imported from [@maticnetwork/fx-portal](https://www.npmjs.com/package/@maticnetwork/fx-portal) package. It will be more readable for end-users and auditors because they will not have to verify that you have not changed the copied contracts. It will also help to separate your code from the external one.

Recommendation

To remove copy-pasted contracts and use ones from npm package.

7.2.5 The Risk of Becoming Out-of-Sync by StMatic Between the Contracts

SEVERITY	INFO
STATUS	FIXED

Description

NodeOperatorRegistry and **PoLidoNFT** have **setStMatic** functions. **PoLidoNFT** and **FxStateRootTunnel** has **stMATIC** getters. That leads to several sources of truth. It may lead to some errors in 3rd parties.

FxStateRootTunnel doesn't allow to change **StMatic**, it means that it's necessary to redeploy **FxStateRootTunnel** contract every time **stMatic** is changed.

Recommendation

When updating **StMatic** make sure that the update of it's values is not forgotten at all 3 contracts or to rewrite them in order to have the single source of truth.

7.2.6 Immutable “stMatic” variable in FxStateRootTunnel Contract

SEVERITY	INFO
STATUS	FIXED

Description

Other contracts allow changing [stMatic](#) address by the setter. But [FxStateRootTunnel](#) is immutable and will have to be redeployed which costs more gas than a setter. It will also require redeploying [FxBaseChildTunnel](#). It will lead to state reset and stale data on old [FxBaseChildTunnel](#) which may lead to errors in 3rd parties.

Recommendation

To consider adding a setter and adding information above to the docs.

7.2.7 Non-Fixed Pragma Version

SEVERITY	INFO
STATUS	DISMISSED

Description

It is considered best practice to pick one compiler version and stick with it because different compilers have different bugs and peculiarities. [FxStateRootTunnel.sol#L2](#)
[FxStateChildTunnel.sol#L2](#)
pragma solidity ^0.8.0;

Recommendation

To use a fixed version as used in other contracts.
pragma solidity 0.8.7

7.2.8 Non-Use of IFxStateChildTunnel

SEVERITY	INFO
STATUS	DISMISSED

Description

IFxStateChildTunnel is not used.

Recommendation

To remove unused code.

7.3 Revision 3 Summary

Issue Type	Number of Founded Issues
CRITICAL	0
MAJOR	0
WARNING	1
INFO	8
Total	9

8 Revision 4 Findings

8.1 CRITICAL

8.1.1 Possible Incorrect Exchange Rate from stMatic to Matic

SEVERITY	CRITICAL
STATUS	FIXED

Description

It can be manipulated by a validator that becomes jailed deliberately. Or an attacker may wait for a validator to become jailed and front-run the transaction that will set the validator status to jailed.

Example: 2 validators, 100 Matic staked at each, 200 stMatic minted, 1 stMatic = 1 Matic

An attacker waits for a validator to be jailed

The attacker calls `submit(100)`, sent 100 Matic, gets 200 stMatic

An attacker waits for a validator to be unjailed

Attacker exchanges 200 stMatic for $200 \times \frac{3}{4} = 150$ matic

a. totalShares = 200

b. totalPooledMATIC = 100

c. exchange rate will become $100/200 \Rightarrow 2 \text{ stMatic} = 1 \text{ Matic}$

a. totalShares = 400

b. totalPooledMATIC = 300

c. exchange rate is $300/400 \Rightarrow 3 \text{ stMatic} = 4 \text{ matic}$ Results:

50 Matic profit for the attacker, loss for every other participant

a validator may use it to front-run a whale, so the whale withdrawal will return less Matic

`fxStateRootTunnel.sendMessageToChild` will send unexpected values

Recommendation

To rewrite the logic that calculates stMatic to Matic rate

8.1.2 Lock of Delegated Money in Case of an Operator is Unstaked During The Slash

SEVERITY	CRITICAL
STATUS	FIXED

Description

An operator may be unstaked during slash

[StakeManager.sol#L703](#)

```
if (validatorStakeSlashed == 0) { _unstake(validatorId, currentEpoch); }
```

Delegated money will be locked forever because:

[requestWithdraw](#) allows to withdraw only from [active](#) (inactive are filtered in [getOperatorInfos](#)), but it has status 'UNSTAKED'

[unstake](#) will also revert because of [getOperatorStatus\(no\) == NodeOperatorStatus.ACTIVE](#)

It will have status UNSTAKED forever, no way to change it

[stopOperator](#) will revert because of status \leq [NodeOperatorStatus.ACTIVE](#)

[unstake](#) will revert because of

[getOperatorStatus\(no\) == NodeOperatorStatus.ACTIVE](#)

[exitOperator](#) will never be called

=> because [claimTokens2StMatic](#) will never be called with [tokenId](#) for this operator

=> because [withdrawTotalDelegated](#) will never be called for this [validatorShare](#)

=> because [unstake](#) will revert

Almost the same goes for jailed, but jailed validator may call [unjail](#) and fix the issue. It gives him/her the ability to:

- manipulate [stMatic/Matic](#) exchange rate when he/she wants it.
- go to jail before a big withdrawal that will lower [totalDelegated](#) and the withdrawal will [revert](#)
- lock all the money delegated to him/her and then ask for a ransom

Recommendation

To rewrite the logic to make sure that the validator share of validators having JAILED or UNSTAKED status are stoppable and unstakable

8.1.3 No Operator May Join or Stake

SEVERITY	CRITICAL
STATUS	FIXED

Description

[joinOperator](#) has a check that an operator status is INACTIVE
[getOperator](#) returns a [nodeOperator](#) with validatorId set to 0 (set in addOperator)
[getOperatorStatus](#) will request [IStakeManager.Validator](#) with that [validatorId](#)
returned status will be incorrect, a validator with id 0 may have a status other than INACTIVE
[joinOperator](#) will revert
[NodeOperatorRegistry.sol#L304](#)
The same goes for stake

Recommendation

To rewrite the logic so the status of joining/staking operator does not depend on validator with ID 0.

8.1.4 Failure of “delegate” Function on a Second Call

SEVERITY	CRITICAL
STATUS	FIXED

Description

[StMATIC.sol#L283](#)
Not everything will be distributed after the first call, some approval will remain.
Because of that second call to [safeApprove](#) will fail

Recommendation

To call `safeApprove(address(stakeManager),0)` before calling
`safeApprove(address(stakeManager), totalToDelegatedAmount)`

8.2 MAJOR

8.2.1 No Incentive to Join for New Operators

SEVERITY	MAJOR
STATUS	DISMISSED

Description

Because of the [issue 8.3.2](#) below there will be less and less incentive for new validators to join because all the rewards will go to old ones.

Recommendation

To change `getOperatorInfos(true)` to `getOperatorInfos(false)`

8.3 WARNING

8.3.1 Unchangeable WAIT status

SEVERITY	WARNING
STATUS	FIXED

Description

WAIT status can only be changed in

`exitOperator`

`exitOperator` is called inside `claimTokens2StMatic`, which must be called after

`withdrawTotalDelegated`

Which is called by:

- `stopOperator`, that requires status **INACTIVE** or **ACTIVE**
- `unstake`, that requires status **ACTIVE**

Thus, the operator with **WAIT** status will always stay **WAIT**.

Recommendation

To rewrite the logic, so it's possible to change WAIT status.

8.3.2 Unfair Rewards Distribution for New Operators

SEVERITY	WARNING
STATUS	FIXED

Description

Validators with an already big stake (old ones) will have rewards > threshold more often

=> more often they will be returned by [getOperatorInfos](#)

=> more stake leads to more delegation, more delegation to more stake

=> early ones will become bigger and bigger while the new ones won't get as much

It especially dangerous because of If an operator was unstaked during slash delegated money will be locked forever

Recommendation

To change [getOperatorInfos\(true\)](#) to [getOperatorInfos\(false\)](#)

8.3.3 Potential Delegation Disablement using Front Running

SEVERITY	WARNING
STATUS	FIXED

Description

A griever can disable delegation by front-running calls to delegate and calling

[distributeRewards](#)

Or just call

[distributeRewards](#) often enough

Recommendation

To change [getOperatorInfos\(true\)](#) to [getOperatorInfos\(false\)](#)

8.3.4 Potential Overstepping of “maxDelegateLimitsSum” variable

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

[StMATIC.sol#L273](#)

Because of checks to

`if (validator.delegation())`

Prerequisites:

one of validators has delegation set to false

`maxDelegateLimitsSum <= availableAmountToDelegate`

`totalToDelegatedAmount = maxDelegateLimitsSum`

`amountToDelegatePerOperator` is less than required for full delegation

Result: not everything is delegated because denominator is bigger than it should be in

```
(operatorShares[i].maxDelegateLimit * totalToDelegatedAmount) / maxDelegateLimitsSum
```

Recommendation

To consider not adding `maxDelegateLimit` to `maxDelegateLimitsSum` for operators with delegation set to false.

8.3.5 Incorrect Contract State in case of the Polygon Government set validatorShare to a Invalid Address

SEVERITY	WARNING
STATUS	ACKNOWLEDGED

Description

See [issue 6.2.3](#) in the Revision 2 report. Also issues [6.3.1](#), [6.3.2](#), [6.3.4](#) and [6.3.5](#) is not fixed

Recommendation

To handle a case when the Polygon government will set validatorShare for a broken or zero address.

8.4 INFO

8.4.1 Non-plural “totalNodeOperator” Variable Naming

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L68](#)
uint256 private [totalNodeOperator](#);

Recommendation

To change to

[totalNodeOperators](#)

8.4.2 Misleading Status Calculation at Runtime for INACTIVE and UNSTAKED Statuses

SEVERITY	INFO
STATUS	DISMISSED

Description

When someone reads that code they expect that the status will be set to INACTIVE/UNSTAKED.

[NodeOperatorRegistry.sol#L204](#)

```
operators[operatorId] = NodeOperator({ status: NodeOperatorStatus.INACTIVE,
```

[NodeOperatorRegistry.sol#L438](#)

```
no.status = NodeOperatorStatus.UNSTAKED;
```

However, in fact, it will be ignored and will be calculated at runtime from [stakeManager](#) in [getOperatorStatus](#) .

Recommendation

To consider adding a status that shows that it will be calculated at runtime. E.g.
CALCULATE_AT_RUNTIME, REQUEST_FROM_STAKE_MANAGER

8.4.3 Commented Code

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L265](#)

```
// no.statusUpdatedTimestamp = block.timestamp;
```

Recommendation

To remove this commented code code.

8.4.4 Misleading Function Argument

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L398](#)

`_restakeRewards` argument in `restake` function is not used.

It may be **misleading** for a user, they will expect that `restakeRewards` will restake rewards as the natspec says.

Moreover, if it's called with 0 amount nothing will change in the state but user may expect that they have restaked.

Recommendation

To remove `_restakeRewards` argument

8.4.5 Incorrect NatSpec for unjail Function

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L464](#)

```
/// @dev when an operator is UNSTAKED the owner can switch back and stake the  
/// operator by calling the unjail func, in this case, the operator status is set  
/// to back ACTIVE.
```

Recommendation

To replace UNSTAKED with JAILED

8.4.6 Meaningless Variable Names

SEVERITY	INFO
STATUS	FIXED

Description

It would be better for readability to use full names

```
_op => nodeOperator, res => result, v => validator
```

[NodeOperatorRegistry.sol#L799](#)

```
length => operatorIdsLength
```

[NodeOperatorRegistry.sol#L901](#)

```
uint256 length = operatorIds.length;
```

Recommendation

To consider using meaningful variable names

8.4.7 Incongruity in the PR Description

SEVERITY	INFO
STATUS	DISMISSED

Description

You wrote in PR that “Handled by getting the current state of validator in functions [getOperatorInfos](#) and [getOperatorIds](#) directly from the [StakeManager](#).” However, in fact, [getOperatorIds](#) is returned from the contract storage.

Recommendation

To make sure that it's the expected behavior

8.4.8 Misleading Naming of getOperatorInfos Function

SEVERITY	INFO
STATUS	DISMISSED

Description

A user may expect that they will get info about all the operators, however, in fact, they get it only for active ones.

[_rewardData](#) may also be misleading because you don't expect it to filter ones without reward

Recommendation

To rename those functions to [getActiveOperatorInfos](#), [_ignoreOnesWithoutRewards](#) or similar

8.4.9 High Cyclomatic Complexity

SEVERITY	INFO
STATUS	DISMISSED

Description

High cyclomatic complexity decreases readability.
for->if->if->if is too deep
[NodeOperatorRegistry.sol#L967](#)

Recommendation

To consider splitting it into several functions

8.4.10 Typo “herimdall”

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L356](#)
/// @param _heimdallFee [herimdall](#) fees.

Recommendation

To replace [herimdall](#) with [heimdall](#)

8.4.11 Misleading Naming of operatorShares Variable

SEVERITY	INFO
STATUS	FIXED

Description

[operatorShares](#) should be renamed to
[operatorInfos](#)

[StMATIC.sol#L144](#)
[StMATIC.sol#L258](#)
[StMATIC.sol#L636](#)

[validatorShare](#) to

[stakedAmount](#)

[StMATIC.sol#L317](#)

RecommendationTo rename the variables

8.4.12 Unreachable Statement

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L548](#)

[validatorShare2OperatorId](#)[[no.validatorShare](#)] is never 0 here

It is set to 0:

after [exitOperator](#) is called

Impossible to call [claimFee](#) , status is set to EXIT

after [claimFee](#) is called

Impossible to call it again, status is set to EXIT

Recommendation

To remove unreachable statement

8.4.13 Debug Import

SEVERITY	INFO
STATUS	FIXED

Description

In Validator and [StakeManagerMock](#)

Recommendation

To remove debug import

8.5 Revision 4 Summary

Issue Type	Number of Founded Issues
CRITICAL	4
MAJOR	1
WARNING	5
INFO	13
Total	23

9 Revision 5: Findings

9.1 CRITICAL

9.1.1 Possible Funds Lock for Unstaked Operator

SEVERITY	CRITICAL
STATUS	FIXED

Description

An unstaked operator may call *claim* and then *claimFee* and get status 'EXIT'

Steps:

1. Evil operator calls unstake or is unstaked by the DAO
 - `StMatic.withdrawTotalDelegated` is called, funds are locked until `claimTokens2StMatic` is called, and we need to wait for a `withdrawalDelay` to call it
 - The operator becomes UNSTAKED
2. The operator waits for `withdrawalDelay`, and front-run call to `claimTokens2StMatic`
 - It may be very easy and cheap because `claimTokens2StMatic` is not probably called the same block the request epoch is reached
 - But even if it is the attacker may just overbid the call or use a private relayer
3. He/she calls `unstakeClaim`, becomes CLAIMED
4. He/she calls `claimFee`, becomes EXIT (WAIT is impossible because of '12. Unreachable statement' in last report)
5. `claimTokens2StMatic` fails inside a call to `nodeOperatorRegistry.exitOperator`
[StMATIC.sol#L498](#)
[NodeOperatorRegistry.sol#L261](#)

Result: Funds that were delegated to this operator are locked forever.

Recommendation

To add logic to handle this case.

9.1.2 Potential Non Return of Delegated Funds for Jailed Operators

SEVERITY	CRITICAL
STATUS	FIXED

Description

See the [issue from section 8.1.2](#)

`StMATIC.requestWithdraw` does not allow withdrawing from a jailed one

NodeOperatorRegistry.stopOperator does not allow to stop it and withdrawTotalDelegated
The status may be changed only by the validator by calling unjail
The attacker may lock the funds and ask for a ransom.

Recommendation

To allow withdrawing from a jailed validator

9.1.3 Potential Non Return of Delegated Funds for Ejected Operators

SEVERITY	CRITICAL
STATUS	FIXED

Description

The [issue from section 9.1.2](#) is relevant here as well.

StMATIC.requestWithdraw does not allow withdrawing from an ejected one

NodeOperatorRegistry.stopOperator does not allow to stop it and withdrawTotalDelegated

The status may be changed only by unstake, but because of 'An unstaked operator may lock funds delegated to it' it may not help

The attacker may lock the funds and ask for a ransom.

Recommendation

To allow withdrawing from an ejected validator, add logic to handle 'An unstaked operator may lock funds delegated to it'

9.2 MAJOR

9.2.1 Unexpected INACTIVE Status for Validator Whos is Jailed and Unstaked Same Time

SEVERITY	MAJOR
STATUS	FIXED

Description

A jailed operator may become unstaked.

It will lead to deactivationEpoch != 0 and to status INACTIVE

[NodeOperatorRegistry.sol#L849](#)

Results:

join will fail because of check poValidator.status == IStakeManager.Status.Active

[NodeOperatorRegistry.sol#L320](#)

stake will create a new validatorShare contract, so delegated funds will be lost

may only be stopped (stopOperator) by the DAO which will lead to loss of delegated funds

Recommendation

To handle a case when an operator is jailed and unstaked

9.3 WARNING

No warning issues were found

9.4 INFO

9.4.1 Missing punishment for Disabling Delegation

SEVERITY	INFO
STATUS	FIXED

Description

A validator may disable delegation, and it will not be punished for it, he/she will get the rewards for funds already delegated to him/her

Recommendation

To consider adding a punishment because it may lead to uneven delegation

9.4.2 Misleading Naming of “NodeOperator.statusUpdatedTimestamp” variable

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L835](#)

statusUpdatedTimestamp can not be updated for statuses that are calculated at runtime

Recommendation

To add that info to the docs or remove it if it's not used

9.4.3 Uneven Rewards Distribution Depending on Delegated Funds Value

SEVERITY	INFO
STATUS	DISMISSED

Description

Because of a filter in `getOperatorInfos(true, false, false)` most rewards will go to the validators that have most funds delegated to them which is not fair.

It's also possible to front-run `distributeRewards` just before the small one should receive rewards. And then just after that. Because of that small validator may receive almost nothing

Recommendation

To consider updating `distributeRewards` logic.

9.4.4 Ambiguous Term “Active”

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L971](#)

It is better when all used terms have an same meaning. `NodeOperatorStatus.ACTIVE` and `_allActive` parameter uses the same word “active” but in different meanings.

Recommendation

To consider using a separate term for ACTIVE, EJECTED, JAILED. E.g. `_allWithStake`

9.4.5 Flags in One Function Lower Readability

SEVERITY	INFO
STATUS	DISMISSED

Description

[NodeOperatorRegistry.sol#L974](#)

function `getOperatorInfos(bool _withdrawRewards, bool _delegation, bool _allActive`
Because of 3 flags a call to `getOperatorInfos` may look like

`getOperatorInfos(true, true, false)`. It would be more readable if it would use packed flags, e.g.
`getOperatorInfos(InfoFlags.WITHDRAW_REWARDS & InfoFlags.DELEGATION)` (bitwise and).

Recommendation

To consider using packed flags or a struct

9.4.6 Incongruity of Flags and Filters

SEVERITY	INFO
STATUS	DISMISSED

Description

[NodeOperatorRegistry.sol#L974](#)

function `getOperatorInfos`(`bool` `_withdrawRewards`, `bool` `_delegation`, `bool` `_allActive`
It would be a little more readable if filters and flags were in the same order. I.e.

```
if (_withdrawRewards) { come first
```

inside the for loop or
`_withdrawRewards` flag is last.

Recommendation

To consider reordering the flags or the filters

9.4.7 Complex Conditional

SEVERITY	INFO
STATUS	DISMISSED

Description

[NodeOperatorRegistry.sol#L995](#)

It takes some time to understand a complex conditional:

```
if ( status != NodeOperatorStatus.ACTIVE && !(_allActive && (status ==  
NodeOperatorStatus.EJECTED || status == NodeOperatorStatus.JAILED)) ) continues;
```

By extracting conditional code to clearly named methods, you are able to reduce a cognitive load for the person who will be maintaining the code later.

Recommendation

To split if to several variables or to a function, remove negations where possible. E.g.

```
bool isActive = status == NodeOperatorStatus.ACTIVE; bool isEjectedOrJailed = status == NodeOperatorStatus.EJECTED || status == NodeOperatorStatus.JAILED; bool getActiveRejectedAndJailed = _allActive; bool hasExtendedStatus = getActiveRejectedAndJailed && isEjectedOrJailed; if (!isActive && !hasExtendedStatus) continue;
```

9.4.8 Unnecessary Nested ifs Statements

SEVERITY	INFO
STATUS	DISMISSED

Description

[NodeOperatorRegistry.sol#L1002](#)

```
if (_delegation) { if (!ValidatorShare(no.validatorShare).delegation()) continue; }
```

Recommendation

To place both checks in one if

9.4.9 Incorrect Term “operator” Instead of “operatorRegistry”

SEVERITY	INFO
STATUS	FIXED

Description

[Validator.sol#L26](#)

[Validator.sol#L30](#)

```
address private operator; ... modifier isOperator() {
```

[ValidatorFactory.sol#L21](#)

[ValidatorFactory.sol#L26](#)

```
/// @notice the node operator address. address public operator; ... /// @notice Check if the operator contract is the msg.sender. modifier isOperator() {
```

Recommendation

To rename to “[operatorRegistry](#)” and “[isOperatorRegistry](#)”

9.5 Revision 5 Summary

Issue Type	Number of Founded Issues
CRITICAL	3
MAJOR	1
WARNING	0
INFO	9
Total	13

10 Revision 6: Findings

10.1 CRITICAL

No critical issues were found

10.2 MAJOR

10.2.1 Unexpected INACTIVE Status for Validator Whos is Jailed and Unstaked Same Time

SEVERITY	MAJOR
STATUS	FIXED

Description

The same [issue 9.2.1](#) might be found in the Revision 5 report.

Recommendation

To see the same issue in the last report.

10.3 WARNING

10.3.1 Impossibility to Withdraw In Case of No Active Validators

SEVERITY	WARNING
STATUS	FIXED

Description

If there are no active validators `getMinValidatorBalance` will return `type(uint256).max` because `getOperatorInfos(false, false)` will return an empty array [StMATIC.sol#L707](#) .
And `requestWithdraw` function will revert because of overflow in [StMATIC.sol#L182](#)

Recommendation

To replace `getOperatorInfos(false, false)` in `getMinValidatorBalance` with `getOperatorInfos(false, true)`.
The same as in [requestWithdraw StMATIC.sol#L160](#)

10.3.2 “minValidatorBalance” Might Be Greater Than Expected

SEVERITY	WARNING
STATUS	FIXED

Description

minValidatorBalance is calculated for only active validators because of `getOperatorInfos(false, false)` [StMATIC.sol#L707 \(See the issue 1 above\)](#). While withdrawal in `requestWithdraw` happens for all staked validators - `getOperatorInfos(false, true)` [StMATIC.sol#L160](#). It may lead to the locking of some funds of **jailed/ejected** validators because 10% of the smallest active validator may be bigger than 100% of a **jailed/ejected** one. Until the DAO unstake or stops the validator, or it calls `unjail` in case of a jailed validator. Also, it may block withdrawing even so there are enough funds, e.g.:
There is 1 active validator with 100 Matic and 1 **jailed/ejected** with 10 Matic. A user requests 100 Matic. If both validators were active the function would allow to withdraw up to 99 from the first one and up to 9 from the last, 108 in sum. But in this case, only 90 Matic is allowed to withdraw.

Recommendation

To replace `getOperatorInfos(false, false)` in `getMinValidatorBalance` with `getOperatorInfos(false, true)`.
The same as in `requestWithdraw` [StMATIC.sol#L160](#)

10.4 INFO

10.4.1 Unused “WAIT” NodeOperator Status

SEVERITY	INFO
STATUS	FIXED

Description

It is used only in `getState` [NodeOperatorRegistry.sol#L903](#)

```
} else if (status == NodeOperatorStatus.WAIT) { _totalWaitNodeOperator++; }
```

However, this status is never assigned to an operator.

Recommendation

To remove unused WAIT status.

10.4.2 Duplicating Logic in “unstake” and “stopOperator” Functions

SEVERITY	INFO
STATUS	ACKNOWLEDGED

Description

[NodeOperatorRegistry.sol#L414](#)

[NodeOperatorRegistry.sol#L220](#)

They do almost the same if you allow stopping an ejected validator.

[unstake](#) allows an operator to [unstakeClaim](#) and [claimFee](#) after, while [stopOperator](#) allow migrating

Recommendation

To consider removing [unstake\(uint256 _operatorId\)](#) and allowing to stop an ejected operator in order to save gas and remove duplicated logic.

10.4.3 A Jailed or Ejected Operator will Still Keep minValidatorBalance of Funds

SEVERITY	INFO
STATUS	ACKNOWLEDGED

Description

An evil or an unfortunate validator that is ejected or jailed will have [minValidatorBalance](#) of funds locked on its [validatorShare](#) until a DAO stops or unstakes it.

Because every validator, even ejected and jailed, will keep [minValidatorBalance](#) ([StMATIC.sol#L215](#)) until the DAO stops or unstake it.

It will also lead to a little non-optimal distribution because funds are withdrawn in random order, with the same weight for active, ejected and jailed. Even so, active ones generate rewards, and it's better to keep them.

Recommendation

To consider rewriting the logic, so first, withdraw from ejected validators, then jailed ones and then active ones.

10.4.4 Strict Inequality in withdrawRewards Function

SEVERITY	INFO
STATUS	FIXED

Description

You use `>` in [StMATIC.sol#L383](#) while in [ValidatorShare.sol#L163](#) `>=` is used. Because of that even so [ValidatorShare](#) allows withdrawing when `rewards == rewardThreshold` you do not.

Recommendation

Replace

```
stMaticReward > rewardThreshold
```

with

```
stMaticReward >= rewardThreshold
```

10.4.5 Usage of Comparison for Checking NodeOperatorStatus enum Values

SEVERITY	INFO
STATUS	FIXED

Description

[NodeOperatorRegistry.sol#L228](#)
[NodeOperatorRegistry.sol#L566](#)
[NodeOperatorRegistry.sol#L593](#)

Despite enum values represented by compiler as `uint8` type it is recommended not to use comparison when checking enum values because it might lead to bugs if enum values would be reordered. Moreover it significantly decreases code readability.

Recommendation

To use explicit comparison for needed statuses, eg:

```
status == NodeOperatorStatus.ACTIVE || status == NodeOperatorStatus.INACTIVE
```

instead of

```
status <= NodeOperatorStatus.ACTIVE
```

10.5 Revision 6 Summary

Issue Type	Number of Founded Issues
CRITICAL	0
MAJOR	1
WARNING	2
INFO	5
Total	8

11 Final Summary

Smart contracts have been audited and 12 critical and 12 major issues were found. Also a lot of recommendations were marked as warning and informational. Some changes were proposed to follow best practices, reduce potential attack surface, simplify code maintenance and increase its readability. The severe attack vectors and potential broken features identified, together with documentation inconsistencies were the reflection of a work-in-progress code base. As stated in each particular issue, all critical, major and warning issues identified have been correctly fixed or acknowledged by the client, so contracts are assumed as secure to use according to our security criteria. Final commit identifier with all fixes: [5be86d9700201397b2fcff13daaaf9549cfe0272](#). This version is recommended to deploy to testnet for further system testing.

As to further help the project reach a production-ready state, we highly advise additional rounds of security reviews after every change in contracts.

The following table contains total issues found during all audit revisions.

Issue Type	Number of Found Issues
CRITICAL	11
MAJOR	12
WARNING	32
INFO	130
Total	185